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The impact of learning assistant facilitation practices on student in-the-moment learning

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Abstract

Background Learning assistants (LAs) in undergraduate STEM lectures facilitate discussions between students in small groups. In this research study, we investigate the impact of LA facilitation on student learning as it occurs during LA–student interactions. To do so, our work builds on two sociocultural frameworks focused on LA facilitation and student in-the-moment learning. We conceptualize LA facilitation as either authoritative if it centers one perspective or dialogic if it centers multiple perspectives. Student in-the-moment learning is understood as the progression of student needs and the filling of those needs with LA and student ideas.

Results Our analysis of 78 video recordings of LA–student interactions from 37 different chemistry and physics LAs revealed that LA facilitation had four major impacts on student in-the-moment learning: increasing grappling, reaching closure, sharing ideas and reasoning, and revisiting an earlier need. Rather than these impacts differing upon the use of authoritative and dialogic facilitation, all four impacts sometimes resulted from authoritative and sometimes from dialogic facilitation. However, authoritative facilitation was more often correlated with LA-centered manifestation of these impacts, while dialogic facilitation was more often correlated with student-centered manifestation. In addition to these conceptual impacts, we also found five socioemotional impacts: less participation, dominance continues, fostering participation, students choose not to participate, and lighthearted conversation. LAs added socioemotional components to both authoritative and dialogic facilitation, and actions aimed at bringing more students into the conversation indeed had this impact, while actions addressing specific students often continued to privilege the participation of the same students.

Conclusion Our study expands theory on authoritativeness and dialogicity as it empirically validates that authoritative facilitation is more often correlated with LA-centered learning and dialogic facilitation is more often correlated with student-centered learning. Further, our work is the first to explore the socioemotional impact of LAs in the moment of interaction. Our findings can be used in LA trainings to teach LAs how to intentionally use authoritative and dialogic facilitation, how to incorporate socioemotional components to their facilitation, and how to adjust their practice to align with learning goals for students in their context.

Keywords Learning Assistant, LA, Chemistry education, Physics education, Facilitation practices, In-the-moment learning, Authoritative, Dialogic, Epistemology, Undergraduate science, STEM

Introduction

Instructional strategies that place students' needs at the center of instruction shift the focus of a classroom from teaching to learning. In STEM courses, student-centered active learning leads to improved learning outcomes (Freeman et al., 2014; Theobald et al., 2020) as well as increased positive student attitudes towards learning (Flaherty, 2020; Mooring et al., 2016). The type of active

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learning we reference here is a partially or fully flipped lecture with multiple small group problem-solving sessions followed by whole class discussions about the problems. Instead of in class, some to all direct content instruction is provided via online textbook and/or videos before class.

Due to typically large class sizes in introductory STEM courses, it is impossible for one instructor to meet all students' needs; therefore, active learning can be implemented with the help of learning assistants (LAs). LAs are undergraduate students who are hired to assist in a course that they have previously taken for which their main role is to facilitate small group discussions during active learning (Otero et al., 2006, 2010). The implementation of LAs leads to increases in student learning conceptually and also positively impacts the affective components of their learning (Barrasso & Spilios, 2021). While most of the studies reviewed by Barrasso and Spilios (2021) are grounded in *post-hoc* measurements of student success, we have limited knowledge that LA actions *during* their interactions with students in class can change how students engage with an activity (Knight et al., 2013, 2015), emphasizing that student learning outcomes are mediated by their interactions with LAs.

While implementing LAs leads to improved student learning outcomes, not much is known about the ways different LA facilitation practices lead to these improved outcomes or how LAs attend to and influence the progression of students' learning as it occurs in the moment of the interaction. In other words, not much is known about the mechanism by which LA actions impact student in-the-moment learning. Thus, our research study aims at addressing the following research question: How do LA actions impact student in-the-moment learning? In the following sections, we review facilitation practices and in-the-moment learning in the LA context before we turn to the sociocultural frameworks that guided our study.

Literature review: facilitation practices and in-the-moment learning in the LA context

The LA model was developed at the University of Colorado Boulder and has a few characteristics that differentiate it from other near-peer teaching models (Otero et al., 2006, 2010). One is that LAs are pedagogically trained concurrent to their first semester as an LA, where they enroll in a pedagogy course to learn teaching methods that are centered around increasing student engagement and scientific thinking (Top et al., 2018). LAs also have weekly preparation meetings with the instructional team, which serve as the basis of collaborative relationships between LAs and instructors aimed at course design, execution of the curriculum, and supporting students (Davenport et al., 2017; Hamerski et al., 2021; Hill et al., 2023; Hite et al., 2021; Indukuri & Quan, 2022; Jardine, 2019, 2020; Sabella et al., 2016).

The implementation of LAs positively impacts multiple stakeholders, including students (e.g., Ferrari et al., 2023; Herrera et al., 2018; Kornreich-Leshem et al., 2022), LAs themselves (e.g., Breland et al., 2023; Cao et al., 2018; Close et al., 2013, 2016; Conn et al., 2014), the instructional team (e.g., Caravez et al., 2017; McHenry et al., 2009; Sabella et al., 2016), and even the institution (e.g., Goertzen et al., 2011; Koretsky et al., 2018). Here, we review the positive outcomes for students in more depth as the impact of LAs on students is the focus of our study.

LA implementation in STEM courses increases student conceptual understanding, evidenced by increased concept inventory scores and higher-order reasoning skills (e.g., Ferrari et al., 2023; Herrera et al., 2018; Miller et al., 2013; Sellami et al., 2017; White et al., 2016). LA-supported courses also decrease DFW rates and increase student retention in STEM (Alzen et al., 2017, 2018), especially for students marginalized by racism (Sempértegui et al., 2022; Van Dusen & Nissen, 2020). Furthermore, LAs support socioemotional aspects of students' learning in the classroom — e.g., increasing students' levels of engagement, their satisfaction, and their attitudes towards learning (Donis et al., 2024; Kiste et al., 2017; Schick, 2018; Talbot et al., 2015; Thompson & Garik, 2015). Hernandez et al. (2021) suggest that this increased engagement and attitude shift could be through three types of social support: appraisal, emotional, and informational support. LAs have also been linked to disciplinary identity development for students (Kornreich-Leshem et al., 2022), as well as increasing their sense of belonging in the classroom (K. Clements et al., 2023; T. Clements et al., 2022). The presence of "inspirational role models" (i.e., LAs) in the classroom lowers the risk of negative judgement and increases the opportunities for students to talk about science in a low-stakes way, further contributing to increased engagement and increased confidence amongst students (K. Clements et al., 2023). Furthermore, LAs notice status differences in student–student interactions and work towards disrupting those differences (Auby & Koretsky, 2023).

