Making In-the-Moment Learning Visible: A framework to identify and compare various ways of learning through continuity and discourse change

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Abstract

Small group interactions and interactions with near-peer instructors such as learning assistants serve as fertile opportunities for student learning in undergraduate active learning classrooms. To understand what students take away from these interactions, we need to understand how and what they learn during the moment of their interaction. This study builds on practical epistemology analysis to develop a framework to study this in-the-moment learning during interactions by operationalizing it through the lens of discourse change and continuity toward three ends. Using video recordings of students and learning assistants interacting in a variety of contexts including remote, in-person, and hybrid classrooms in introductory chemistry and physics at two universities, we developed an analytical framework that can characterize learning in the moment of interaction, is sensitive to different kinds of learning, and can be used to compare interactions. The framework and its theoretical underpinnings are described

in detail. In-depth examples demonstrate how the framework can be applied to classroom data to identify and differentiate different ways in which in-the-moment learning occurs.

Keywords: learning, sociocultural theory, framework development, undergraduate science, learning assistants, chemistry, physics

1. Introduction

Enacting active learning pedagogies in STEM classrooms can create spaces for students to interact with each other, collaboratively grapple with concepts, and further their scientific understandings and practices. However, identifying and characterizing what "counts" as learning in these interactions is often challenging for both instructors and researchers. The social spaces in which these learning moments occur are complicated since they are mediated by complex interpersonal dynamics during which students navigate and negotiate competing social and cognitive needs and a heterogeneity of knowledge resources and starting points (Barron, 2003; Brookes et al., 2021; Keen & Sevian, 2022; Lo & Ruef, 2020; Ryu & Sikorski, 2019; Sohr et al., 2018). This complexity may impede understanding whether and what students are learning. This begs the question: how do we make learning in interaction visible? To answer this question, we develop an analytical framework that characterizes learning in complex interactions in a way that does not reduce the importance of these complexities and is robust enough that it can be used to meaningfully compare across interactions.

To situate our framework, we will primarily draw on literature related to the context of our study: undergraduate learning and discipline-based education research, particularly that which investigates learning assistants, supporting it with research from K-12 science education. We sought to better understand what this part of the research community knows about learning during interaction, in particular: when do we assess student learning, what do we pay attention to in these moments, and how do we identify the mechanism of learning? We will demonstrate how different research traditions have contributed to answering these questions and what limitations remain to situate our framework within this broader landscape.

1.1 When do researchers assess whether students learned during an interaction?

Science education research and practice have established different methods to find evidence of learning from classroom interactions. Learning outcomes are often evaluated after an interaction via assessments or post-tests. Different strategies can be used to relate these post-tests with the interaction. In one strategy, learning from interaction is generally assessed at the whole-class level, by evaluating how including certain kinds of interactions in the classroom impacts student learning outcomes. This approach is commonly taken in studies with pseudo-experimental designs that compare an active learning intervention with a traditionally taught "control" (e.g., Herrera et al., 2018; Van Dusen & Nissen, 2020), or in large survey reviews that evaluate learning outcomes across active learning models (e.g., Bennett et al., 2010; Hartikainen et al., 2019; Theobald et al., 2020). These approaches are useful for a birds-eye view of student learning, but neglect what happens during interactions.

In another strategy, researchers may connect what happens during an interaction to the learning outcomes. Connections to discourse in small groups can be made by characterizing the quality or frequency of a single student's classroom talk, and seeing whether that corresponds to their learning outcomes (Almahrouqi & Scott, 2012; Bianchini, 1997; Ryu & Sikorski, 2019; Sedova et al., 2019; Zhang, 2008). Other approaches may involve gathering additional sources of data to capture students' classroom experiences—for example, Kornreich-Leshem and colleagues (2022) used surveys to collect information about students' individual and social experiences in small group discussions with learning assistants, to assess what kinds of experiences predicted metacognitive learning and identity development. However, the relationship between interaction and post hoc learning outcomes can be complex, because interactions involve competing social needs (Barron, 2003; Keen & Sevian, 2022; Sohr et al., 2018), and the complexity or quality of student reasoning during a group discussion may not be reflected by immediate post-assessments like clicker questions (Knight et al., 2015). Thus, to understand student learning during discussions, we need an approach that can capture and characterize student learning in-the-moment of interaction.

1.2 What do researchers consider learning in small-group interactions?

The complexity we describe above introduces a second challenge: students may have a variety of cognitive and affective learning outcomes during small-group interactions, and determining which we focus on depends in part on our perspective and values as researchers. For example, approaches that center conceptual disciplinary understanding might focus on how students and instructors co-construct knowledge and meaning in interaction (e.g., Grimes et al., 2019; Scott et al., 2006; Siry et al., 2012), and how students sense make when faced with new ideas (e.g., Kapon, 2017; Odden & Russ, 2019). Learning might be seen in how students productively engage with disciplinary substance (Engle & Conant, 2002). What students learn might include deeper understanding of concepts or fluency in disciplinary ways of thinking.

Other approaches center developing scientific practices as one important object of learning science (Berland et al., 2016). These approaches might focus on how students act like scientists or do science by carrying out investigations, modeling, posing arguments, or by acting as an epistemic agent (Chinn & Malhotra, 2002; Ford & Forman, 2006; Hutchison & Hammer, 2010; National Research Council, 2011; Zhang et al., 2022). Learning in this perspective might be seen as how students become enculturated into and fluent in the practice and discourses of science (Airey &

Linder, 2009; Lave & Wenger, 1991; Lemke, 1990) or how they develop disciplinary identity (Kornreich-Leshem et al., 2022).

These perspectives are often entangled; for example, Grimes et al. (2019) analyzed how students engaged in argumentation arrive at conceptual convergence during interactions. One reason for this entanglement may be that certain discursive practices, such as sense-making, are seen both as a form of discourse, which supports students in figuring out the world in productive ways, and a way of reaching conceptual coherence (e.g., Odden & Russ, 2019). Another is that the structure of scientific knowledge does not just include facts and concepts, but also methods and values which are enacted through practices (Ford, 2008). Scientific practices, then, are both an object of learning, and something that supports learning.

These lenses give researchers useful frameworks to identify valuable discourse and ways of acting in the classroom. However, the limitation of these approaches is that they, by necessity, often narrow the scope of what is attended to in science learning to specific scientific concepts or practices. While this may be productive for understanding students' conceptual development and development as scientists, it may limit our ability to see how and what students learn in unexpected ways (Park et al., 2016; Graham et al., 2013; Lee et al., 2021).

1.3 How do researchers identify the mechanism of learning?

To understand how learning occurs, we can attend to the discourse during an interaction. A great body of literature has attended closely to what makes interactions productive or not productive for learning (Barron, 2003; Engle & Conant, 2002; Keen & Sevian, 2022; Sohr et al., 2018). We will focus on two approaches: identifying specific discursive activities and characterizing learning through changes in discourse.

One common approach has been to attend to students' engagement in certain discursive activities that are assumed to lead to meaningful science learning, as opposed to other types of activities which may be less productive. For example, researchers compare sense-making, where students grapple with concepts and negotiate their understandings (e.g., Kapon, 2017; Lo & Ruef, 2020; Odden & Russ, 2019), with playing a "classroom game," in which students recite rote content to get the "correct" answer (Hutchison & Hammer, 2010; Lemke, 1990; Oh et al., 2022; Russ et al., 2012). This framing implies that sense-making is more productive for meaningful scientific learning than playing the "classroom game." Similar stances are taken in works that focus on other meaningful kinds of scientific activity, such as argumentation (e.g., Grimes et al., 2019), productive disciplinary engagement (e.g., Engle & Conant, 2002; Koretsky et al., 2021), and problem solving (e.g., Karch & Sevian, 2022; Rodriguez, Bain, & Towns, 2020; Sevian & Couture, 2018). It is important not to conflate these constructs with learning as a general phenomenon, as Odden and Russ (2019) cautioned in their work on sense-making, because while these activities are productive for learning science, other mechanisms for learning exist. For example, rote memorization is also a way of learning—just not one necessarily endorsed by instructors in active learning classrooms.

An alternative to these approaches is to characterize the learning mechanism directly from student discourse, rather than identifying meaningful activities. This approach characterizes learning as changes in discourse, and typically builds from sociocultural theories that conceptualize learning as occurring in the social plane (Vygotsky & Cole, 1978). For example, in practical epistemology analysis (PEA), learning is conceptualized through how students' discourse changes during an interaction, and what pieces of their prior experience are picked up during that interaction (Hamza & Wickman, 2013; Karlsson et al., 2020; Kelly et al., 2012; Wickman, 2006; Wickman & Östman, 2002). Similar to PEA, transactional approaches examine continuity of prior experiences by focusing on the interplay between the individual and the environment and how the person-in-setting is transformed (Jornet et al., 2016; Östman & Öhman, 2022). Activity theoretical approaches, which are often focused on changes in systems, view learning as a cycle of internalization and externalization initiated by experiencing contradictions (Engeström, 2000). For example, Keen and Sevian (2022) focused on how students experienced struggles in the chemistry lab, which they operationalized as contradictions within the activity system (e.g., between students' rule that the TA should check their work, and the TA's role to help students figure things out on their own). In their dissertation, Keen (2021) found evidence of externalized learning outcomes when students repeated certain productive actions that had helped them overcome that struggle. Studies conducted based on this premise are often sensitive to the highly contextualized nature of discourse (Hamza & Wickman, 2013; Karlsson et al., 2020; Keen, 2021). For example, they often take the form of deep case studies elucidating how learning may occur in a single interaction (e.g., Hamza & Wickman, 2013). This sensitivity is both an affordance and a limitation; while it provides a high-resolution picture of how learning occurs, it is often challenging to compare across interactions and across the contexts these interactions occur in.

1.4 Research Question

The dilemmas named in the previous section suggest three important takeaways for our framework: to understand students' in-the-moment learning, it is important to understand what is happening in the moment of the learning, not just to analyze it post hoc. Second, it is important to be aware that there may be a range of learning outcomes in interactions. Students are not just learning content, they may be learning practices, or habits, or [in]equitable ways of working with each other and interacting with the world. Third, there is a need for a framework that can be used to compare multiple interactions, and which grapples with the complexity of a general definition of in-the-moment learning that is sensitive to context. Our research study aims to fill this gap by developing an analytical framework for making different mechanisms for in-the-moment learning visible and facilitating comparisons across different interactions. The study is guided by the following overarching questions: *How can learning in interactions be made visible? And more specifically, how can this be done in a way that captures a range of learning outcomes and ways of learning as well as comparison across multiple contexts?*

1.5 Limitations of the scope of our work

Suárez and collaborators (2023) named three scales at which learning in interaction occurs: cognitive interactions within an individual (e.g., the activation of resources); interactions within groups between individuals (e.g., social dynamics); and interactions with political and social systems (e.g., cultural context or institutional racism). This work is situated at the border of interactions within an individual and between individuals, to identify how learning progresses in interaction, as evidenced by the use of disciplinary ideas. It is important to acknowledge that our data corpus primarily consists of English-language interactions in formal undergraduate science classrooms that use normative Western scientific discourses, and thus our understanding of learning is primarily developed from these Western-centric discourses. From that lens, our analytical framework enables high-resolution microanalyses of the progression of ideas in discourse. However, the current work does not foreground or examine some sociopolitical factors that may influence interaction dynamics, such as how racism influences whose voices and ideas are attended to over others or how the dominance of Western scientific discourse diminishes other ways of speaking and thinking. This is a limitation that we need to address in future scholarship.

2. Theoretical Background

This study aims to develop an approach for characterizing *in-the-moment learning* during interactions. We define in-the-moment learning as the collaborative process of negotiating meanings, understanding, and knowledge as they come into contact with discursive and physical mediating artifacts that lead to changes in ways of speaking. To meet the criteria for an analytical framework on learning we named in 1.4, we build on pragmatist and sociocultural theories of learning. These conceptualize learning as the transformation of meaning that can be seen through an analysis of social and discursive practices, and which is mediated by tools and discourse (Dewey, 1938; Engeström, 2000; Kelly et al., 2012; Vygotsky & Cole, 1978; Wertsch, 1998; Wickman & Östman, 2002).

A pragmatist lens for in-the-moment learning attends to the moment-to-moment practice of learners achieving "a change of old meaning in light of new experiences" (Wickman & Östman, 2002, p.602). Wickman (2004) characterizes in-the-moment learning as having two parts: how it is connected to, or made continuous with, prior experience; and how it is a process of change and transformation, as evidenced by changes in discourse through the introduction of new ideas and ways of speaking. These two pieces, continuity and discourse change, exist in a dialectic tension as learners simultaneously draw on and leverage familiar experiences and ways of thinking and transform them into something new. Over time, learners develop new habits that shape how they interact with the world (Kelly et al., 2012).

2.1 Learning as Continuity and Discourse Change

Continuity bridges between the contingent nature of encounters and the continual nature of learning (Kelly et al., 2012; Wickman, 2004). Wickman (2004) names three facets that characterize continuity: the utterances that are taken for granted as shared ("stand fast"), the "prior experiences that people relate to" (p. 329), and the formation of habits as practices are made continuous across multiple encounters. This illustrates continuity's contingent nature: it is shaped by the shared expectations and language in the encounter, which is in turn shaped by the sociohistorical context in which the encounter occurs. For example, in the classroom this can play out when learners bring unique cultural or linguistic resources and prior experiences that are not part of the dominant culture, which may lead to them experience discontinuity in their learning (Karlsson et al., 2020). Continuity is also established when learners bridge across different arenas of their life and ways of interacting with the world, for example bringing aesthetics and ideas about beauty into their learning of science (Wickman, 2006).

Focusing on continuity can allow an expansive, asset-based view of learning centered on the resources, ideas, feelings, and epistemological norms students bring to bear in a learning encounter rather than on the acquisition of canonically correct ideas and prescribed ways of thinking and speaking. A shift from deficit- to asset-oriented theories of learning allows space for the diverse and heterogeneous resources students bring to learning encounters, such as language and cultural resources (Barton & Tan, 2009; González-Howard & Suárez, 2021; Karlsson et al., 2020; Suárez, 2020). Research on emotion and aesthetics has also highlighted the importance of attending to non-cognitive resources to fully understand learning (Appleby et al., 2021; Park et al., 2016; Wickman et al., 2022). These bodies of work speak to the importance of expanding our definition of learning beyond the acquisition of canonical scientific content or practices.