In addition to the body of literature on positive student outcomes, a few approaches have been taken to investigate what LAs do during their day-to-day classroom practice. Knight et al., (2013, 2015) described five different types of moves LAs use — e.g., asking prompting questions, requesting student reasoning, providing their own reasoning, making background statements, and acknowledging student answers. Similarly, in their Action Taxonomy for Learning Assistants (ATLAs), Thompson

et al. (2020) categorized LA actions into six different types of facilitation — e.g., LA-directed facilitation, LA-guided facilitation, advice, feedback, course-related talk, and non-course-related talk. Attending to the frequency of different types of LA moves, both Thompson et al. (2020) and Pak et al. (2018) found that LAs more often directed the conversation towards an answer than using moves that give students space for sharing their ideas and making sense of problems collaboratively.

Given that some LA moves rely on more input from the LA while others leave more room for the students to respond (Knight et al., 2013; Pak et al., 2018; Thompson et al., 2020), it is important to characterize whose perspective, i.e., the LAs or the students, is centered in the conversation during LA facilitation (Carlos et al., 2023; Stuopis, 2023; Stuopis & Wendell, 2023). In our previous work, we found that LA actions exist on a spectrum from authoritative (one perspective is centered) to dialogic (multiple perspectives are centered) (Carlos et al., 2023). More specifically, LA actions range from very authoritative (i.e., the canonical perspective) to moderately authoritative (i.e., the LA perspective) and from moderately dialogic (i.e., the student and another perspective) to very dialogic (i.e., the student perspective).

While it is important to know how LAs facilitate student group discussions, it does not tell us how this facilitation impacts student learning as it occurs during these discussions. One reason for why this impact on student in-the-moment learning is understudied is because it is challenging to capture, and an analytical tool that can be used to analyze in-the-moment learning during student group interactions has only very recently emerged from our research (Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024). The tool guides the researcher to analyze which needs drive group interactions, and how students connect their past experiences, i.e., continuity, and form new relations around new ideas, i.e., discourse change. Importantly, continuity and discourse change revolve around norms, such as socioemotional support and care, and around conceptual ideas (Karch, Maggiore, et al., 2024). LA–student interactions provided a fruitful context for the development of this analytical tool because they are embedded in highly dynamic, active learning courses, but the analytical framework itself does not yet characterize patterns of learning in these interactions or how the LA influences this learning, rather, it provides the necessary tools to do so.

To our knowledge, only one group of researchers made the connection between how LAs facilitate student group discussions and what students do during these group discussions (Knight, et al., 2013, 2015). Knight et al., (2013, 2015) evidenced that questioning prompts fostered student reasoning while LA explanations often ended student discussions. While this work accounted for how LA prompts influenced student discussion, the focus was on changes in discussion patterns rather than on how students' needs and conceptual ideas progress, i.e., students' in-the-moment learning. To investigate the impact of LA facilitation on student in-the-moment learning, we use our previous characterization of authoritative and dialogic LA facilitation (Carlos et al., 2023) as well as the previously developed analytical tool for studying in-the-moment learning and its application to the same data (Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024). Our study is the first to investigate patterns of in-the-moment learning in LA-facilitated student interactions and the impact authoritative and dialogic LA facilitation has on these patterns. We will now turn to two sociocultural frameworks, i.e., the formative assessment enactment model (FAEM) that facilitates characterizing LA actions as authoritative and dialogic and practical epistemology analysis (PEA) that provides the foundation for understanding student in-the-moment learning.

Sociocultural frameworks: the formative assessment enactment model (FAEM) and practical epistemology analysis (PEA)

Our study was guided by two frameworks that are both grounded in sociocultural theory, which views learning as a transformation of meaning occurring via a process of mediation (Vygotsky, 1978; Wertsch, 1993). This process of mediation occurs within an Activity System where a subject's work on an object is mediated through tools, such as discourse, rules (i.e., stated and unspoken ways of behaving), community (i.e., members of the classroom), and divisions of labor (i.e., who takes on certain roles) (Engeström, 1999; Roth & Lee, 2007). The processes of learning and mediation can be understood through an analysis of social and discursive practices (Wickman, 2006; Wickman & Östman, 2002). The formative assessment enactment model (FAEM) focuses on LAs' discursive actions in the context of their mediational function for student learning. Practical epistemology analysis (PEA) attends to discursive practices to investigate how students transform meaning during their interactions with each other and their LA, i.e., how they learn in the moment of interaction.

The FAEM was developed in the context of K-12 science teachers (Dini et al., 2020), deeply informed by the literature on teacher noticing (Sherin & van Es, 2005; van Es & Sherin, 2002), and adapted to the LA context to characterize LA actions (Carlos et al., 2023). Dini et al. (2020) draw on Bell and Cowie's (2001) definition

of formative assessment, that is "any teacher-student interaction that has purposes related to learning and is situated in discourse" (Dini et al., 2020, p. 296). This framework relies on the aforementioned assumption that learning occurs through discourse with others and further assumes that instructors enact different types of formative assessment throughout their practice (Dini et al., 2020). The FAEM characterizes instructor actions with respect to what instructors notice about student thinking, how they interpret this thinking, and the purposes that they develop while working with students. These actions could be eliciting, which find out more about student thinking, or advancing, which move student thinking forward towards ideas they have not thought about yet. The FAEM further characterizes these actions as being enacted in authoritative or dialogic ways (Dini et al., 2020; Mortimer & Scott, 2003). Building on Mortimer and Scott's (2003) understanding of authoritativeness and dialogicity and Freire's (2000) notion of power differentials, authoritative moves center one perspective as authority while dialogic moves acknowledge multiple perspectives as equal (Carlos et al., 2023). In the LA context, authoritative actions include all moves that center the LA perspective only, whether this perspective is focused on canonical correctness or not. Dialogic actions include all moves that center multiple perspectives, including one or more student perspectives in addition to the LA perspective, as well as any perspectives brought in by the LA from the problem space or from students outside the group the LA is working with. FAEM allows us to describe LA actions in terms of how they are situated in the learning context and includes whose perspective is being focused on, making it an ideal framework for investigating the impact that LA actions have on student in-the-moment learning.

Practical epistemology analysis (PEA) (Wickman, 2004; Wickman & Östman, 2002) is used to characterize student in-the-moment learning, which we define "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" (Karch, Maggiore, et al., 2024, p. 1296). In this sense, practical epistemologies are "what students count as knowledge" and "how they get knowledge" during discourse (Wickman, 2004, p. 327). This framework's utility lies in its ability to track students' learning progression throughout an activity through the lens of how *gaps* are noticed and filled with *relations* (Wickman & Östman, 2002). *Gaps* are not conceptual gaps in knowledge, rather, they are contextualized and socially situated needs to make sense of something to be able to move forward in an activity. *Gaps* can be noticed explicitly by asking questions, or they can be noticed implicitly by being discussed and filled. *Relations* are connections between pieces of knowledge or actions that are strung together to fill gaps. *Pieces* are thus the individual meaning units that are constructed together to form relations (Karch, Maggiore, et al., 2024). These constructs allow a close investigation of the progression of learning before and after an LA intervenes, offering a lens to investigate the impact of LA actions on student in-the-moment learning.

Methods

This study is part of a larger project (Karch & Caspari-Gnann, 2022; Carlos et al., 2023; Maggiore et al., 2023; Karch, Maggiore, et al., 2024, Karch, Mashhour, et al., 2024) that seeks to develop a model of LA facilitation practices using a sociocultural perspective, in which multiple facets of LA facilitation are independently characterized by different sociocultural frameworks before combining them toward the development of an overall model of LA facilitation. The study we present here combines and extends two out of three of these independent analyses to describe the impact of LA actions on student in-the-moment learning, i.e., one that used the FAEM to characterize LA actions as they are related to LA purposes and noticing and interpreting of student thinking (Carlos et al., 2023) and one that used PEA to characterize student in-the-moment learning during LA–student interactions (Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024). Our study is the first to characterize different authoritative and dialogic LA eliciting and advancing actions in terms of a detailed codebook layered on top of the FAEM analysis and the first one to describe patterns of in-the-moment learning during LA–student interactions in terms of a codebook layered on top of the PEA analysis. It is also the first to describe the impact of one on the other.

Research context

Data for this study were collected from 12 introductory chemistry and physics courses at two institutions in the Northeast region of the United States (Table 1). Institution A is a public, R2, highly diverse university and Institution B is a private, R1, predominantly white university. Data were collected over four semesters: fall 2020, spring 2021, fall 2021, and spring 2022, in six chemistry courses at Institution A and two chemistry and four physics courses at Institution B. All data in fall 2020 and spring 2021 at both universities were collected in large, LA-supported Zoom lectures. The remaining data collection in fall 2021 and spring 2022 was completed in in-person settings, including one synchronous hybrid chemistry course at Institution A. Both institutions' institutional review boards approved this study.

Table 1 Demographics of participants at both institutions compared to the demographics of the population at the respective institutions

	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%

Table adopted with permissions from Karch, Maggiore, et al., (2024)

For full details on recruitment, see Carlos et al. (2023). 37 different LAs and 843 students participated in the study. Table 1 shows participants' demographics compared to the demographic make-up of each institution. All participants consented via a Qualtrics form and were asked to provide a codename used to deidentify the data. Table 2 shows a more detailed account for all courses in our study and the study participants in each course.

Data collection and selection

Data collected for this study were video-recorded LA–student interactions and stimulated recall interviews with LAs (Dini et al., 2020; Thompson et al., 2020). Participating LAs video recorded their interactions with students during small group discussions from their point of view. During in-person courses, LAs wore a harness with their cell phone to video record the interactions (Dini et al., 2020; Thompson et al., 2020), whereas in remote courses

Table 2 Classes and number of LAs and students who participated in the study

University	Class	Modality	Semester	Number of LAs enrolled in study	Number of students enrolled in study
A	Chemistry 2	Virtual	Fall 2020	4	96
A	Chemistry 1	Virtual	Spring 2021	2	36
A	Chemistry 1	Virtual	Spring 2021	1	50
A	Chemistry 2	In-person	Fall 2021	1	80
A	Chemistry 1	Hybrid	Spring 2022	2	28
A	Chemistry 1	In-person	Spring 2022	2	51
B	Chemistry 2	Virtual	Fall 2020	5	129
B	Chemistry 2	In-person	Fall 2021	5	113
B	Physics 1	Virtual	Fall 2020	4	112
B	Physics 2	Virtual	Spring 2021	3	40
B	Physics 1	In-person	Fall 2021	3	82
B	Physics 1	In-person	Spring 2022	5	26

Table adapted with permission from Carlos et al. (2023)

they recorded via the Zoom recording feature. For each course, LAs recorded all their interactions with student groups three times throughout the semester, i.e., towards the beginning, the middle, and the end of the semester. For each lecture of the three data collections, LAs had anywhere from one to 10 interactions with students, with an average of three interactions per lecture. These interactions ranged from 20 s to 20 min, with an average interaction lasting between 5 and 7 min.

Semi-structured stimulated recall interviews with LAs were conducted over Zoom within two weeks of data collection (Meade & McMeniman, 1992). Each LA was interviewed three times per semester and shown no more than three interactions in one interview. If more than three videos were recorded by an LA in one lecture, members of the research team selected videos based on audio/video quality and variety in the interactions. More specifically, interactions across various problems and ways of interacting amongst groups were prioritized for interviews. The interview protocol for LAs was designed based on sociocultural theories that guided our study (Dini et al., 2020; Engeström, 1999; Wickman & Östman, 2002) with the main goal of situating the LAs in the moment of class that day to gain insight into their perspectives. Specific to the FAEM (Dini et al., 2020), interviewees were asked to describe what they noticed about student thinking, what their purposes were when working with students, and how they would describe what they did and why. Follow-up questions were used to find out more about what interviewees were saying in the interviews when it seemed relevant to the study or of importance to the participants. Interviews lasted about 90 min. Various members of the research team, including undergraduate students, a graduate student, a post-doctoral researcher, and a professor conducted all interviews. Intensive training of all interviewers ensured that interviews were conducted in consistent ways and resulted in in-depth data targeted towards the goals of the research project.