In tandem with continuity, discourse change accounts for in-the-moment learning. Discourse change is the change in mediated action and meaning in encounter with the world when one is engaged in purposeful practice (Kelly et al., 2012; Wertsch, 1998; Wickman & Östman, 2002).

All learners have habits and ways of speaking that allow them to interact with the world and that provide a framework to cope and make sense of their reality. These habits may transform and adapt in response to new situations (Kelly et al., 2012; Wickman, 2006; Wickman & Östman, 2002).

Changes in discursive practices do not necessarily reflect conceptual change. They may occur because a given discourse is particularly useful to reason about certain concepts in a situation or because of the interaction's social dynamics (Hamza & Wickman, 2008; Hutchison & Hammer, 2010; Russ et al., 2012; Sohr et al., 2018). At the same time, the continual practice of certain kinds of discourse can lead to fluency in using that discourse, as it becomes an acquired habit for working with the world, and other ways of speaking become less useful (Östman & Öhman, 2022).

Depending on one's analytical lens, continuity and discourse change can be looked at in several different time scales and grain sizes. The most granular (our focus) may look at the introduction of new ideas (discourse change) within a single interaction, over the span of minutes, and attend to what ideas are picked up and which are not (continuity). Longer time scales may give insight into how students change their habits through new ways of speaking (discourse change), which may only be visible over time as students work on new but similar tasks, drawing on their prior experiences (continuity).

Together, discourse change and continuity allow us as researchers to grapple with the push-and-pull of in-the-moment learning: its connection to prior experience (something known) and its transformation toward something new (something learned). The contingent nature of in-the-moment learning creates opportunities for new habits to be put into practice and tested against familiar and unfamiliar situations that reveal the boundaries of their utility. By making these processes visible in encounters, we can document them and examine how one moment influences or is disconnected from the next. To do so, we build on an analytical framework grounded in these two facets of learning: practical epistemology analysis.

2.2.Practical Epistemology Analysis as a Foundational Analytical Framework

Practical epistemology analysis (PEA) is an analytical framework that has been used extensively in science education (Hamza & Wickman, 2013; Karlsson et al., 2020; Lidar et al., 2006, 2010; Lundqvist et al., 2009; Manneh et al., 2018; Piqueras & Achiam, 2019). It enables a high-resolution analysis of discourse. PEA studies learning by attending to students' practical epistemologies, e.g., "what *they* count as knowledge and how *they* get knowledge as *acting participants*" in a social practice (Wickman, 2004, p.327). This allows us to analyze students' knowledge-in-use by attending to how their discourse changes and is continuous with prior experience (Wickman & Östman, 2002).

PEA operationalizes the progression of learning in an interaction through several constructs (italicized below) (Wickman & Östman, 2002). The first is *encounter*, or an interaction amongst multiple individuals or between an individual and a material or epistemic artifact within a sociohistorical context. The use of the word "encounter" emphasizes the contingent and situated nature of learning, as it occurs when one comes into contact with these artifacts.

Within an encounter, certain meanings *stand fast*, i.e., they are immediately intelligible and not open to interpretation in that moment. What stands fast depends on the nature of the interaction. For example, three chemistry students may be discussing the substance, "NaCl." One might refer to the "atoms" in the substance to indicate the composite parts "Na" and "Cl." If this meaning is understood by the others in the interaction, the word "atom" stands fast, because it is part of the shared repertoire of the encounter.

The third construct of PEA is *gap*. A gap is an agent's need to make something intelligible during the conversation. A gap does not imply a cognitive gap in knowledge, but rather a socially situated and contextually dependent need for sense making, which can be expressed directly through asking questions, or indirectly through being filled. In the example above, as the students continue forward in the encounter, they may talk about the behavior of the individual parts, Na^{+} and Cl^{-}. This may lead one student to wonder, "Are these atoms or ions?" Here, the concept of "atom" stood fast for most of the encounter, until there was a need to figure out the distinction between atom and ion—i.e., when a gap was noticed by the students and opened for discussion.

These gaps are filled with *relations* between ideas or actions whose meanings stand fast. These relations address the need to make something intelligible by building connections between ideas. To fill the gap from the above example, "Are these atoms or ions?" one student may respond: "They're ions, because they have charges, and atoms are uncharged." The relations are the connections between each idea that collectively respond to the need and can be represented as follows using dashes to indicate relations between each idea: "ions—have charges — atoms — uncharged." We will use this formalism to represent relations throughout this paper.

Finally, we introduce the concept of *piece*, which refers to the individual meaning units that are used to construct a relation. Pieces stand fast and may consist of one or multiple words that hold a meaning within the encounter. For example, in the relation "ions—have charges — atoms — uncharged," each term separated by the dashes would be considered a piece.

These five constructs facilitate the analysis of continuity and discourse change at the granular level of in-the-moment learning within an interaction. By attending to gaps and relations, we can pay attention to how students shape needs that drive a learning encounter and make connections between their past experiences (establishing continuity) and form new relations and shape the discursive space around new ideas (establishing discourse change). Attending to pieces and what stands fast helps make clear which shared prior experiences the students draw upon or call into question. Finally, by looking at these through the lens of an encounter, we can pay attention to the nature of learning in the moment of the interaction and center students' perceptions of their own learning and needs. In doing so, we can characterize learning through their experience rather than in relation to prescribed scientific canon or practices.

3. Methods

3.1 Study Context: The Learning Assistant Model

This study is part of a larger one that seeks to understand the facilitation practices of learning assistants (e.g., Walsh, Karch, & Caspari-Gnann, 2022; Carlos et al., 2023). The Learning Assistant (LA) model is a near-peer active learning model where more advanced undergraduate students, or LAs, assist in courses to support student engagement and increase the number of facilitators with whom students have contact (Barrasso & Spilios, 2021; Otero et al., 2006, 2010). It is well documented that the presence of LAs leads to positive cognitive and affective outcomes in the classroom, such as higher course and exam grades (Alzen et al., 2017, 2018; Sellami et al., 2017), conceptual understanding (Herrera et al., 2018; Kiste et al., 2017; Miller et al., 2013; Talbot et al., 2015; White et al., 2016), and sense of belonging (Clements et al., 2022), particularly for marginalized students (Sellami et al., 2017; Van Dusen et al., 2016; Van Dusen & Nissen, 2020).

LA-facilitated interactions offer a fruitful context to study learning within a wide range of interaction types. The deep body of evidence about the positive impact LAs have on student learning outcomes suggests productive and meaningful learning happens in these interactions. How exactly these interactions play out varies. Interactions with LAs can range from very authoritative, in which the LA is positioned as an arbiter of content, to very dialogic, in which the LA may behave more like a student or take a backseat role and remain completely silent (Carlos et al., 2023). This may provide a broader range of interactions to characterize undergraduate in-the-moment learning than interactions with students alone or with someone with a more rigidly authoritative social positioning, such as a TA or a professor, and thus may give insight into learning that occurs in various contexts. In the study at hand, we will attend to how LAs and students collectively negotiate and establish discourse change and continuity while solving problems.

3.1.1 Specific Classroom Contexts

We collected data from 12 LA-facilitated introductory undergraduate physics and chemistry courses over two academic years at two institutions (see Table 1): Institution A, an R2, highly diverse, mid-sized public university and Institution B, an R1, highly privileged, mid-sized private university. These included six chemistry courses at Institution A and two chemistry and four physics courses at Institution B. Of the 12 courses, six were taught remotely, five in-person, and one synchronous hybrid. All courses were at least partially flipped, large-lecture classes served by LAs, whose primary role was to facilitate group learning during active learning sessions. To recruit these 12 study classrooms, we contacted all instructors teaching with LAs in chemistry and physics at the two institutions and invited them to participate in the study. Seven professors agreed, and some participated in multiple semesters. Data were collected with approval from the Institutional Review Boards of both institutions.

The courses had some broad commonalities and differences that can help contextualize data collection. All classes in the study were taught by instructors trained in science education research. All chemistry classrooms used the same reformed chemistry curriculum, *Chemical Thinking* (Talanquer & Pollard, 2010), which emphasizes learning how to think like a chemist based on common cross-cutting practices rather than being organized by content (e.g., atoms-first). 3 of the 4 physics courses were taught by the same instructor, and both physics instructors taught physics from the stance of responsive teaching (Hammer et al., 2012). All classes had planned problem-solving sessions, during which LAs worked with students to help facilitate their learning. On average, the classes taught at Institution A tended to have a lower LA-to-student ratio and a higher lecture-to-problem solving ratio compared to the classes at Institution B. The purpose of the interactions and how interactions were carried out varied broadly from context to context (Karch, Mashhour, & Caspari-Gnann, 2023). On one end of the spectrum, in one course (Chem A, Fall 2021) LAs had very frequent, and very brief interactions with students, which consisted of approaching students with their hands raised and answering their questions before moving on. At the other end of the spectrum, in one course (Physics B, Fall 2021) LAs were assigned to specific sections of the classroom for which they were responsible, and would work with a single group for an entire problem. Sometimes, these LAs were completely silent during interactions; their contribution to the learning was their presence and attention. Encounters in most classes fell within these two extremes and were modulated by features of the class such as the instructors' pedagogy, the course modality, the relationship the LA had with a given group of students, and the specifics of a given problem.

3.1.2. Participants

Study participants included both LAs and students. 843 students and 37 different LAs participated in the research study. Participant demographics and numbers are shown in Table 1. Anywhere from half to all LAs in each course and as many of the students as possible were recruited to participate. LAs were recruited via their supervising professor and received a $500 stipend for participating in the study. Students were recruited via an announcement in lecture from a study team member and electronically via their course management system and received either a $10 stipend or a small amount of extra credit not exceeding 2% of their final grade. All participants consented via an online Qualtrics form.

Table 1. This table shows the racial and gender demographics for our participant pool from each university and the institutional demographics as a whole, in order to contextualize our population and findings. A few caveats on our comparison: All institutional data are presented as the federal categories for degree-seeking undergraduates enrolled in Fall 2021. In our survey, we allowed students to select multiple racial categories. In processing our data to make them comparable to institutional demographics and to add up to 100%, we included those students who selected multiple categories under “Two or more races.” For example, 1.8% of our participant pool self-selected Native American, but all selected additional races; thus, in the table below, they are counted towards the category “Two or more races” and 0% are shown for Native American. We processed the Latino/Latinx/Hispanic category similarly to institutional data and included all students who marked “Latino/Latinx” as a racial category and/or said yes to a question about Hispanic origin. Additionally, one racial category in the institutional data for Institution A was “Cape Verdean;” we are reporting this category here as part of Black to make the numbers comparable between the two different institutions as well as between the institutional data and the data we collected from our participants. This categorization may or may not accurately represent those students’ racial identities. For the institutional data, students’ international status was reported with racial demographics, whereas we asked about it separately. For our participant pool, we report international students’ self-identified race, while including them with “other” for the institutional comparison. For categories that were directly comparable between the different institutions and our survey data, we display here the language of the actual answer choices that students could self-identify with. We recognize that this language choice in some instances is not just (e.g., the use of “Female” and “Male” for gender rather than “Woman” and “Man” or the use of “Native American/Alaskan Native” rather than “First Nations”). Finally, demographics are reported for a subset of the entire participant pool (85.7%, n=714) because in one semester of data collection, demographic surveys were sent at the end of the semester and there was a low response rate.

	Institution A (Public University) (n = 353)		**Institution B (Private University) (n = 527)**	
	Participant Pool	Institution A	Participant Pool	Institution B
Race/Ethnicity				
Native American American/Alaskan Native	0%	<1%	0%	<1%
Asian	20.1%	15.4%	24.8%	15.5%
Black	16.6%	16.7%	8.6%	5.2%
Latino/Latinx or Hispanic	24.2%	18.9%	7.3%	9.1%
Pacific Islander	0.6%	<1%	0%	<1%
White	26.8%	34.4%	47.0%	47.9%
Two or more races	5.7%	3.8%	11.4%	6.9%

Other / Prefer not to answer	5.4%	10.7% (includes non-resident alien)	0.9%	14% (includes international)
Gender				
Female	75.5%	58%	66.6%	55%
Male	22.0%	42%	30.5%	44%
Nonbinary / Genderqueer / Other	1.0%	<1%	0.7%	1%
Prefer not to answer	1.6%	<1%	2.3%	<1%

3.2 Data Generation and Selection

Data were collected in the form of video recordings of student-LA interactions. LAs recorded their interactions with groups of students from their perspective, via a cell phone camera mounted by a body harness with a secondary audio recorder for quality purposes during in-person instruction or via Zoom breakout room recording during remote instruction. Each LA recorded their interactions in three class sessions near the beginning, middle, and end of the semester. This allowed us to see not only many problem and content contexts, but also as many student groups as possible. Each recording day yielded an average of 2-4 videos per LA ranging from 1-20 minutes each, depending on the number of group work sessions and on how often the LAs switched groups. Because of the nature of our recordings being from the LA's perspective, all encounters in our data set began when an LA approached a group (began recording) and ended when they moved onto another group (ceased recording). After recording dates, interactions were transcribed either by a member of the research team or a professional transcriptionist, and names or any identifying details were removed from the transcript and replaced with codenames selected by the participants.

Because our data corpus is so large (302 interactions total), and our analysis was time intensive (8-10 hours per interaction, including time for consensus discussion) we analyzed a small subset of the data, and made decisions to prioritize having as many different kinds of LA-facilitated interactions as possible. We analyzed data from half of the LAs and prioritized data from at least one LA per course. The decision of which LAs' data to include was deeply informed by the development of our coding and will thus be discussed in section 3.3. For each LA, we only considered data that the LA had seen in retrospective interviews (227 interactions; 1416 minutes), because we needed these specific interactions to be analyzed for other parts of the larger study (Carlos et al., 2023, Karch et al., 2023). Overall, we analyzed two interactions from 18 LAs, for a total of 36 interactions (see Table 2), which represented 220 minutes of interaction data (approximately 16% of the data seen by LAs in retrospective interviews).

These two interactions per LA were selected from all interactions an LA was interviewed about based on a criterion we called the "intuitive effectiveness of learning". In order to mitigate biasing our analysis toward interactions we thought were "better," three of the authors watched and rated each LA's interaction videos and wrote detailed memos about their rating. The first author selected one interaction that was rated "more effective" and one that was rated "less effective" for each LA that were representative of that LA's practice. We considered the following metrics for "effectiveness:" (1) the extent to which all students were involved versus one or two students dominating the conversation; conversations where all students spoke were considered "better" than if a single student explained their answer, or if the students seemed to be mostly talking to the LA and not to each other. (2) The balance of LA-student talk; interactions that were more student-centered were considered intuitively "better", e.g., when the students were the primary speakers and question posers. Interactions led by the LA, particularly when the LA was guiding the students through a stepwise way to solve the problem, or when it felt like they asked confusing questions were rated as "less effective." (3) The extent to which students made progress in their thinking.

Progress was considered not in terms of progress made toward a canonically correct answer, but progress in considering different questions of disciplinary substance.

Each author came into this process with bias about what constituted an "effective" interaction based on our prior experiences as instructors or students, and sometimes we disagreed. For example, the fourth author (an undergraduate student) rated one interaction we analyzed as effective because "[the LA did a] great job listening to the students' responses and helping them work toward an answer. Asked good questions to clear up their confusions and broke it down for them." The first author (a postdoctoral researcher) rated this same interaction as less effective because "[it was] very guiding, lots of unproductive feeling confusion until LA gave them answer at the end; disregards what the students had already done to that point." Ultimately, the purpose of this sorting was not done to claim that the learning in these interactions was more or less effective (our understanding of the interactions often changed with closer analysis), but rather to capture a range of typical interactions within each class, and to mitigate biasing our analysis toward interactions we thought were "better" by selecting the same number of interactions we thought were less effective.

Table 2. This table shows the number of interactions included in analysis from each context. "In-person" and "remote" refer to the modality of the interaction. From the one hybrid class in our dataset, all interactions selected were in-person interactions.

	Chemistry - A	Chemistry - B	Physics - B
In-Person	6	4	8
Remote	8	4	6

3.3 Analyzing for Continuity and Discourse Change

To analyze the data, we used PEA to capture how the conversation progressed by reducing the encounter to what gaps were opened, what relations were established to fill these gaps, and who contributed to the conversation through noticing or filling gaps (Walsh et al., 2022; Wickman & Östman, 2002). We started this process by reading each transcript alongside the video. Then we identified gaps, guided by the question, "What needs to be made intelligible here?" and identified what relations filled the gaps. We coded for gaps, pieces, and relations within a Google sheet (see Supporting Information 1 for a sample). In the spreadsheet, each cell represented one instance of a gap being noticed and filled using a single line of reasoning. New lines of reasoning were put in separate cells to indicate that they may or may not have built on prior relations. Gaps were organized by row, numbered in the order in which they were first noticed in the encounter, and could be returned to multiple times. Columns represented the progression forward in the conversation. In this way, we systematized our coding process such that multiple coders could engage in it, and to visualize the conversation's progression.

After coding the data using this first level gap analysis, we analyzed the Google sheets to examine how continuity and discourse change were established over the course of an entire interaction. To do so, we traced how the pieces were used throughout the encounter to track how already present pieces were picked up (establishing continuity), and how new pieces and ideas were introduced (establishing discourse change). We assigned each gap four qualitative codes that captured how the gap affected the encounter in terms of (a) establishing continuity, and (b) changing discourse, as well as whether that effect occurred within the noticing and filling of that gap itself, or during a gap later on during the interaction (see Supporting Information 2 for a sample analysis). These 4 codes were called: discourse change within gap, discourse change across gaps, continuity within gap, and continuity across gaps.

To develop these codes, we started with the first-level gap analysis from a small number of LAs and engaged in a collaborative and reflexive process, where the author team met weekly and discussed the developing codes. To refine the codes and ensure they were applicable to different contexts, we coded interactions from more LAs, always ensuring that the next LA was in a different classroom context and facilitated student learning in a different way as characterized by our previous work on dialogic and authoritative facilitation (Carlos et al., 2023). Based on our deep familiarity with the interactions, we further ensured that learning in interactions with the next LA analyzed seemed to progress in a different way than for the previous LA. We stopped adding interactions from more LAs when the codes completely stabilized and we had included at least 1 LA from each context (the total of 36 interactions from 18 LAs described in Section 3.2).

In the following sections, we illustrate the codes by including visualizations of each alongside the transcript excerpt (see Figure 1). These visualizations resemble our first-level Google sheet analysis. We track the progression of the interaction using graphics placed left to right. Because we apply codes to gaps as the unit of analysis, we specify the gap under analysis with a dashed and bolded box in each figure. Since gaps often linger and are returned to, we place them on different horizontal levels and demarcate them with grey boxes. A gap lingering is indicated by a dashed line that connects multiple boxes. Within the boxes, we present our first level analysis, where we show the gaps (the need to make something intelligible) that were noticed and the pieces and relations (indicated by short phrases or words connected by dashes) that filled the gaps. When gaps are explicitly noticed (e.g., a direct question is asked), we use the language "Gap Noticed;" when gaps are implicitly noticed (e.g., the question is inferred from what the group says without asking a specific question), we use the language "Gap noticed and filled." When different lines of reasoning are used to fill a gap, we separate them with a dashed line within a single box.

We represent the continuity and discourse change codes with arrows: blue arrows represent discourse change codes and are supported with blue text; and brown arrows represent continuity codes and are supported with brown text. We place references to the codes next to transcript lines in the excerpt tables, so the reader can directly map the analysis to the transcript. For the sake of clarity, we only demarcate pieces directly relevant to the example at hand in this way. Additionally, we omit lines for brevity in a way that does not materially change the story of the encounter (see Supporting Information 2 for an example of a whole interaction represented with these visualizations). To keep track of the gaps, we use the numbering from our original analysis. It is important to emphasize that for each of these codes, the unit of analysis is a single gap, which may be returned to multiple times throughout an interaction. All examples are presented with pseudonyms.

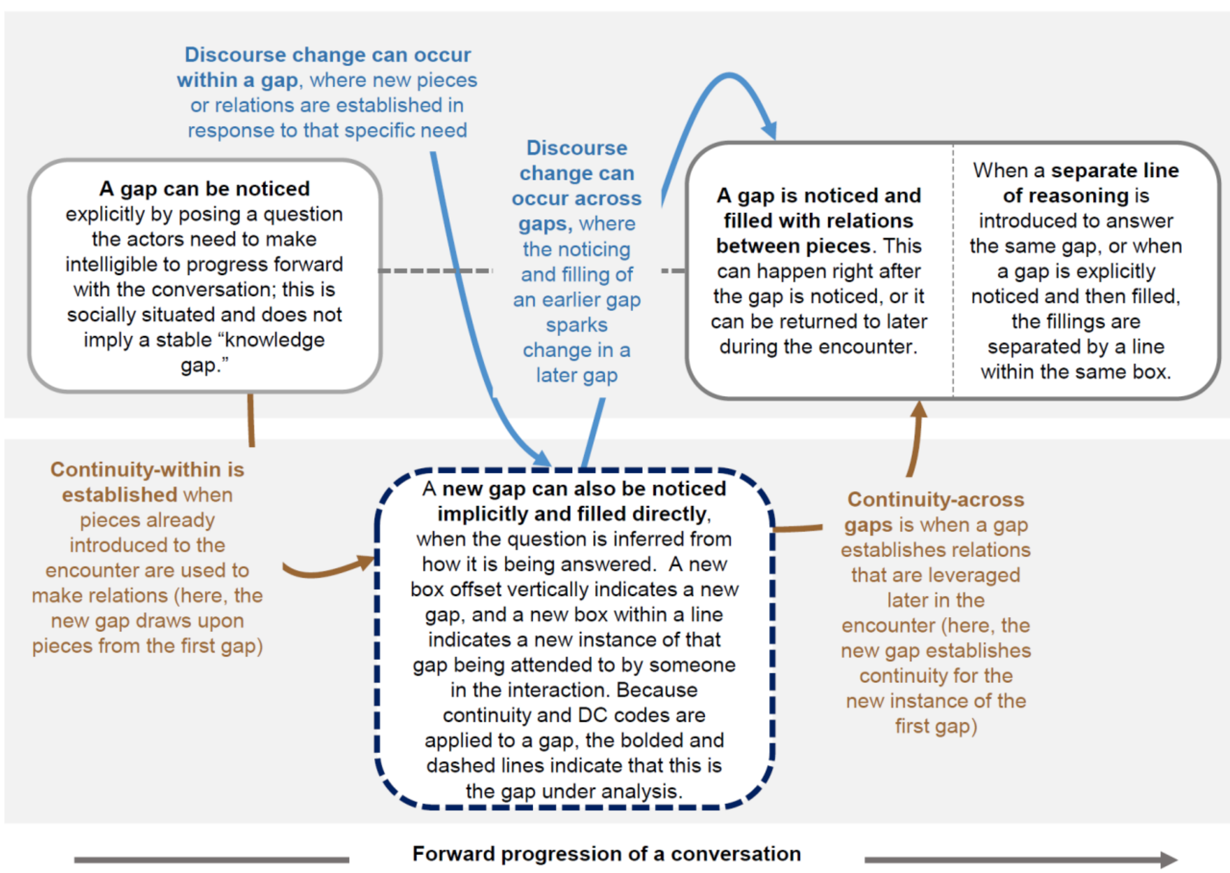

Figure 1. Representation of how the first-level gap analysis and the second level DC/continuity analysis will be depicted, with definitions for each code. The depiction of the gaps was developed from our initial coding method using excel spreadsheets to keep track of instances of gaps being noticed and filled. The dashed line between two instances of a single gap indicates that the gap lingers, e.g., is not fully resolved.

3.3.1 Discourse change within gap

Discourse change within gap (DC-within) was coded when new pieces that had not been previously used up to that point were introduced to notice and/or fill the gap at hand. DC-within could happen for many different reasons. For example, students could start talking about a different part of the problem, which also could induce a shift in the ideas and relations they were discussing. Another example: students could open a gap because the conversation had not fulfilled a need they had to make something intelligible, and thus they brought in new ideas from class. Graphically, DC-within will be represented as a blue arrow pointing toward the gap under analysis.

To describe DC-within further, consider Gap 3 (Figure 2a, Table 3) from an interaction in a remote physics class at Institution B, in which two students, Noor and Josephine, were trying to decide which right-hand rule was appropriate to figure out whether two loops with opposite currents would attract or repel each other (see Figure 2b).

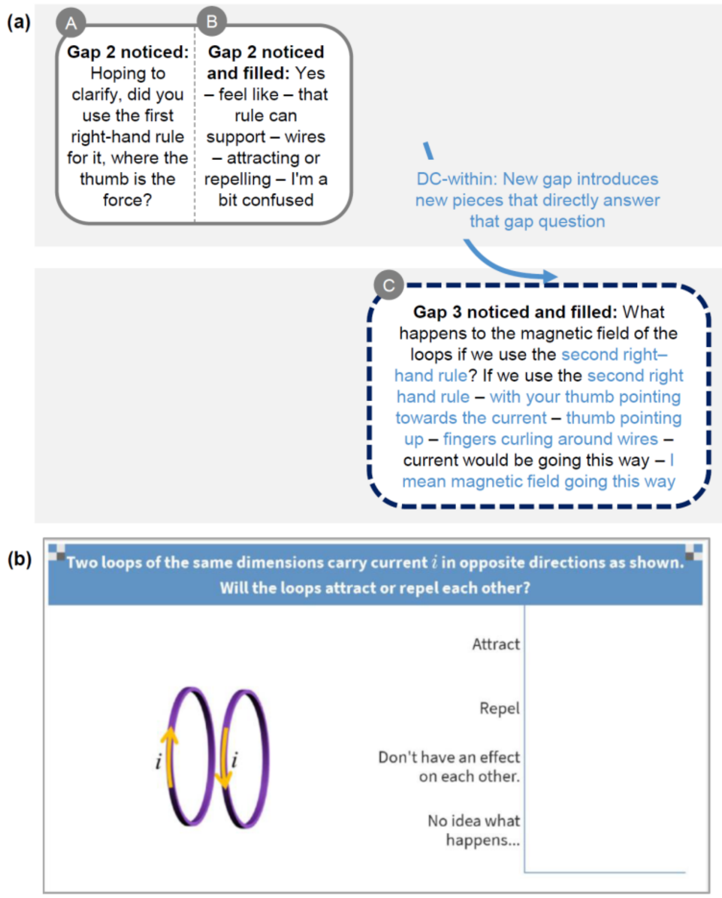

Figure 2. (a) Representation of DC-within coding, shown with the blue arrow pointing toward the gap. **(b)** Problem context for the example interaction illustrating the code.

Table 3. Transcript excerpt for the example used to illustrate DC-within.

Transcript Line	Coding (with reference to Figure 2a)
LA Shin: All right, so I'm just trying to clarify for— Did you use the first right-hand rule for it, where the thumb is the force, Noor?	Gap 2 noticed (Box A)
Noor: Yeah. But I feel like that rule, that rule can support the wires attracting and repelling, so I'm a bit confused about that part.	Gap 2 noticed and filled (Box B)
Josephine: Well, if we were— Well if we were to use the second right-hand rule with your thumb, like your thumb pointing towards the current, and the— For that one? Okay, so if your thumb— Like do you guys want to use the second right-hand rule for it? Cause like for that one, your thumb would be pointing up, and your fingers will be curling around the wires, so the current would be going this way, I mean the magnetic field will be going this way. Can you guys see it?	Gap 3 noticed and filled (Box C)

Gap 3 (Figure 2a, Box C) was coded with DC-within because Josephine constructed an argument based on the second right-hand rule, which had not been part of the discussion before this point in time, as the conversation had been revolving around the first right-hand rule. A comparison between the pieces used to fill the prior gap, Gap 2 (Figure 2a, Boxes A and B), and Gap 3 demonstrates this change in discourse as new pieces such as “with your thumb pointing towards the current” and “fingers curling around the wires” were brought into the discussion space (blue text in Figure 2a, Box C).