The analysis presented in this paper triangulates and extends the analyses completed in our two-prior works (Carlos et al., 2023; Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024), thus, the data selected for analysis was determined prior to this study. Analysis with the FAEM relied on LAs' perspectives on interactions. Therefore, only interactions LAs were interviewed on were eligible for analysis out of the whole data set; 227 interactions were analyzed out of 302 total interactions. Relying on this subset of 227 interactions, time-intensive PEA was completed for two interactions per LA for each semester they participated. Because 2 LAs participated twice, a total of 78 interactions were analyzed across the 37 different LAs in our study. Criteria for data selection are outlined in detail in the methods sections of our two prior studies (Carlos et al., 2023; Karch, Maggiore, et al., 2024) including how two interactions per LA were chosen in a way that maximized variety of interactions included in the data set (Karch, Maggiore, et al., 2024).

All interviews were transcribed via the automatic transcription feature on Zoom and then corrected and anonymized by research team members. All LA–student interaction recordings were transcribed and anonymized by a professional transcriptionist, followed by a research team member further correcting the transcripts if necessary.

Data analysis

As mentioned earlier, interactions for this study were pulled from two sets of independent analyses, one done with the FAEM, which only focused on LA actions, (Carlos et al., 2023; Dini et al., 2020) and one done with PEA, which only focused on student learning (Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024; Wickman, 2004; Wickman & Östman, 2002). In the FAEM analysis, a narrative was written that tightly connected LA actions to their purpose and what they noticed about student thinking. The LA actions were coded as eliciting or advancing moves enacted in authoritative or dialogic ways. In the PEA, a spreadsheet was created to capture the progression of student gaps across the span of an interaction, noting all gaps opened and attended to by the group along with the pieces and relations used to fill these gaps.

Based on these two separate analyses, the theories underlying them, the raw data, and our own experiences as professors, LAs, and students, we then used thinking with theory (Jackson & Mazzei, 2013) to write thick descriptions (Ponterotto, 2015) about how LA actions impacted student learning, extending the prior, more descriptive analyses to describe a complex system of interaction and impact amongst multiple actors and using multiple perspectives and data sources. Thinking with theory entailed plugging data, previous analyses, theory, and our own experiences as teachers and facilitators in LA-supported classrooms into each other. We made sense of how LA actions impacted student learning in our data through the lens of our own experiences and the frameworks that guided our work. At the same time, the data reciprocally shaped how we understood the theories we were working with and what experiences we drew on, thereby refining our theoretical understanding and leading to the generation of our thick descriptions (Jackson & Mazzei, 2013). These thick descriptions described detailed accounts of each LA action and how it was situated in context of the interaction it occurred in through the lens of thinking

with theory (Creswell & Miller, 2000; Ponterotto, 2015). Through thematic analysis of these thick descriptions (Saldaña, 2013), we developed an action-impact codebook. Figure 1 shows an overview of our complete data analysis process that will be described in more depth in the following paragraphs with references back to the numbers in the top right corner of each box.

To investigate the impact of LA actions on student in-the-moment learning, we organized the most important aspects of the two prior analyses into action-impact analysis tables (see Table 3 for an example). For LA actions, this included a quote of the LA's move, the FAEM coding of that action, and summaries of what the LA noticed and of the purpose the LA had when engaging in the action (Fig. 1 box 1). For student learning, we included which gap the action occurred and linked directly to the PEA spreadsheet (Fig. 1 box 2). When engaging in thinking with theory, we consulted the video of an interaction, the corresponding transcript, the action-impact analysis table, and the PEA spreadsheet as needed.

We then engaged in an interpretive process considering what function LA actions served in the interaction, what ideas were being discussed before the LA action, and if these ideas were built on (continuity) or if new ideas were introduced (discourse change) after the LA action, whose ideas were centered, and any other salient impacts. This interpretive thinking process was deeply informed by theory on dialogicity and authoritativeness (from the FAEM) and in-the-moment learning (from PEA) and our own interpretations as professors, LAs, and students of the connections between LA actions and their impacts (Jackson & Mazzei, 2013). To capture this additional analytical layer of the connection between actions and their impacts, we wrote thick descriptions that gave detailed accounts of the interaction at the point in time we were investigating them along with our interpretations (Fig. 1 box 3) (Creswell & Miller, 2000). Our thick descriptions were not limited to a description of the LA actions and how student in-the-moment learning compared before and after the LA actions. Instead, our thick descriptions captured the rich context that gave the connection