3.3.2 Discourse change across gaps

Discourse change across gaps (DC-across) was coded when the noticing and filling of a gap was the impetus for discourse change during a later point of the interaction, i.e., when introducing new pieces to notice or fill a later gap was directly influenced by the noticing or filling of an earlier gap. For example, this could happen when an earlier gap introduced or problematized a piece that sparked a student to wonder about something different, or it could be because filling the earlier gap established the relations necessary to provide an entry point into a need that was lingering. DC-across will be represented as a blue arrow pointing away from the gap under analysis.

To describe DC-across further, consider Gap 4 (Figure 3a, Table 4) from an interaction in a remote chemistry class at Institution B, in which a student group was tasked with drawing two plots to represent (1) how reaction rate changes with the changing concentration of a reactant, and (2) how the concentration of a reactant changes over time (see Figure 3b).

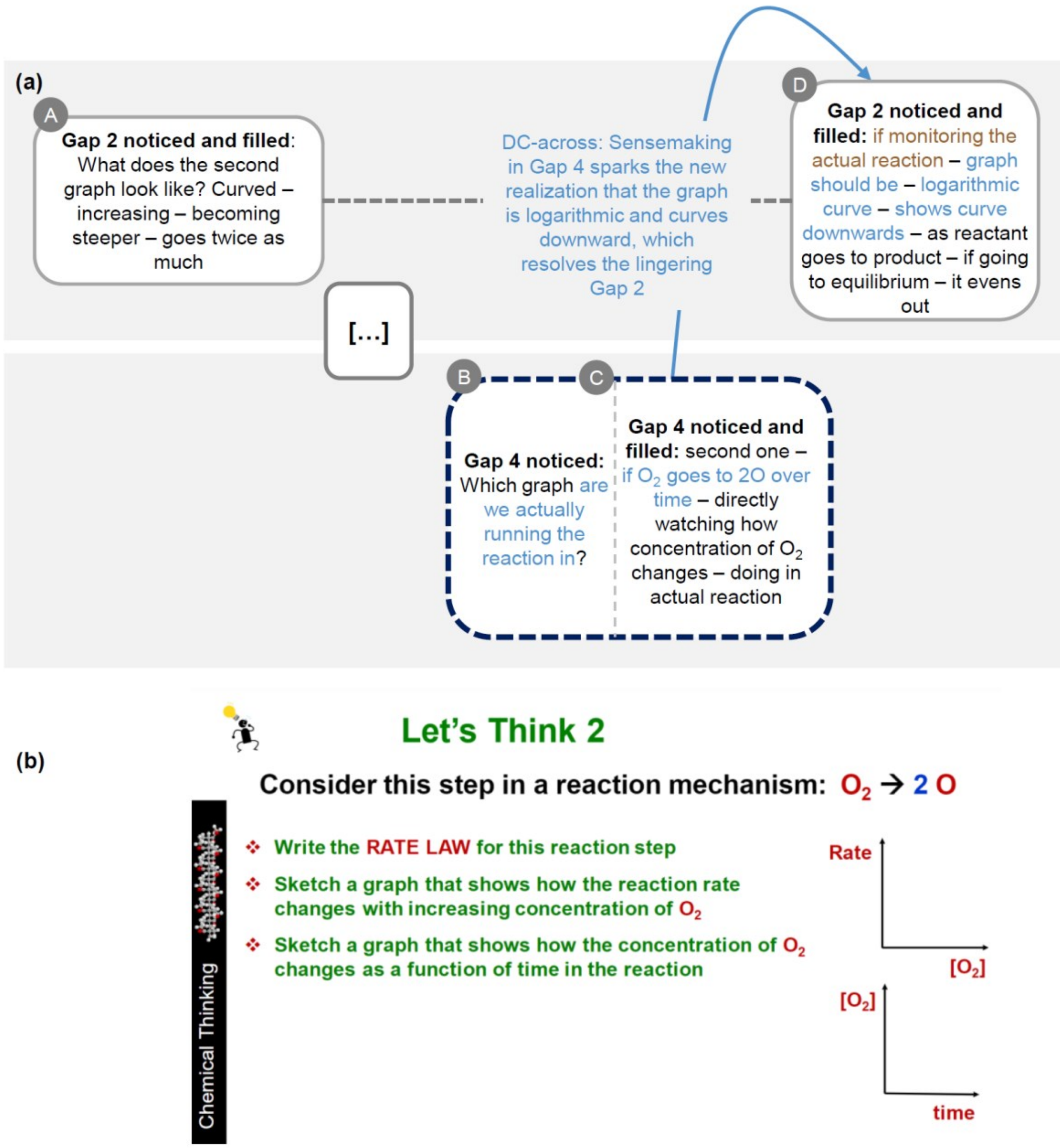

Figure 3. (a) Representation of DC-across coding, shown with the blue arrow pointing away from the gap. **(b)** Problem context for the example interaction illustrating the code.

Table 4. Transcript excerpt for the example used to illustrate DC-across.

Transcript Line	Coding (with reference to Figure 3a)
Anby: And then isn't it going to be like a little, it's just going to go like in a curve, sort of, but like increasing, but like increasing more as—Like sort of like twice as much, if that makes sense? [shows increasing with her hands]	Gap 2 noticed and filled (Box A)
[…the students become confused about what Graph 2 represents and grapple with what happens to the concentration over time]	Omitted from figure for clarity
LA John: Well let me ask you this. In the first graph versus the second graph, which one are we actually running the reaction in?	Gap 4 noticed (Box B)
Catherine: The second one, right? […] Cause that would be, I mean, if you think of O_2 going to 2O as time goes on, you're directly watching how the concentration of O_2 changes, which it would be doing in an actual reaction, I guess.	Gap 4 noticed and filled (Box C)
[…the LA asks the rest of the group their thoughts, and everyone agrees]	Omitted from figure for clarity
Catherine: Um, if we're just thinking of it like we're monitoring the actual reaction, then I feel like it would be like a logarithmic type curve [shows curve downwards, but cutting off], because as the reactant's going to the product, if it's going to equilibrium, then it should even out, maybe.	Gap 2 noticed and filled (Box D)

Gap 4 (Fig. 3a, Boxes B and C) was coded with DC-across because the gap drew the group's attention to new ideas such as which graph they are "actually running the reaction in" (blue text in Fig. 3a, Box B and C), which led to discourse change in Gap 2, such as realizing the graph is logarithmic and curves downward (blue text in Fig. 3a, Box D). In part, this is evidenced by the construction of an "if-then" logic, where the conclusions they made in Gap 4 were picked up and built on in Gap 2 (brown text in Fig. 3a, Box D). In this way, DC-across and DC-within can be pairs, where DC-across coded in one gap (e.g., Gap 4) leads to DC-within in another (e.g., Gap 2).

3.3.3 Continuity within gaps

While the DC codes focus on how new pieces are introduced, the continuity codes focus on how old pieces are picked up. Continuity-within was coded when pieces that had already been introduced to the encounter were used to make relations to notice or fill the gap at hand. This could occur, e.g., when students were focused on making sense of a common idea that they continually revisited, or when a student or LA picked up a piece or relation established by someone else. Continuity-within will be represented as a brown arrow pointing toward the gap under analysis.

To describe continuity-within further, consider Gap 2 (Figure 4a, Table 5) from an interaction in an in-person chemistry class at Institution A, in which a student, Pedro, was working with an LA on a problem about balancing a redox reaction (see Figure 4b).

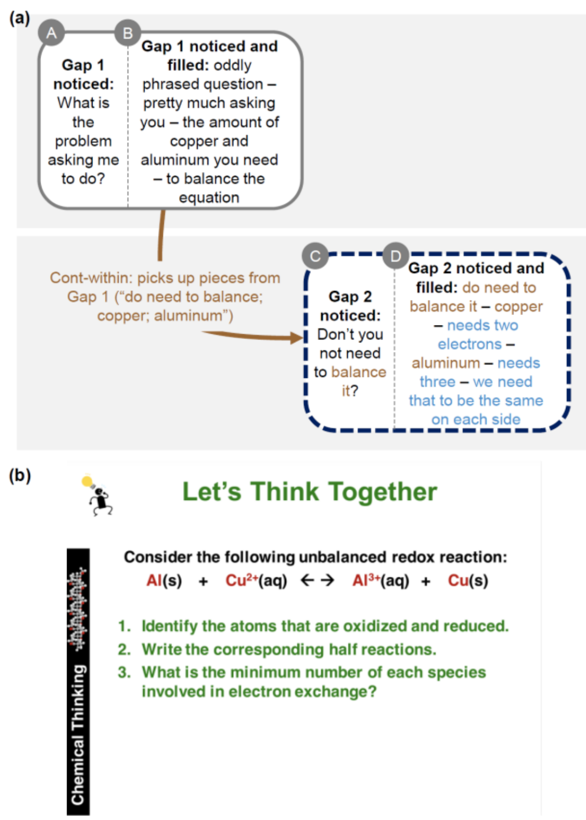

Figure 4. (a) Representation of continuity-within coding, shown with the brown arrow pointing toward the gap. **(b)** Problem context for the example interaction illustrating the code.

Table 5. Transcript excerpt for the example used to illustrate continuity-within.

Transcript Line	Coding (with reference to Figure 4a)
Pedro: So I don't understand what it means by like what's the minimum number of each species. Like I don't understand what's on the board.	Gap 1 noticed (Box A)
LA Mango: For these species. It's an oddly phrased question. Oh, I see. So that's um, that's pretty much asking you the amount of copper and aluminum you would need to balance the equation.	Gap 1 noticed and filled (Box B)
Pedro: Oh, okay. So would it be like, don't you like not need to balance it?	Gap 2 noticed (Box C)
LA Mango: You do need to balance it. So you could see copper needs two electrons. Here you could see this aluminum needs three. We need that to be the same on each side.	Gap 2 noticed and filled (Box D)

Gap 2 (Fig. 4a, Boxes C and D) was coded with continuity-within because the new gap questioned and built on pieces introduced in Gap 1 (Fig. 4a, Boxes A and B). Pedro opened the gap by picking up on pieces like balancing from the LA's explanation (brown text in Fig. 4a, Box C), and the LA's response in filling the gap further picked up on pieces from Gap 1 (brown text in Fig. 4a, Box D). Comparing the pieces used in Gaps 2 and Gaps 1 shows that the noticing and filling of Gap 2 (Fig. 4a, Boxes C and D) builds on these old pieces introduced earlier.

3.3.4 Continuity across gaps

Continuity-across gaps was coded when the noticing or filling of a gap established an experience that was later drawn upon, e.g., by establishing relations or pieces that were leveraged later during the interaction or first establishing a discursive habit. For example, this could happen when an established relation is later used to support a different argument or is called into question, or when an LA started to frame noticing gaps in a particular way that was repeated by the students. Continuity-across will be represented as a brown arrow pointing away from the gap under analysis.

To describe continuity-across further, consider Gap 4 (Figure 5a, Table 6) from an interaction in an in-person chemistry class at Institution B, in which two students, Salsa and Pastel, were discussing what happens to a system when water evaporates out of it (see Figure 5b).

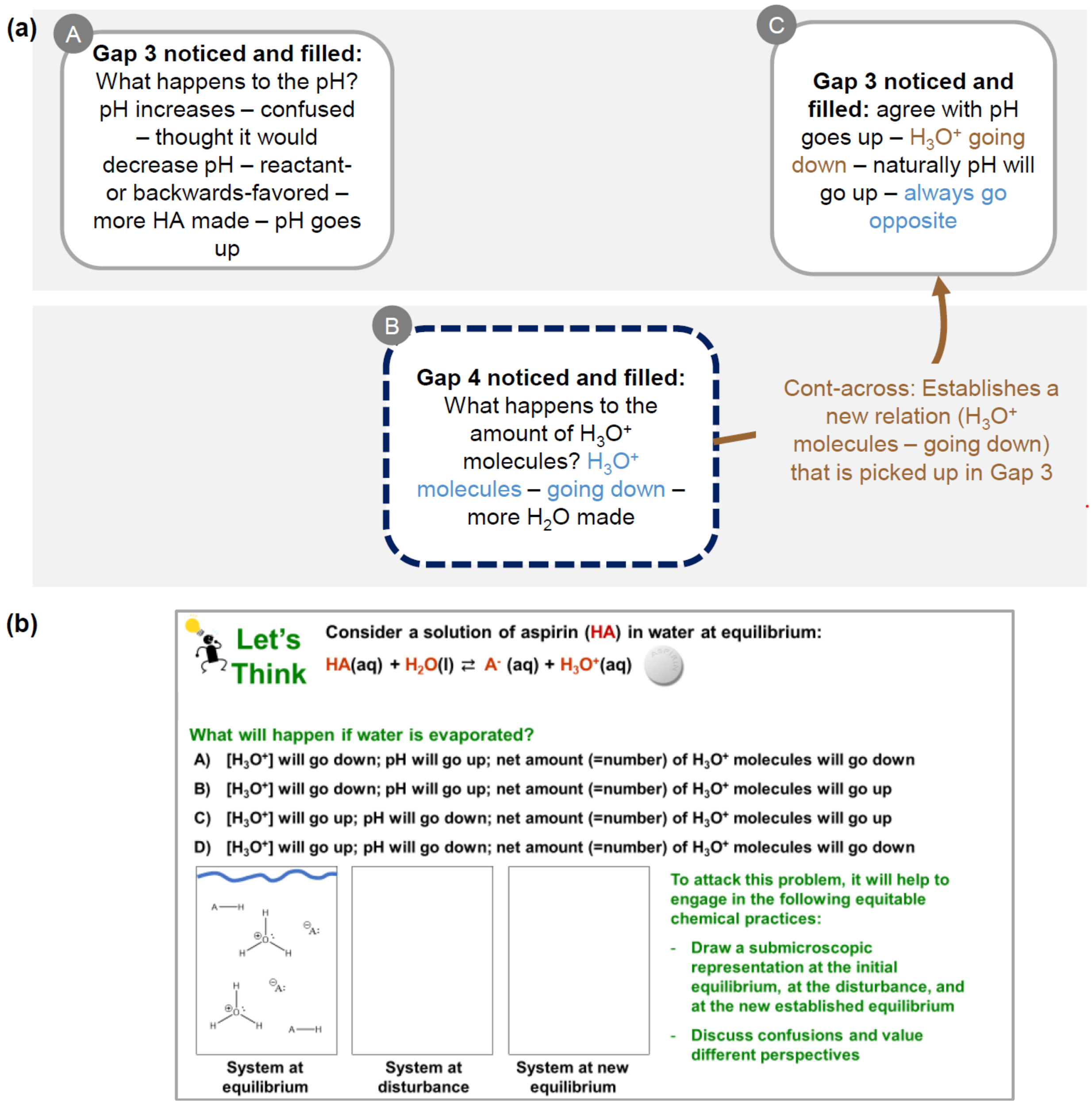

Figure 5. (a) Representation of continuity-across coding, shown with the brown arrow away from the gap. **(b)** Problem context for the example interaction illustrating the code.