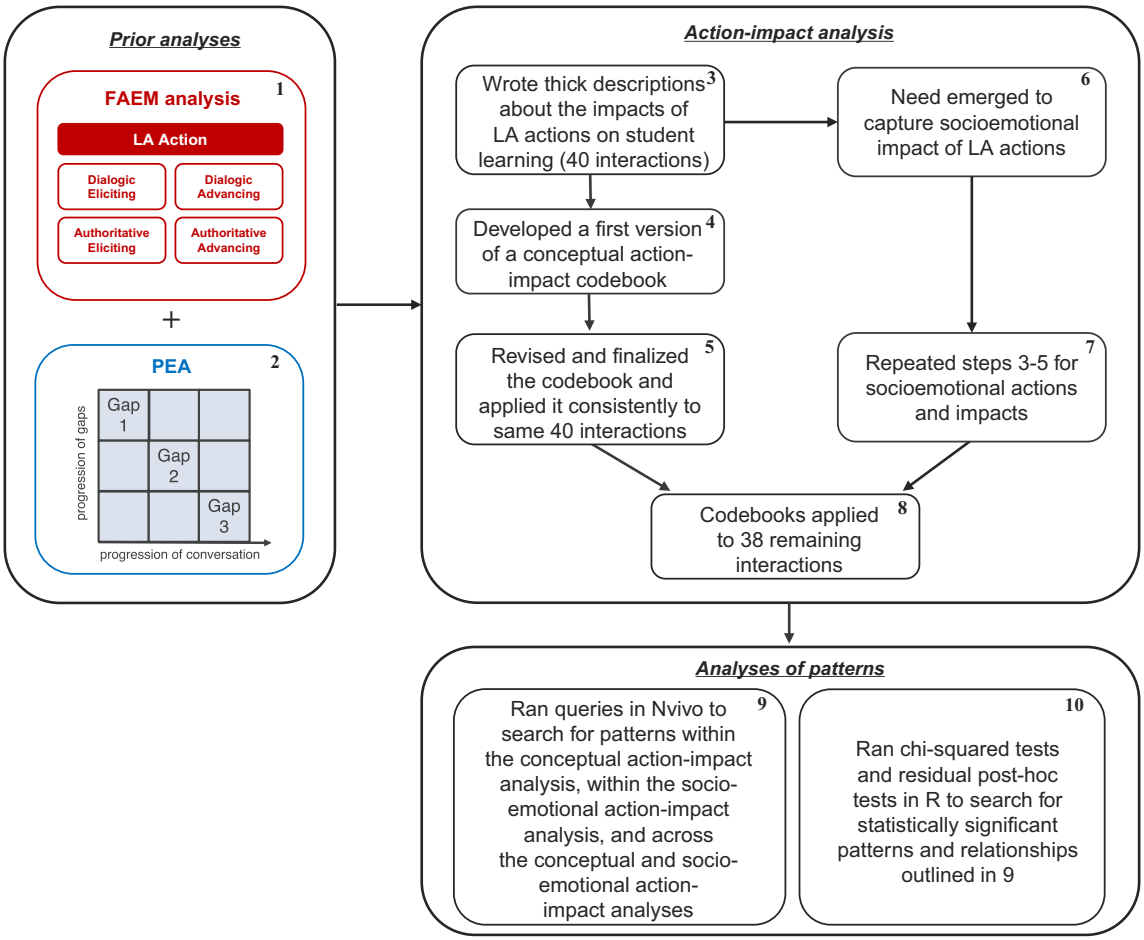

Fig. 1 Overview of the data analysis process

Table 3 Action-impact analysis table example of one move by LA Maria

LA action	LA action code (FAEM)	LA purpose (FAEM)	LA Noticing & interpreting (FAEM)	PEA code	Thick description
LA Maria: "Does anyone remember the equation for Q?" (line 37)	Authoritative Advancing	The LA remembers that the equation helped her think about these problems when she was a student. She wants to prompt students to help further along their thinking when possible	The LA notices that students are trying to understand the relationship between Q and K (she also thinks an understanding of this relationship is needed to solve this problem)	Gap 4 noticed	The students were asked to think about how a disturbance impacts the equilibrium of a reaction. Student Moon wonders about how Q and K work in general (gap 2), and student Kehlani wonders about which (Q or K) is bigger or smaller in this specific problem (gap 3). The LA notices that there is a discussion around Q and K. She also remembers that the equation for Q was helpful to her when she was a student in this class working on these types of problems. To act on her purpose of wanting to prompt the students further to help them with their thinking, **the LA asks them if they remember the equation (authoritative), which opens a new gap (gap 4) for the students as they have not thought about the equation yet (advancing).** Moon, who started the initial conversation about Q and K (gap 2), says that she does not remember the equation (gap 4), continues to provide additional pieces and relations towards her lingering gap 2, and acknowledges that knowing the equation would be helpful. Following this reasoning from Moon, student Pink comes into the conversation, elaborates on the equation (gap 4), and uses it to reason about the relationship between Q and K, thus, addressing gaps 2, 3 and 4 simultaneously. After this, the group moves on to talk about another part of the problem. *It appears this group took LA Maria's idea (about something that helped her when she was a student – the equation) and leveraged it by sharing ideas about the equation to revisit and consider old, lingering needs further (gaps 2 and 3) that ultimately helped them reach group consensus to close all three gaps*

Additional descriptions of details of the table from left to right: The number in the first column refers to the line number in the transcript. The LA purpose and noticing/interpreting were summarized based on the LA interviews in the first level FAEM analysis. The PEA code refers to the position in the PEA spreadsheet in which this move occurred, which was also directly linked to this analysis table. Lastly, the bold font in the thick description column demarcates the LA action and Italic font demarcates the summarized impact on student in-the-moment learning

between LA action and in-the-moment learning. Specifically, they captured what the LAs noticed about students, what their purposes were, how both of these informed their actions, and how all components of the LAs' facilitation (noticing, purpose, action) related to the in-the-moment learning that followed each action.

We now turn to an example demonstrating our interpretive thinking process. We include parentheticals to map parts of the example to the FAEM and PEA frameworks. In an interaction from a chemistry class (see Table 3 for action-impact analysis table) two student needs, i.e., gaps 2 and 3, discussed before the LA action revolved around figuring out the relationship between the reaction quotient of a chemical reaction, Q, and the equilibrium constant, K (PEA, student in-the-moment learning before LA action). LA Maria noticed the need was to figure out the relationship between Q and K (FAEM, noticing and interpreting), so she wanted to help them and remembered that the equation for Q had helped her in her past with this topic (FAEM, purpose). LA Maria thus asked the students if they remembered this equation (FAEM, authoritative), which opened a new gap 4 for the students (PEA, gap in which the LA move is situated) as they had not thought about the equation yet (FAEM, advancing). The student group then grappled with the equation to revisit and reconsider old lingering needs further, i.e., gaps 2 and 3, which ultimately helped the student group to reach consensus to close gaps 2 to 4 (PEA, student in-the-moment learning after LA action).

This interpretive thinking process was initially applied for 40 of the 78 total interactions (approximately half the dataset). Once the action-impact analysis tables with the thick descriptions were generated for these 40 interactions, the first and the corresponding author collaboratively engaged in thematic analysis (Saldaña, 2013). Thematic analysis resulted in a preliminary categorization of LA actions and impacts on student in-the-moment learning that went beyond the original FAEM and PEA analyses (Fig. 1 box 4). For LA actions, this process yielded action subcodes, which included more specific descriptions of the LA move. For example, authoritative advancing moves included actions such as an LA explanation or an LA directing students to use an idea they had established to explicitly revisit a lingering gap or confusion. For student in-the-moment learning, patterns that emerged went beyond gaps being noticed and filled and beyond a description of continuity and discourse change of ideas. For example, when students picked up an idea and worked towards incorporating that idea into their discussion, we characterized this impact as student grappling. In addition to these broader impacts, this process also yielded impact subcodes, for example grappling with student or LA ideas.

After this preliminary categorization was created, the first author then looked back at the raw data, the thick descriptions, and consulted outside perspectives to revise the preliminary categorization to achieve full consistency with the raw data and formalized this categorization as a conceptual action-impact codebook (Fig. 1 box 5; see Tables 4 and 5 in the Appendix for the full codebook) (Saldaña, 2013). This two-part codebook generated from 40 interactions consists of action codes (i.e., the codes from FAEM), action subcodes (more specific descriptions of what the LA did), conceptual impact codes (how students were learning in the moment of interaction following an LA move), and conceptual impact subcodes (more specific descriptions of how students were learning).

During the processes of writing the thick descriptions and developing and revising the action-impact codebook, the first author noticed that LAs were impacting the student groups beyond conceptual reasoning—the LAs' actions had socioemotional components to them that led to socioemotional impacts on the student learning. These socioemotional components were not entirely captured in her thick descriptions and thus not captured in the conceptual action-impact codebook (Fig. 1 box 6). For example, after LA Maria's utterance (Table 3), student Pink joined the conversation when she previously had not spoken, thus increasing the level of participation and collaboration amongst group members. To analyze for these impacts further, the second author engaged in a very similar interpretive process as the one described above (Fig. 1 boxes 3-5) to capture thick descriptions of the socioemotional impacts of LA actions (Fig. 1 box 7). Additional factors paid attention to for this interpretive process were body language, tone of voice, and participation levels amongst students. Re-watching the interaction videos became specifically important for the socioemotional analysis as it provided key insight to body language and tone of voice. After the second author wrote thick descriptions of the socioemotional aspects of 40 interactions, the second, first, and corresponding authors collaboratively developed a preliminary categorization of LA socioemotional actions and impacts in the same way as previously described. After this preliminary categorization was created, the second author then formalized this categorization as a socioemotional action-impact codebook (see Tables 6 and 7 in the Appendix).

The first and second authors applied the conceptual and socioemotional codebooks to the remaining 38 interactions in parallel (Fig. 1 box 8). No new codes emerged from this second portion of the data analysis, confirming that data saturation had been met (i.e., that no new conceptual or socioemotional actions or impacts emerged). For this second portion of data analysis, all analyses were completed via coding tables like the one in Table 3; the

thick description column was omitted as it was only necessary to create the codes but not to apply them. This time, LA actions were directly given action and impact codes in the action-impact analysis tables.

Following the completion of all 78 analyses, the coding was input into NVivo (Lumivero, 2020) to explore trends across the different combinations of action and impact codes given to LA moves within conceptual action-impacts, within socioemotional action-impacts, and across conceptual and socioemotional action-impacts. We used the NVivo "query coding" feature for this investigation (Fig. 1 box 9). This feature allows for direct summation of the number of times an LA move was coded with any two codes of our choosing. In line with patterns the first and second authors noticed throughout their respective data analysis processes, various coding combinations across conceptual and socioemotional actions and impacts were explored.

To explore whether there were any statistically significant relationships between certain actions and impacts, the first author conducted chi-squared tests of independence on the different patterns that emerged from the Nvivo queries within and across conceptual and socioemotional action-impact codebooks (Fig. 1 box 10). Chi-squared tests were measured at $p < 0.05$, and data from these tests can be found in Tables 8, 9, 10, 11, 12, 13, 14, 15 in the Appendix.[1] Because all our chi-squared tests were associated with degrees of freedom larger than one, a statistically significant chi-squared value was only indicative of independence but did not show which relationships between actions and impacts existed. Thus, following Beasley and Shumacker's (1995) suggestion that, "no chi-squared test should stop with the computation of an omnibus chi-squared statistics," we conducted post-hoc testing using the calculating residuals method (Sharpe, 2019). Standardized residuals and critical thresholds were calculated using the Bonferroni adjustment (Sharpe, 2019), and data from these tests can also be found in Tables 8, 9, 10, 11, 12, 13, 14, 15 in the Appendix. Post-hoc tests were run to measure the specific relationships between individual actions and impacts that were significant. All calculations were performed using R version 4.3.3 (R Core Team, 2024). Alongside our qualitative interpretations of the relationships between actions and impacts they had on student in-the-moment learning captured as thick descriptions, quantitative insights from the Nvivo and R investigations of these relationships inform the results presented in the following section.

[1] Chi-squared tests assume complete independence of observations, however, each of our 78 interactions and 37 LAs contribute more than one data point to our observed frequency counts (Tables 8–15 in the Appendix). Thus, our results need to be interpreted with caution.

Trustworthiness and reliability

We see our analysis process outlined above in Fig. 1 as containing two separate but deeply related parts that must both be trustworthy: codebook development and codebook application. To establish trustworthiness of both, several strategies were used at critical steps of the data analysis process. These include incorporating multiple perspectives (including collaboration between different members of the project team and insight from researchers outside the project team) and consensus processes for reliability measures (Creswell & Miller, 2000; Saldaña, 2013).

Our first trustworthiness process to develop the codebooks was to incorporate multiple perspectives (Fig. 1 boxes 3–7), ensuring that various lenses to the data were accounted for by members with different closeness to the data and the LA program (Creswell & Miller, 2000). The first author is a graduate student who has been a student in an LA-supported class and an LA during her undergraduate studies, has taught as a teaching assistant (TA) in an instructional team including LAs, and has taught the LA pedagogy course. The second and third authors are undergraduate students who have been students in LA-supported classes and LAs themselves. The corresponding author is a faculty member who teaches general and organic chemistry with LAs and teaches the LA pedagogy course. As described earlier, the preliminary categorizations of both the conceptual and socioemotional action-impact codebooks were developed in collaborative meetings amongst the first, second, and corresponding authors to ensure that multiple researcher perspectives were considered for the categorizations rather than just one (Fig. 1 box 4). Beyond this, weekly meetings were held amongst the first, second, and corresponding author in different combinations of attendees to further discuss the analysis process and any questions that arose throughout the formalization of the codebooks. Oftentimes, questions about specific examples of LA actions and impacts and how they should be coded were discussed in these meetings until consensus was reached.