Table 6. Transcript excerpt for the example used to illustrate continuity-across.

Transcript Line	Coding (with reference to Figure 5a)
Salsa: And in terms of other things, I think that sort of increases the pH. I was a bit confused on that part. I had assumed that it would decrease the pH, but since it is more backwards reac-, backwards-favored or reactant-favored, then more HA is being made, and that's why the pH would go up.	Gap 3 noticed and filled (Box A)
Salsa: And in terms of like overall the H_3O [sic] molecules are going down because more H_2O is being made. So that's what I said here.	Gap 4 noticed and filled (Box B)
Pastel: Yeah, I agree with that, and as for the pH will go up, honestly, since like the H_3O^+ is going down, I was just like, naturally the pH will go up, because they are always going opposite of each other.	Gap 3 noticed and filled (Box C)

Gap 4 (Fig. 5a, Box B) was coded with continuity-across because it established relations that were picked up and used as something that stood fast in Gap 3 (Fig. 5a, Box C). Salsa made a relation between two new pieces that established that the number of H_3O^+ molecules should be going down (blue text in Fig. 5a, Box B), the first time this relation was made. Pastel picked up these pieces to help fill the lingering Gap 3, leveraging the relation Salsa established between H_3O^+ molecules and "going down" as something that stood fast (brown text in Fig. 5a, Box C). Thus, Gap 4 established continuity-across, because it introduced the pieces and ideas that were used when Pastel brought the encounter back to Gap 3. Continuity-within and continuity-across can be considered pairs: when Gap 3 picked up pieces from Gap 4, Gap 3 established continuity-within (picked up pieces) and Gap 4 established continuity-across (provided pieces).

To summarize, our approach introduces four qualitative codes: discourse change-within, discourse change-across, continuity-within, and continuity-across (See Table 7 for summary definitions of all parts of our analysis). We coded every gap in an encounter for the presence or absence of these four codes. That is, a single gap could be assigned up to four codes depending on its impact on the rest of the interaction.

Table 7. A summary of all relevant constructs for our analysis. The definitions of gap and relation are adopted from the original PEA literature (Wickman & Ostman, 2002); all other constructs presented in this table are presented in this paper.

Code	Definition	Representation in Figures
Gap (from PEA)	The socially situated need to make something intelligible, which can be noticed explicitly (through the direct asking of a question) or implicitly (inferred from how someone answers an unspoken question)	Rounded box; gap under analysis demarcated by a dashed border
Relation (from PEA)	Connections between pieces of knowledge or actions whose meanings stand fast and which help address (fill) a gap	Dash connecting two pieces within a box
Piece	Individual meaning units that are used to construct a relation	Short phrase or word connected by a dash within a box
DC-within	Introduction of new pieces to notice and/or fill the gap under analysis	Blue arrow with the head pointing toward the gap under analysis
DC-across	Introduction of new pieces to notice and/or fill a later gap that was directly sparked by the noticing and/or filling of the gap under analysis	Blue arrow originating at the gap under analysis
Cont-within	Picking up pieces that were already introduced to make relations to notice and/or fill the gap under analysis	Brown arrow with the head pointing toward the gap under analysis
Cont-across	Establishing relations or pieces in the gap under analysis that are used in a later gap, or establishing some kind of discursive habit	Brown arrow originating at the gap under analysis

3.4 Researcher Positionality and Trustworthiness

Our research team held multiple positionalities with regards to our perspectives on learning, our relationship to the data, and our positions of power within systems of oppression. All members of the author team are situated at a predominantly white university. The first author identifies as a queer, white Chicana who is a postdoc and who previously taught chemistry with LAs and collected a large proportion of the data. Her familiarity with and proximity to the study course professors' intentions and her own orientation toward learning as asset-based gave a bigger perspective on what the grain size of a gap was, and how it differed from context-to-context, which also led to tension in figuring out whose perspective (e.g., the professor's) she privileged during analysis. The second author identifies as a white woman first-generation college student trained at a large state university, who has previously been a student in courses with LAs, worked as an LA herself, and conducts research on LAs. Her prior training and lived experience as a first-generation student and current position as a graduate student at a privileged PWI provided her an insider-outsider perspective on both learning contexts, which at first manifested as a learning curve in viewing gaps as socially situated rather than related to canonical correctness, and later manifested as viewing many ways of learning as equally valuable and contextually situated. The third author identifies as a Haitian-American woman who has been a student in LA-facilitated undergraduate courses. As a student who is typically quiet in the class, she finds it hard to express her thoughts and what she is confused about. By working on the data analysis, she not only learned to pay close attention to her own learning and thoughts but also focused on the thoughts of the students whose voice may not be directly heard in order to have no thoughts overlooked and that our analysis matched closely what the students were saying to not accidentally misinterpret them. The fourth author identifies as a queer Black woman who has been a student in LA-facilitated undergraduate courses. As a student who experienced marginalization in STEM spaces, she paid close attention during data analysis to whose contributions were attended to over others' and how group dynamics influenced who felt empowered to contribute. The fifth author identifies as white male who is a faculty member teaching physics with LAs. He has familiarity with the physics context that led to bias in deciding on gaps being slanted toward the disciplinary substance. The corresponding author identifies as a white, international woman who is a faculty member teaching chemistry with LAs and the LA pedagogy course. Since she teaches chemistry with a strong focus on making sense of different student perspectives while also being the principal investigator for the larger research project, her focus on data analysis was directed towards interpreting what students meant when they were speaking and towards the meaningfulness of the analysis for the broader project. Due to her focus on supporting her LAs to prioritize the student perspective over their own, she was biased when coding data from classrooms that emphasized stepwise problem solving towards the correct solution. She experienced challenges valuing the learning in these contexts and following small grain size gaps when coding the data.

Rather than following a single method to establish trustworthiness in our analysis, we used a combination of strategies to incorporate multiple perspectives at all stages of project development, including researcher reflexivity, incorporating multiple voices and positionalities through collaboration, and consensus processes (Cian, 2021; Creswell & Miller, 2000; Saldaña, 2013). For the PEA coding, all interactions were separately analyzed by 2-3 coders, including all 6 authors and other group members, and then discussed to consensus. Because of our different positionalities toward the data, including forms of membership (Creswell & Miller, 2000), we brought different interpretations and perspectives to bear on how we viewed the data. Including multiple voices at the critical first level of analysis helped us come to consensus about what was happening and to center the students' perspectives, rather than our own. During development of the discourse change and continuity coding, 4 of the authors participated in weekly meetings led by the first author to discuss the developing data analysis procedures and interpretations of the interactions. This grounded the development of the data analysis procedure in its utility to explain the phenomena present in the data and allowed us to incorporate multiple epistemological perspectives into development. After this collaborative development phase, the first author coded all interactions, and the second and corresponding authors coded 22% of the data independently (8 interactions). We discussed the independent analyses in several meetings until we reached 100% agreement in coding interactions. The first author revised the codebook and coding of all interactions based on our discussions.

3.5 Methodological Limitation

There are three limitations related to our methods. First, our framework is developed solely using LA-facilitated interactions. Although we believe that these interactions are comparable to learning in other contexts, the framework would need to be applied in those contexts to affirm that. Second, although we tried to select a range of interactions, we were limited by our capacity in how many interactions and contexts we could analyze. Finally, although we did as much as possible to mitigate disruption when collecting classroom recordings, our data collection approach may have changed the way students behave in class. Students did not always work in their usual groups, and they interacted with LAs wearing an obvious body camera. In post-interviews, students and LAs reflected that these disruptions sometimes changed the way they interacted—they would talk more, stay on topic longer than usual, and generally tried to be on their "best behavior" for the recording. However, they also reflected that despite these changes, video recordings were accurate representations of their interactions in class, thus we believe that our framework was developed from authentic learning encounters.

4. Findings and Discussion

The goal of this study was to develop an analytical framework for learning that meets three fundamental criteria we named in the introduction: ability to identify learning in the moment of the interaction and not post hoc, ability to characterize different kinds of learning, and comparability across multiple interactions that remains sensitive to context. The following sections will be organized around each of these criteria to show how analyzing for discourse change and continuity can help us see and conceptualize in-the-moment learning. The example introduced in 4.1 will serve as a point of comparison for the other two sections.

4.1 Identifying Learning in-the-Moment of Interaction

The first feature for our analytical framework on learning is the ability to characterize learning from the discourse of the interaction rather than from post hoc assessment, and to do so by finding evidence directly from the discourse rather than by identifying different types of meaningful scientific activities. We will use an example from our dataset to illustrate how our framework operationalizes learning through two fundamental mechanisms, continuity and discourse change (Kelly et al., 2012; Östman & Öhman, 2022; Wertsch, 1998; Wickman & Östman, 2002), and how it provides meaningful insight into the progression of learning.

In the interaction, a group working with LA Ayaoba in an in-person chemistry course at Institution B was tasked with increasing the voltage of a galvanic cell by making the reaction more product-favored (see Figure 6). To help the reader follow our analysis, a part of the interaction is depicted graphically in Figure 7 and the corresponding portion of the transcript is provided in Supporting Information 3 in Table S2, with references to Figure 7 to corroborate the analysis with the transcript excerpt. This part of the interaction was typical for how learning in this interaction progressed more generally. In Figure 7, the first-level gap analysis is shown in the boxes, which can be read left to right, to follow the progression of the conversation. The second level continuity and discourse change analyses are depicted over the arrows. Continuity and discourse change codes are shown in relation to Gap 4 as the unit of analysis, indicated by the dashed box.

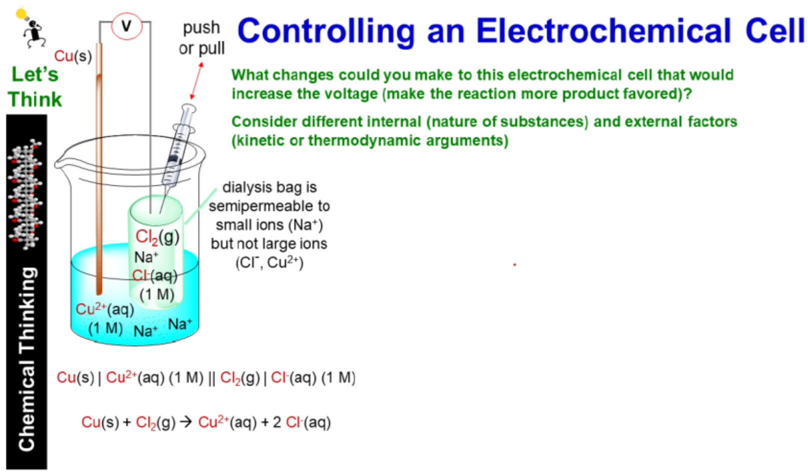

Figure 6. Problem context for the interaction with LA Ayaoba presented in 4.1.

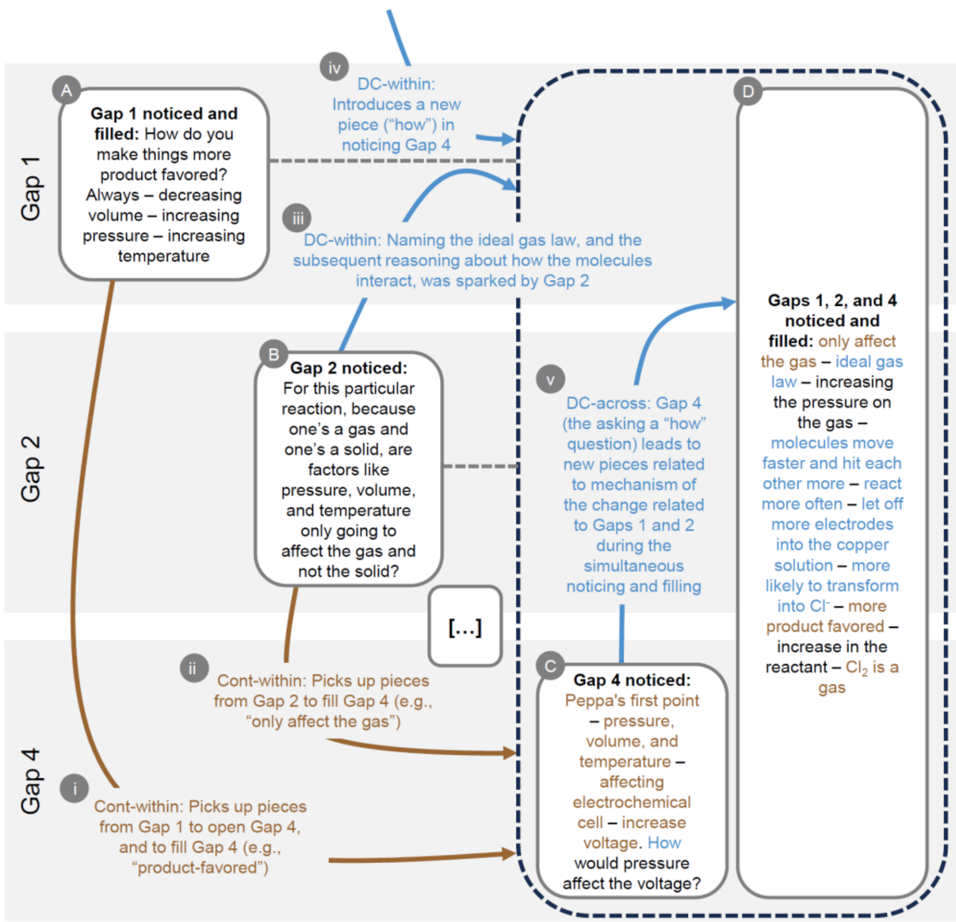

Figure 7. Diagram depicting our analysis of an interaction involving a group working with LA Ayaoba. Gaps are shown in Boxes. Continuity and discourse change codes are depicted over arrows. Brown arrows represent continuity codes, and brown text represents pieces associated with those codes (picked up from earlier parts of the encounter). Blue arrows represent discourse change codes, and blue text represents pieces associated with those codes (new ideas introduced to the encounter).

Before diving into the details of the analysis, we summarize three important things that happen in the portion of the interaction displayed in Figure 7 between two students, Peppa and Science, and the LA. First, Peppa named two gaps that became focal questions for the interaction (Fig. 7, Boxes A and B): restating the problem as she started to grapple with it (Fig. 7, Box A) and wondering about which reactants will be affected because some are gases and some are solids (Fig. 7, Box B). Second, LA Ayaoba drew on Peppa's initial hypotheses in response to the first focal question to pose her own question of how pressure affects voltage (Fig. 7, Box C). Third, these three questions were addressed simultaneously as the students drew on ideas related to increasing the pressure and effects on gases and introduced new ideas related to molecular level change and kinetics to address their gaps in a more complex and mechanistic way (Fig. 7, Box D).

In our analysis, we found extensive continuity and discourse change established during this interaction. Continuity-within (Fig. 7, Arrows i and ii) was evidenced by LA Ayaoba's question (Fig. 7, Box C) referring back to Peppa's original hypothesis (Fig. 7, Box A) and by how the students picked up specific ideas (brown text in Fig. 7, Box D) from Gaps 1 and 2 (Fig 7, Boxes A and B). Continuity-across (represented by a single box spanning multiple gaps) was established by students Science and Peppa attending to all three gaps simultaneously (Box D) creating a continuous relationship between the state of matter and the impact of pressure on voltage.

With regards to discourse change, we saw three sources of discourse change. First, DC-within (Fig. 7, Arrow iv) happened when LA Ayaoba opened Gap 4 (Fig. 7, Box C) and introduced a new "how" piece, which introduced a mechanistic aspect that was new to the interaction. DC-within (Fig. 7, Arrow iii) also occurred because Peppa brought in "the ideal gas law" while filling Gaps 1, 2 and 4 simultaneously (Fig. 7, Box D), which was sparked by her earlier idea of considering "factors only affecting the gas" during Gap 2 (Fig. 7, Box B). DC-across came from LA Ayaoba's question (Fig. 7, Arrow v). Posing Gap 4 as a how question led to new pieces that provided a mechanistic explanation about how molecules hit each other (blue pieces in Fig. 7, Box D), which not only answered Gap 4 directly, but also justified why it only affected the gas (filling Gap 2) and why it was product-favored (filling Gap 1).

Analytically, this example illustrates that our DC and continuity codes provide a layer of analysis that can be used in conjunction with the gaps and relations coding already established in the PEA literature. The DC and continuity codes allow us to track the mechanism of how in-the-moment learning progresses in detail, by attending to how needs develop and are interrelated during the conversation, and how earlier parts of an encounter influence later parts. Conceptually, the presence of DC and continuity was evidenced directly in the discourse (Hamza & Wickman, 2013; Karlsson et al., 2020; Kelly et al., 2012; Östman & Öhman, 2022; Wickman, 2006; Wickman & Östman, 2002), which suggests that the students were collaboratively learning, refining and making sense of their mechanistic explanation for how voltage changes. Second, it showed how the contingent needs and the encounter's particularities drove learning. Here, the original two gaps lingered throughout the interaction—the need to make them intelligible persisted and was transformed through being continually revisited. By having those gaps as anchors in the interaction, continuity was established, because the same relations were leveraged repeatedly as they were reckoned with and consolidated. They also served as a space for establishing discourse change, as the students made sense of new ideas and tried to figure out how they related to these overarching gaps. New gaps that were opened gave the students new entry points to think about these lingering needs, and the students collaboratively sought for the best and most coherent solution. By coming into contact with new discourse, meanings were transformed and negotiated: our original definition of in-the-moment learning.

4.2 Identifying different kinds of learning

The second feature of our analytical framework on learning was the ability to identify and characterize different types and objects of learning. This is vital, because in classroom interactions, students draw on heterogeneous prior experiences and learn much more than scientific content, including how to navigate interpersonal tensions and struggles (Keen & Sevian, 2022; Sohr et al., 2018), how to engage in the community and practices of science (e.g., Ford, 2008; Grimes et al., 2019; Lave & Wenger, 1991), and how their personal histories are or are not valued as meaningful learning resources in the classroom (e.g., Appleby et al., 2021; González-Howard & Suárez, 2021; Karlsson et al., 2020; Lyon, 2023; Suárez, 2020). Below, we will show how our framework begins to identify some different ways in which in-the-moment learning can progress by contrasting two examples with the one presented in 4.1. The first shows learning that is conceptual like the previous example but progresses in a different way, and the second one demonstrates the learning of norms rather than specific disciplinary substance.

To compare and contrast these different ways of learning, let us first revisit how learning progressed in the example in 4.1. In this example, learning occurred through a mechanism of revisiting and revising relations that were established to fill earlier gaps and as-of-yet unintelligible needs related to their conceptual understanding. As the group worked through the problem, they returned to the focal gaps Peppa identified. This established continuity (students drew on insights from other needs addressed throughout the interaction) to spark discourse change (they built on those insights to develop new ideas). This demonstrates one mechanism of in-the-moment learning: revisiting and continually making sense of lingering needs that are conceptual in nature.

4.2.1 Identifying different mechanisms for conceptual learning

In contrast to learning as revisiting, learning in the example below occurred through a mechanism of exploring, in which the driver of learning was to understand how ideas new to the interaction, e.g., from other parts of class, related to the encounter at hand. These new ideas were introduced by opening more general gaps, leading to an exploration of how it related to the task at hand. Noticing and filling these gaps often served the purpose of establishing continuity *beyond* the encounter to the rest of class by introducing discourse change *within* the encounter.

In this interaction, a group of students working with LA Physics in an in-person physics class at Institution B was trying to figure out what direction a ball would go in if it was hit three times (see Figure 8). To illustrate the exploring mechanism, the analysis is depicted in Figure 9 and relevant parts of the transcript are excerpted in Table S3 (Supporting Information 3). Both should be read using the same conventions as in 4.1.

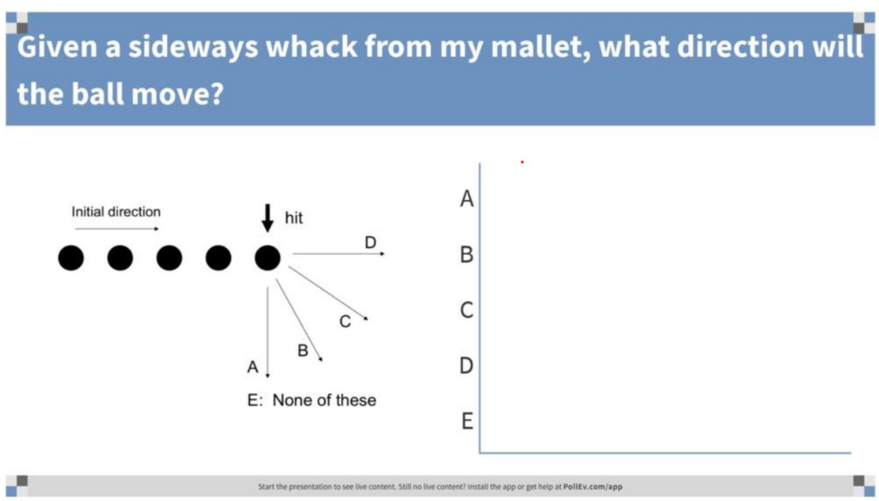

Figure 8. Problem context for the interaction with LA Physics presented in 4.2.1.

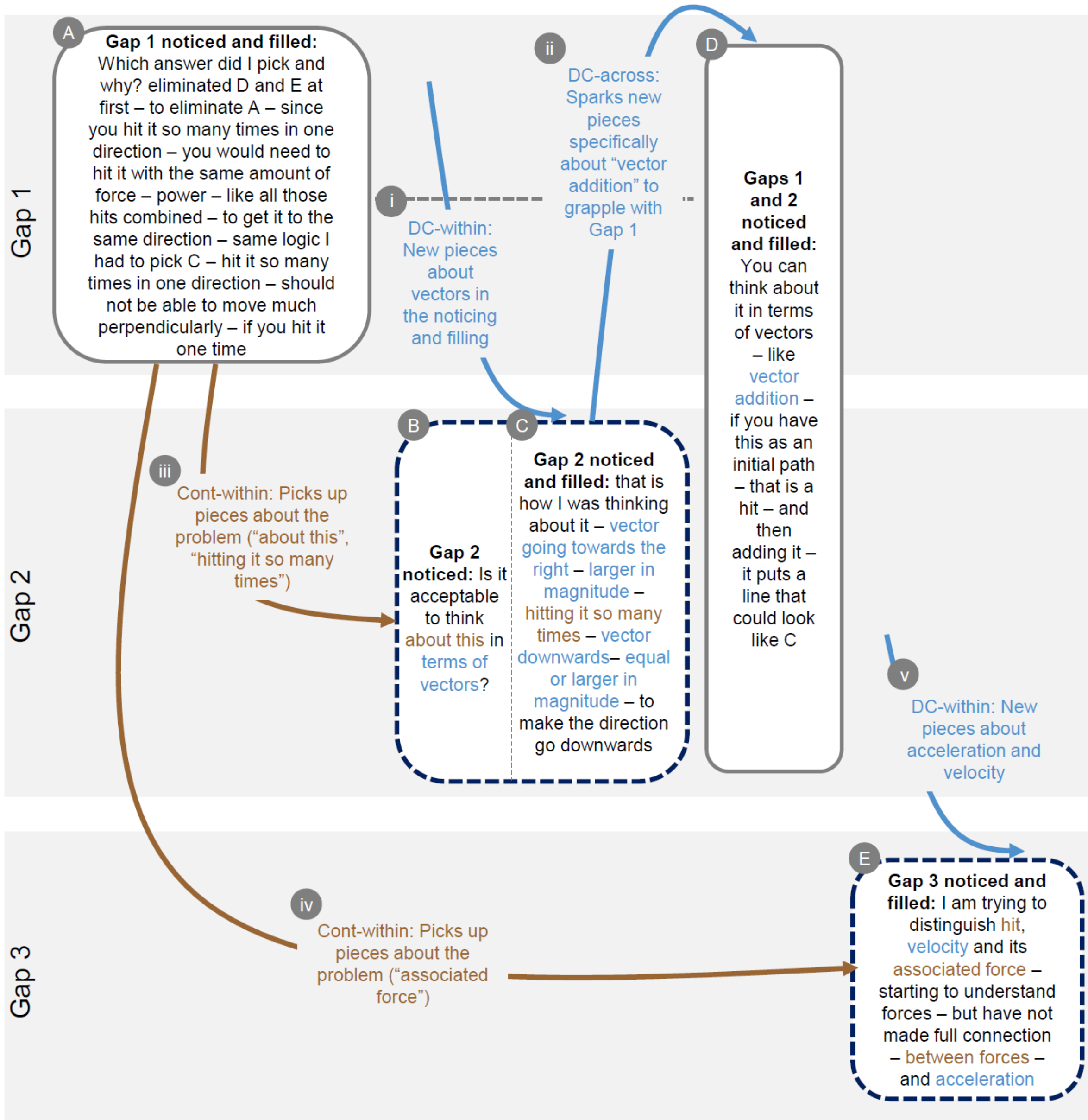

Figure 9. Diagram depicting our analysis of an interaction involving a group working with LA Physics. Gaps are shown in Boxes. Continuity and discourse change codes are depicted over arrows. Brown arrows represent continuity codes, and brown text represents pieces associated with those codes (picked up from earlier parts of the encounter). Blue arrows represent discourse change codes, and blue text represents pieces associated with those codes (new ideas introduced to the encounter).

In our presentation of the exploring activity below, we attend to what happened with two gaps; thus, in Figure 9, we have included the continuity and discourse change codes that relate to both Gaps 2 and 3. To summarize the interaction, the group of four (Elle, Blueberry, Tate, and Box) had already figured out and come to consensus on an answer, which Elle recapped for the LA (Fig. 9, Box A). This gave space for Blueberry to begin more generally exploring how different concepts from class (e.g., vectors and acceleration) related to the problem they were working on, which she did by opening two new gaps (Fig. 9, Boxes B and E).

Applying our framework to analyze this excerpt, we see similarities in Gaps 2 and 3 (Fig. 9, Boxes B and E) that relate to how the learning progressed. Gap 2 established continuity-within by picking up the idea of the problem in general and the piece about the number of hits (Fig. 9, Arrow iii) to figure out how it related to vectors, which established DC-within (Fig. 9, Arrow i). Gap 3 established continuity-within by picking up the pieces of hit and force from Gap 1 (Fig. 9, Arrow iv) to figure out how it related to velocity and acceleration, which established DC-within (Fig. 9, Arrow v). After being noticed, the continuity and discourse change analysis diverges for the two gaps. For Gap 2, DC-across is sparked when it allows the group to re-engage with thinking about Gap 1 through the lens of vector addition (Fig. 9, Arrow ii). Gap 3, however, has no across codes associated; it is never attended to, but rather lingers throughout the rest of the interaction.