To have others not as close to the data analysis as the authors account for both our process and the product of our inquiries, researchers outside the immediate research team were involved in an audit trail procedure before the codebook was officially formalized (Creswell & Miller, 2000). After the development of the preliminary categorization of the conceptual actions and impacts, we met twice with two experienced researchers who were part of the larger project team and thus deeply familiar with the data but not with the specific analysis of this study. Our meetings involved introducing them to the analytical procedures we were using as well as discussing our

preliminary categorization for interpreting the impact of LA facilitation on student in-the-moment learning. Insights from these meetings led to major changes in our preliminary categorization to encompass deeper, more intuitive interpretations on how meaning was transformed during interactions, which helped formalize the codebook (Fig. 1 box 5). After the codebook had been formalized, we had another meeting with a group of researchers uninvolved with the project, including both junior researchers in the research group and a completely external senior researcher, where they applied the codebook and gave feedback on their understanding of the codes. The meeting was used to revise definitions of codes to make them more easily accessible to outside researchers (Fig. 1 box 5).

To ensure that the codebook could be applied reliably and consistently, 25% of the total number of interactions were analyzed by two coders independently (including the first, second, and corresponding author) and then discussed until consensus was reached (Saldaña, 2013). Cohen's kappa was calculated for interrater reliability on the 25% of interactions analyzed by two coders independently. Cohen's kappa is a, "chance-corrected reliability measure that was developed to account for differences in researchers' distributions of applied codes" (Watts & Finkenstaedt-Quinn, 2021, p. 576), thus making it an appropriate measure of agreement for this study. For both phases of analysis (i.e., the preliminary categorization phase when the codebook was being developed involving 40 interactions, and the codebook application phase after the codebook was stabilized involving 38 interactions), 10 interactions were coded by two authors independently and discussed to consensus (20 out of 78 total, or 25%). For the conceptual-action codebook, this process was led by the first author; for the socioemotional action-impact codebook it was led by the second author. All interactions that were analyzed by two coders were randomly selected from the total pool of interactions (Campbell et al., 2013; Watts & Finkenstaedt-Quinn, 2021). Based on the consensus reached between two coders for the first phase of analysis and before the second phase of analysis, the lead researchers revised the codebooks and coding of all interactions of phase 1. Cohen's kappa for the conceptual codebook application was 1.00 (almost perfect). Cohen's kappa for the socioemotional codebook application was 0.62 (moderate).

Results

Analysis of LA actions and their impact on student in-the-moment learning revealed several patterns within the conceptual and socioemotional investigations. First, we discuss the conceptual impacts and then move to discuss the socioemotional impacts.

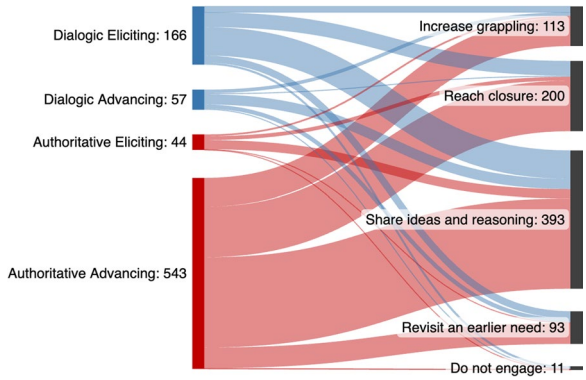

Fig. 2 The impact of different LA actions on student in-the-moment learning. The flows visually demonstrate that there was no difference between authoritative and dialogic actions for increase grappling, reach closure, share ideas and reasoning, and revisit an earlier need, which was confirmed statistically in post-hoc testing[2]. Blue represents dialogicity, red represents authoritativeness

Conceptual impacts

We found five conceptual impacts of LA actions on student in-the-moment learning: increasing grappling, reaching closure, sharing ideas and reasoning, revisiting an earlier need, and students not engaging with the LA move (Table 5 in the Appendix). Based on the previous finding in the literature that an LA asking prompting questions fostered student reasoning, while an LA giving an explanation stopped student discussion (Knight, et al., 2015), we might expect that dialogic LA moves would have impacts, such as sharing ideas and reasoning, while authoritative LA moves would have different impacts such as reaching closure. In our initial test for these relationships, we found that there was a significant difference between dialogic and authoritative actions and their conceptual impacts (χ^2 (4) = 22.20, $p < 0.005$). However, post-hoc testing showed that the only significant relationship between authoritative and dialogic actions was with students do not engage. There was no significant difference for all other conceptual impacts, i.e., increase grappling, reach closure, share ideas and reasoning, and revisit an earlier need[2] (Fig. 2, Table 8 in the Appendix). This indicates that authoritative and dialogic LA moves can induce or fulfill similar needs within the progression of student in-the-moment learning given the contingent nature of LA–student interactions.

[2] Dialogic actions were more often associated with students do not engage than authoritative actions. We suspect dialogic actions, as they are centered on student ideas, might have given students more freedom to decide not to engage with the LA move, which could have led to this correlation. We do not discuss the "do not engage" impact in further detail in this manuscript, as we are more interested in what ways students engage as opposed to when they do not engage, and not engaging only occurred in 11 instances while all other impacts occurred more than 90 times.

A closer investigation of the impacts revealed that the ways in which they manifested during interactions were different across LA moves. More specifically, for authoritative LA moves, impacts were often LA-centered and, for dialogic LA moves, impacts were often student-centered. To show how often authoritative or dialogic moves impacted student learning in LA-centered and student-centered ways, Sankey diagrams and chi-squared values will be presented. We then use one authoritative and one dialogic example for each impact to demonstrate how LA actions related to LA- and student-centered manifestations of each impact in qualitative ways. In these examples, some background of the interaction will be provided along with LA and student quotes to demonstrate the mechanism of how each impact played out following the LA action.