This excerpt illustrates how the exploring mechanism differs from the revisiting mechanism (illustrated by Ayaoba's group). In this example, learning occurred when gaps were opened to introduce a new idea, causing DC-within as other students picked up those ideas and expanded on them. When Tate and Box noticed and filled Gap 2, they centered their discourse around Blueberry's new idea of vector addition while keeping their argument continuous with Elle's original argument for choice C. These new gaps made the encounter explicitly continuous with pieces from class that were not originally part of their problem space, such as vector addition, velocity, and acceleration. Exploring was made visible in our coding by high levels of continuity-within and DC-within, as the new gaps built on earlier pieces and introduced new pieces to grapple with that specific gap question. In the revisiting mechanism exemplified in 4.1, learning instead occurred by making continuity across needs that arose during the encounter, and leveraging new connections established during the encounter to make sense of lingering gaps. This was made visible in our coding by high levels of all four codes, as students grappled with both new questions (within codes) and how those questions caused them to revisit and revise their reasoning (across codes). This demonstrates *how* the mechanism of establishing continuity and discourse change may vary. In addition to this variation, *what* was made continuous could also vary in different interactions, as will be shown in the next section.

4.2.2 Identifying different objects of learning

In addition to conceptual learning, evidence emerged from the data that we can identify in-the-moment learning of things other than conceptual understanding, e.g., learning of norms for collaborative work such as habits of care, normalizing expression of uncertainty, and norms of taking an activity seriously or not. These norms were introduced by filling gaps with pieces that were aesthetic rather than conceptual (Wickman, 2006), in which needs were met by making space for non-conceptual pieces and relations that could be, but were not limited to, expressions of emotions, confusions, and verbal validation (Keen & Sevian, 2022; Park et al., 2016; Sohr et al., 2018).

In the interaction below from an in-person physics class, LA Haseen was working with a group of four students (Vega, Graph, Bucket, and Goldie), who regularly worked together in class and were tasked with answering a problem about torque (Figure 10). To illustrate how we saw the learning of norms, we have shown selected Gaps in Figure 11 and excerpted relevant parts of the transcript in Table S4 (Supporting Information 3). Both should be read using the same conventions as in 4.1. The gap under analysis is Gap 1.

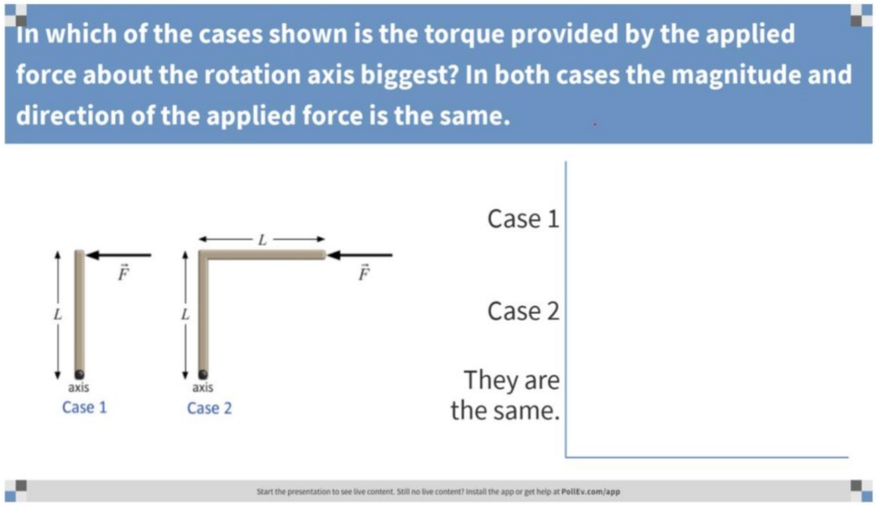

Figure 10. Problem context for the interaction with LA Haseen presented in 4.2.2.

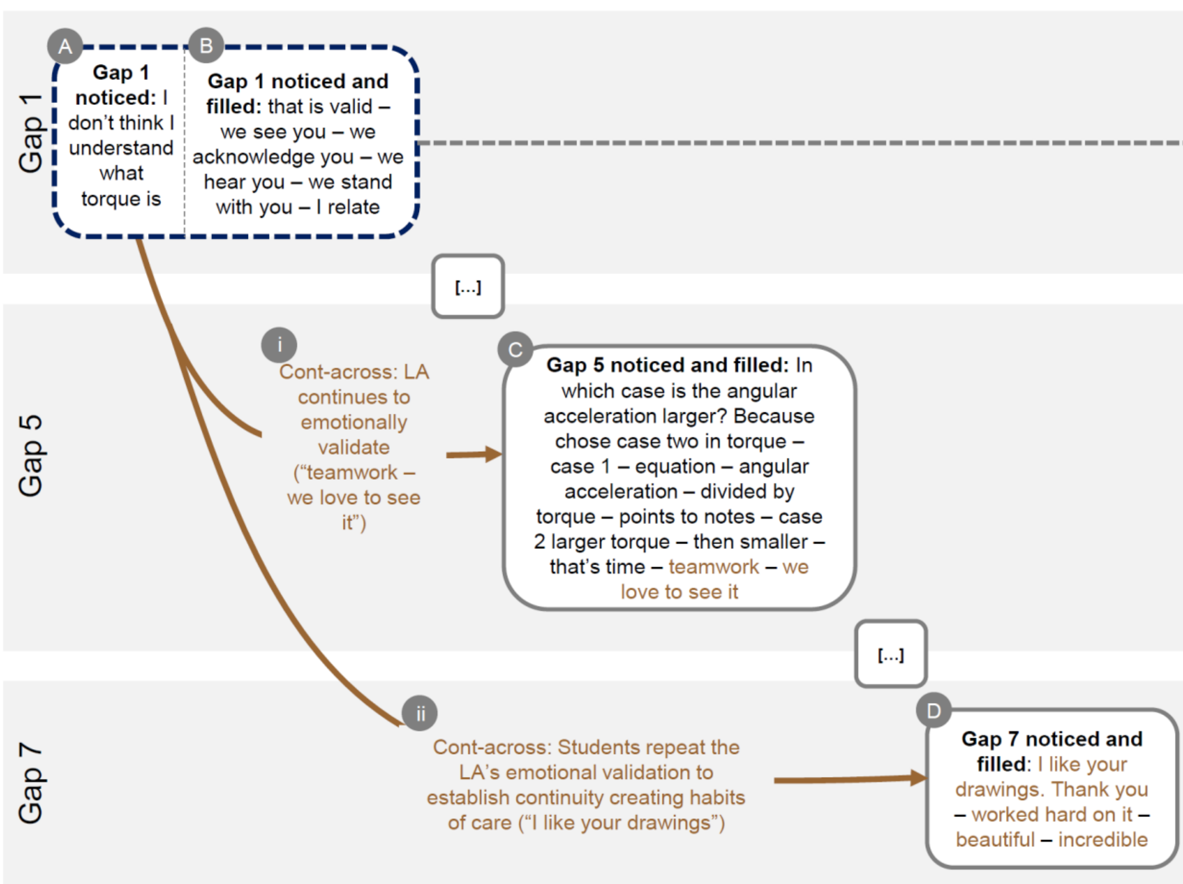

Figure 11. Diagram depicting our analysis of an interaction involving a group working with LA Haseen. Gaps are shown in Boxes. Brown arrows represent continuity codes, and brown text represents pieces associated with those codes (picked up from earlier parts of the encounter).

We summarize the interaction as follows: LA Haseen joined the group mid-way through their problem solving, and student Vega caught her up on what they had been doing by sharing a confusion in a light-hearted way (Figure 11, Box A). The LA and the other students warmly validated her confusion (Figure 11, Box B). This spirit of camaraderie and emotional validation recurred as the group continued to grapple with the problem, fostering a norm of socioemotional care when grappling with conceptual challenges (Figure 11, Boxes C and D).

Applying our framework to this excerpt, we see extensive aesthetic continuity. Continuity-across was established when the spirit of emotional validation established by LA Haseen and Graph in Gap 1 (Fig. 11, Box B) was picked up in two later moments (Fig. 11, Arrows i and ii). First, the LA verbally validated the group's collaboration in how they corrected each other (Fig. 11, Box C, Arrow i); second, Goldie opened an aesthetic gap as she went out of her way to lift up and compliment Vega's sketch of her reasoning (Fig. 11, Box D, Arrow ii). These changes demonstrate how socioemotional validation became a norm of their learning encounter. In Gaps 1 and 5, emotional validation was used to establish relations to help fill gaps (Fig. 11, Boxes B and C), where the collaboration and socioemotional pieces occurred alongside the disciplinary learning. In Gap 7 (Fig. 11, Box D), Goldie opened a gap whose purpose was validation and thus changed the nature of the role that validation played from occurring alongside conceptual sensemaking, to also being a meaningful object of in-the-moment learning in the encounter itself.

This example illustrates how continuity was established by repeating emotional validation and support. This in turn established norms related to how the group interacted with each other and emotionally validated their uncertainty—which was also a goal the instructor had established for his class. Capturing this learning of habits of care is of particular interest because emotional experiences can support disciplinary learning (e.g., Appleby et al., 2021; Park et al., 2016;

Wickman, 2006; Wickman et al., 2022). We saw this kind of non-conceptual learning in several other ways, which were often aligned with the instructor's goals for the class, such as repeating and normalizing expressions of uncertainty, but could also conflict with what the instructor wanted for their students, such as establishing a norm of dismissing others' questions. In an example of the latter, a group of students working on the problem in Figure 6 established a discursive norm around how gaps were closed. One student established a new relation that "things – go crazy," which he expressed in a joking and dismissive tone. He used this relation to close two gaps opened by other students, one related to how heat would increase products ("hot things – go crazy") and one related to the effect of pH ("electrons – going a little crazy"). Repeating this phrase established continuity of this relation and of closing the current line of inquiry, which led to the group attending to something else completely. Although students often engage with non-canonical ideas in fruitful ways, in this example the relation of "things – going crazy" was used to close sensemaking around a gap, and created a norm that the activity was not meant to be taken seriously. For both this group and the group with Haseen, the students were learning ways of speaking related to how they work which each other and the concepts. While learning through the mechanism of exploring and revisiting were related to conceptual continuity and discourse change, in-the-moment learning can also be related to norms of collaborative work. What is learned during interaction can thus go beyond conceptual learning and includes learning of how to interact with each other and the disciplinary substance.

The preceding three interactions illustrate that our framework can identify different types of in-the-moment learning in two important ways: identifying different mechanisms for the progression of in-the-moment learning and identifying different objects of learning during these encounters. Both revisiting and exploring had similar objects, in that they were both geared toward developing conceptual understanding, either within the encounter by bringing in new pieces to make sense of a lingering need (revisiting) or beyond the encounter by explicitly naming a need to connect what students were doing to the other things they were learning in class (exploring). The learning of norms, however, had a different object, in that what the students learned was not related to course content, but rather to the ways they should interact with each other and the scientific content. All three also had different mechanisms that were described through the DC and continuity codes. Revisiting occurred through high levels of all 4 codes, because the purpose of this learning was to think about how emerging gaps changed how the students thought about already present needs. Exploring occurred through continuity-within and across, and DC-within, but not necessarily DC-across, because the purpose was to think about new ideas through the lens of what they had been discussing rather than applying those new ideas to earlier gaps. The learning of norms occurred through establishing continuity within and across gaps because the purpose was to develop and establish certain habits of speaking. This also meant it was not characterized by discourse change, because the norms were established through continuity. These analyses show that we can distinguish different ways in-the-moment learning progresses, as well as different objects of in-the-moment learning. In addition to the three mechanisms we presented here (revisiting, exploring, and learning of norms), we also found two other common mechanisms for learning in our dataset that were conceptual in nature: *elaborating*, in which learning was driven by the need to make sense of each other's ideas (characterized by high continuity-within and -across, and high DC-within); and *stepwise*, in which learning was driven by identifying and filling needs before moving onto the next gap (characterized by low continuity-across and DC-across, and high DC-within), similar to the subsequent gap pattern presented in Walsh et al., 2022. Additionally, these mechanisms commonly coexisted within a single encounter.

4.3 Making learning comparable across interactions

The final feature of our analytical framework was the ability to make interactions comparable, while remaining sensitive to context. In previous sections, we saw that DC and continuity codes were able to help elucidate different in-the-moment learning mechanisms. Below, we use an interaction with the same learning mechanism as the example in 4.1 (revisiting) to explore what a comparison to the example in 4.1 through the lens of our framework reveals.

In the interaction from a hybrid chemistry course at Institution A, a pair of students was working with LA Orange on a problem in which they needed to balance an equation (Figure 12). The analysis is depicted in Figure 13, and the relevant transcript excerpt is provided in Table S5 (Supporting Information 3). The gap under analysis is Gap 3.

Balanced Equation:

$3NO_2\,(g) + H_2O\,(l) \rightarrow 2HNO_3\,(aq) + NO\,(g)$

Average concentrations of HNO_3 in a big city such as Los Angeles are close to 1.0 mg (1 mg = 1 x 10^{-6} g) per m^3. Determine the concentration of NO_2 in g/m3 that is involved in the production of HNO_3 in this environment.

A 7.36×10^{-7} g/m^3

B 1.1×10^{-6} g/m3

C 1.6×10^{-8} g/m3

D 2.4×10^{-8} g/m3

Figure 12. Problem context for the interaction with LA Orange presented in 4.3. Note that we provided the balanced equation for the reader's clarity; however, it was not initially a part of the problem.

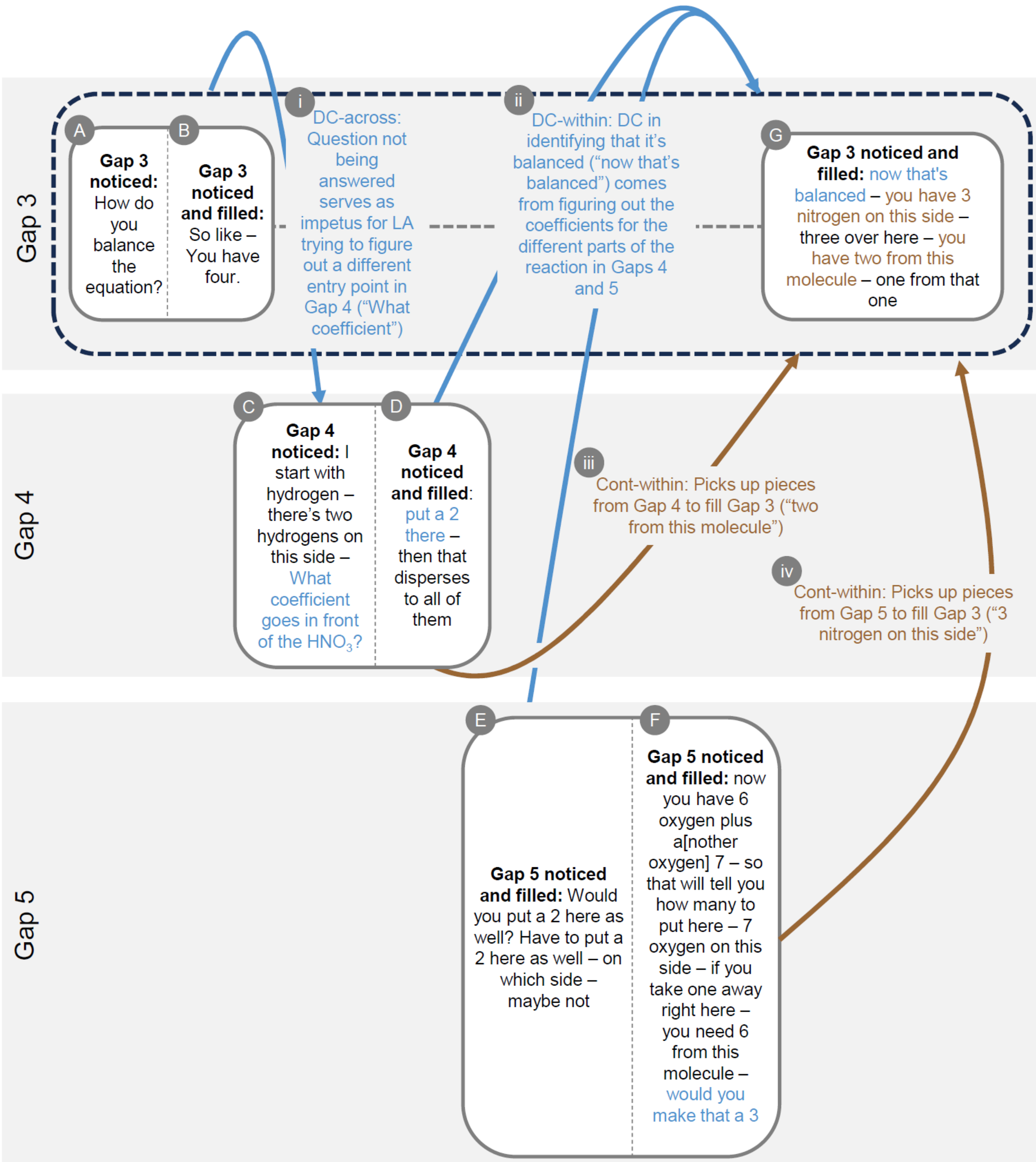

Figure 13. Diagram depicting our analysis of an interaction involving a group working with LA Orange. Gaps are shown in Boxes. Continuity and discourse change codes are depicted over arrows. Brown arrows represent continuity codes, and brown text represents pieces associated with those codes (picked up from earlier parts of the encounter). Blue arrows represent discourse change codes, and blue text represents pieces associated with those codes (new ideas introduced to the encounter).

In this excerpt from the interaction, LA Orange opened Gap 3 to guide one of the students, Lola, toward figuring out how to balance the equation (Fig. 13, Box A). When Lola hesitated to answer, LA Orange and Lola worked through Gaps 4 and 5 (Fig. 13, Boxes C and E) related to balancing specific atoms and molecules, which they leveraged to answer the lingering Gap 3 (Fig. 13, Box G). This mechanism of revisiting an earlier, still lingering gap with new connections aligns with the revisiting mechanism described in 4.1 In the discussion that follows, we elaborate on how our analytical framework provides evidence for this comparison.

In our analysis, there were high levels of continuity and discourse change. Gap 3 (Fig. 13, Box A) was the focal gap the group continued to return to. Continuity-within (Fig. 13, Arrows iii and iv) was established when LA Orange picked up pieces from Gaps 4 and 5 (Fig. 13, Boxes D and F) to fill Gap 3 (Fig. 13, Box G). Picking up these pieces not only answered the question of whether the equation is balanced, but also created continuity between the contingent sub-gaps related to very specific molecules, and the broader question of what it means to balance an equation ("now that's balanced – you have 3 nitrogen on this side"). Continuity-across was not established by Gap 3 in the excerpt of the discussion displayed in Figure 13, but the balanced equation was later used when the group worked on the conversion (establishing continuity-across at a later point, not represented in this figure due to space).

With regards to DC, there are high levels that come from how the gaps relate to each other. DC-within was established when the group returned to Gap 3 because identifying that the chemical equation was balanced (Fig. 13, Box G) came from figuring out the coefficients for the different parts of the reaction in Gaps 4 and 5 (Fig. 13, Arrow ii). DC-across was sparked by Gap 3 and served as the reason Gaps 4 and 5 were opened in the first place: LA Orange tried to figure out different entry points to think about the problem (Fig. 13, Arrow i) in response to Lola's difficulty explaining how the equation balances (Fig. 13, Box B).

Similar to the interaction with LA Ayaoba (Section 4.1), LA Orange's group returned to an established overarching gap. Returning to this gap created an opportunity for learning to occur, by leveraging the relations from other gaps, establishing continuity, and using them to spark new gaps that led to discourse change. Thus, the mechanism by which learning occurred was similar, with high levels of discourse change and continuity. However, these two interactions were also quite different—Ayaoba's interaction was highly student-centered (see Table S2 in Supporting Information 3 for the transcript showing who made which contribution) and focused on making sense of the connections between different conceptual ideas. Students drove gap revisiting, as they tried to identify other ideas from class that could help them make the connection between voltage, pressure, and the molecular-level mechanism. The interaction with LA Orange and Lola, on the other hand, was LA-centered (see Table S5 in Supporting Information 3 for the transcript showing who made which contribution) and focused on figuring out how to balance equations, both in general and for the specific problem. The LA guided the interaction, identified questions that could be used as entry points to address the main question, and primarily drove the discourse change. Lola was still engaged in the learning, contributing relations, and identifying needs. From a pragmatic perspective, the presence of discourse change and continuity was evidence for learning in the group as a whole.

Analytically, this suggests that although these two interactions were quite different, the learning, as operationalized through discourse change and continuity, was similar. Through the lens of our analytical framework, we identified the core similarity in the learning mechanism between them.

Conceptually, identifying core similarities highlights that learning as a phenomenon is distinct from other types of discourse (Odden & Russ, 2019). The two examples represented different kinds of discourse. Peppa, Science, and LA Ayaoba were trying to figure out the connections between different concepts, identifying new pieces that could help them bridge understandings. This could be described as sensemaking, a "dynamic process of building or revising an explanation in order to 'figure something out'" (Odden & Russ, pp.191-192). Sensemaking, as we discussed in the introduction, is a distinct discursive activity often tied with learning (Kapon, 2017; Lo & Ruef, 2020; Odden & Russ, 2019). LA Orange and Lola, however, were not focused on building an explanation. Rather, they were focused on figuring out how to balance the equation, trying out different coefficients until they had successfully solved that part of the problem. This discourse might instead be described as a kind of algorithmic problem solving or mathematical manipulation, in which they tested different values until they reached the solution (Karch & Sevian, 2022; Rodriguez et al., 2020; Sevian & Couture, 2018). Despite these differences, both encounters proceeded through similar learning mechanisms of establishing discourse change and continuity by returning to lingering gaps.

5. Conclusion and Implications

For these four examples, we have demonstrated that a microanalysis with our framework operationalizes learning directly through discourse, is sensitive to different mechanisms for and objects of learning, and can make different types of learning comparable. This kind of microanalysis adds to the literature that aims to bridge the gap between detailed interaction analyses and studies that focus on assessable learning outcomes. It does so by creating a lens that can be used to understand how learning occurs in classroom encounters. It also extends the use of PEA (e.g., Hamza & Wickman, 2013; Karlsson et al., 2020; Lidar et al., 2006, 2010; Lundqvist et al., 2009; Manneh et al., 2018; Piqueras & Achiam, 2019) by adding an analytic layer that allows us to track the mechanism of in-the-moment learning in detail through tracking discourse change and continuity.

We contribute to the pragmatic and sociocultural body of literature on learning (Engeström, 2000; Kelly et al., 2012; Östman & Öhman, 2022; Vygotsky & Cole, 1978; Wertsch, 1998; Wickman & Östman, 2002) an additional tool for analyzing learning. Pragmatic philosophies conceptualize learning as the formation and acquisition of habits that allow learners to cope with the world (Kelly et al., 2012; Wickman & Östman, 2002) as they carry practices from one situation to the next. In our work, we can see how this process occurs through the negotiation of needs from moment to moment, as learners navigate what pieces to make continuous and when to introduce new ideas. In contrast to other works that frame processes of knowing and learning as situated in the mind and affected by context (Hutchison & Hammer, 2010; Rodriguez et al., 2020; Russ et al., 2012; Sevian & Couture, 2018), our work frames knowing and learning as action and a transactional process of continual change (Keen, 2021; Östman & Öhman, 2022; Wertsch, 1998).

Although our framework may be valuable for certain kinds of learning, there are several limitations to note. In this study, we did not attend to important interpersonal dynamics such as racialized and gendered dynamics (e.g., Ryu & Sikorski, 2019) and sociopolitical dimensions (Suárez et al, 2023) that influence how students learn. We only attended to discourse, which means that the experiences of silent students who may be learning but not verbally participating is opaque using this lens. We suggest that to capture these dynamics, it may be necessary to combine our analysis with additional analytical frameworks that attend to them directly. For example, initial work led by the third author found that it is possible to understand the learning experiences of silent students, when PEA is combined with another analytical framework (Shi & Tan, 2020). Her findings suggest that silent students are not passive learners, and that their participation may be disproportionately affected by LAs' pedagogical moves (Pierre-Louis, Karch, & Caspari-Gnann, 2022). Karlsson and collaborators' (2020) work focusing on translanguaging students' marginalizing experiences in Swedish classrooms demonstrates the promise of combining PEA with other lenses to unpack specific experiences. This limitation of our study speaks to a possibility for future work that attends more deeply to these social dynamics, namely to understand who is learning what and why, and whether there are power-mediated asymmetries in student learning.

There are many possibilities for future work using our framework. Some researchers may seek to answer the age-old question, "Are my students actually learning in class?" An analysis of active learning classroom video data using our framework, similar to how we did here, may shed light on the nature of learning during classroom interactions, and when and how those interactions are effective or ineffective. Researchers who are concerned with certain types of learning could use different secondary lenses to examine the data. For example, researchers concerned with the role emotions play on disciplinary learning (e.g., Appleby et al., 2021; Park et al., 2016) could interrogate how socioemotional gaps contribute to the rest of the interaction.

One part of our team's future work will triangulate interaction videos with other sources of data to understand how aspects of a classroom activity system drive learning in the classroom. For example, in section 4.3, we discussed how revisiting played out in dramatically different ways in two different classroom contexts. Preliminary analysis of interviews with LAs, students, and classroom instructors suggests this may be due to professors having different classroom rules (Karch et al., 2023). For example, Prof. Lemur, who taught chemistry at University B, had an explicit rule that LAs should not be authoritative in interactions with students. This may help explain why the learning in the interaction with LA Ayaoba was more student-centered than that in the interaction with LA Orange, whose supervising instructor did not have the same rule. This analysis can shed light on how classroom rules and expectations shape what drives learning in interactions.

Another limitation of our present study is that we attended to how discourse change and continuity were established collectively rather than attending to LA and student contributions separately. In the encounters presented in this paper, the LAs played different roles in shaping how learning in the interaction proceeded. For example, LA Ayaoba (4.1) rarely contributed new relations; however, her questions may have prompted the students to elaborate on their thinking, which contributed to discourse change. In contrast, LA Orange (4.3) directed the learning, driving discourse change both by adding her own pieces and prompting them from the student. The influence the LA had on student in-the-moment learning ranged widely in our dataset; other dynamics we observed included the LA interacting similarly to student (posing genuine questions and being positioned as a meaning-maker) and even not speaking at all. In each of these cases, both the LA and students contribute to the learning, because both contribute to the discourse—the interactions only progress the way they do because those specific individuals are interacting in that specific group in that specific moment. However, we acknowledge that the power relationships between LAs and students shape the role those contributions play in creating meaning. Our team's future work will build on the framework presented here to attend specifically to how LA actions influence student in-the-moment learning.

There are also several implications for practice. For example, our focus on continuity and discourse change provides a lens for what LAs and other instructors can pay attention to when working with students. We have used an activity based on a simplified version of this framework in LA training. In the activity, LAs analyze a transcript to identify how gaps are opened and by whom, to reflect on how LA facilitation relates to and impacts student discourse. It may be possible to use this lens in a similar way for training other instructors. In the K-12 and college noticing literature, there is an increasing call for instructors to notice more openly, e.g., to pay attention to what students say without looking at it through the lens of canonical correctness (e.g., Dini et al., 2020; Gehrtz et al., 2022). However, a common critique by instructors is that they do not know what they should be looking for and then fall back into old habits. Our framework could provide a lens through which instructors pay attention to student conversation. Noticing continuity and discourse change still centers student thinking, because it does not call for noticing specific content, while providing an actionable lens through which instructors attend to student conversation.

In summary, our work speaks to how centering student needs in conversation allows us to attend to conceptual learning without relying on correctness. By being attentive to and centering students' perspective, i.e., what they saw as what needed to be made intelligible, and how they articulated that in the noticing of gaps, we were able to identify many different needs students experience in their encounters (Sohr et al., 2018), and thus some of what it is they are learning. By being sensitive to and making deliberate space for relations and pieces beyond conceptual and cognitive pieces (Wickman, 2006), we were able to identify and parse the co-existence of the learning of norms and conceptual learning (Appleby et al., 2021). Our framework contributes to the literature a lens to see and recognize learning in the moment of its happening and make it comparable across interactions.

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Conflict of Interest Statement

All authors declare that they have no conflicts of interest.

Availability of data and materials

Data used for this study are available upon reasonable request to the corresponding author.

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