Increase grappling

Grappling occurred when students picked up an idea and worked towards incorporating that idea into their discussion. Students oftentimes expressed confusions, asked questions, and thought critically when grappling with an idea. What differed across instances of grappling was whose ideas the students grappled with, i.e., whether these ideas were student-centered or LA-centered. To compare across the different LA actions and how they were associated with differences in what students grappled with, a Sankey diagram is presented in Fig. 3. We found that dialogic actions are significantly more correlated with student-centered grappling (i.e., grappling with student ideas) than authoritative actions, and authoritative actions are significantly more correlated with LA-centered grappling (i.e., grappling with LA ideas) than dialogic actions (χ^2 (2) = 74.71, $p < 0.001$) (Table 9 in the Appendix). To demonstrate the different manifestations of this impact qualitatively, we show two instances of grappling, i.e., one initiated by an authoritative move and one initiated by a dialogic move.

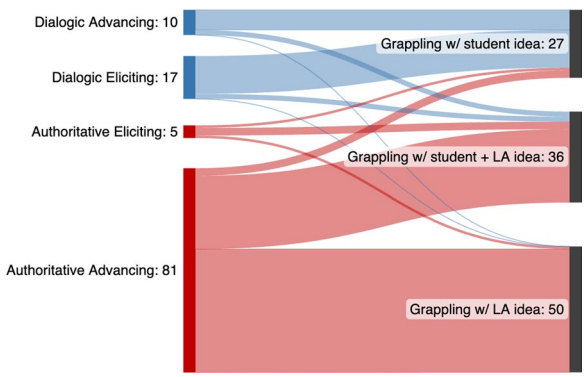

Fig. 3 The impact of different LA actions on how grappling manifested in student-centered (grappling w/ student idea) and LA-centered (grappling w/ LA idea) ways. Dialogic actions (blue) were more often correlated with grappling with student ideas whereas authoritative actions (red) were more often correlated with grappling with LA ideas

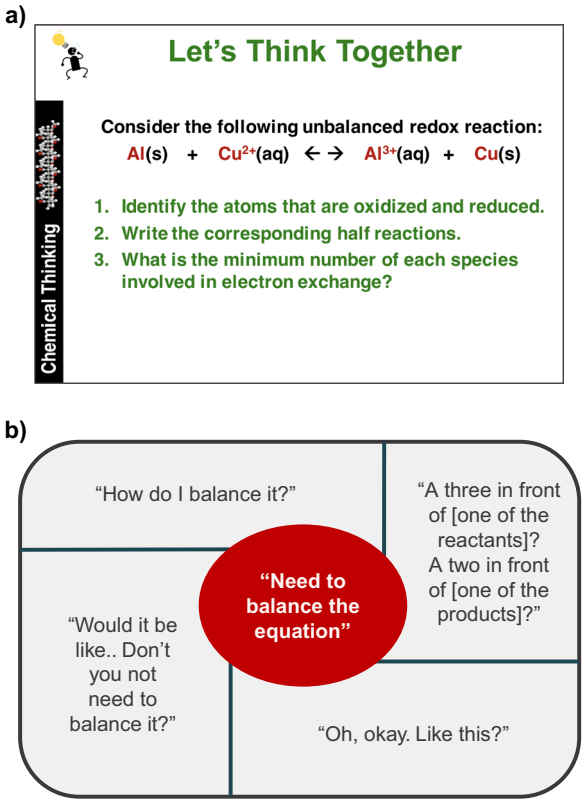

Fig. 4 **a** Question student and LA Mango worked on. **b** Example quotes of student Pedro's grappling (grey) with LA Mango's idea (red)

In the following authoritative example, grappling occurred in an LA-centered way, as the student grappled with the LA idea. Students were asked to consider an unbalanced redox reaction between aluminum and copper, and work through three questions to ultimately balance the equation (Fig. 4).

A student, Pedro, called LA Mango over and expressed confusion about what the question was asking for, and more specifically what was meant by "minimum number of each species." The student and LA had the following exchange:

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.*

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.*

In his response to Pedro's question about what the question was asking her to do, LA Mango focused on the canonically correct solution to the problem and told the

student she must balance the equation (authoritative) to move forward with this problem (advancing). This authoritative advancing move revealed what the student must do to solve the question in Fig. 4 correctly, i.e., balance the equation (bolded).

Following the LA's response to her question, Pedro grappled with the idea of "need to balance the equation" in multiple ways throughout the rest of the interaction. A few different quotes from this grappling are displayed in the grey boxes in Fig. 4, with the idea she picked up on from the LA centralized in the red circle. First, the student questioned the need to balance the equation at all, to which the LA confirmed again that she does indeed need to balance the equation as that is what the question is asking of her. Once Pedro received this confirmation from the LA, she shifted from grappling about if she really must balance the equation to grappling with *how* to balance the equation, attempting to try out different coefficients in front of the different species in the redox reaction. Considering the relationship between the LA action and the impact in this example, the student picked up on the idea that the LA introduced in his authoritative advancing move and worked to understand and implement it for herself.

While in the previous example the student grappled with an idea introduced by the LA, other times students grappled further with one of their own ideas. In the following dialogic example, the grappling that occurred was student-centered, as the students grappled further with student Zara's idea. Students were asked to think about what is true regarding the enthalpy and entropy of a reaction between formic acid and oxygen that produces carbon dioxide and water (Fig. 5).

The students started discussing enthalpy and entropy by bringing in bond and phase arguments. One student, Zara, said that she tried to think about configurations, but that she had not fully explored that idea yet. The LA noticed that Zara might be moving away from the idea of configurations, and they had the following exchange:

Zara: *I also put C, and that was also my logic, the AB bonds, or AA to AB bonds, and the phase change. I didn't think about anything else. I like tried to think about* ***configurations****, but I didn't get there quite...*

LA Cosog: *Do you want to try to dive into configurations a bit now, or if anyone would like to dive into* ***configurations***?

In his response to Zara, LA Cosog picked up on her confusion about configurations (dialogic) and asked the entire group to think about it further in a way they had not yet (advancing). This dialogic advancing move opened space in the discussion to expand upon Zara's idea (bolded).

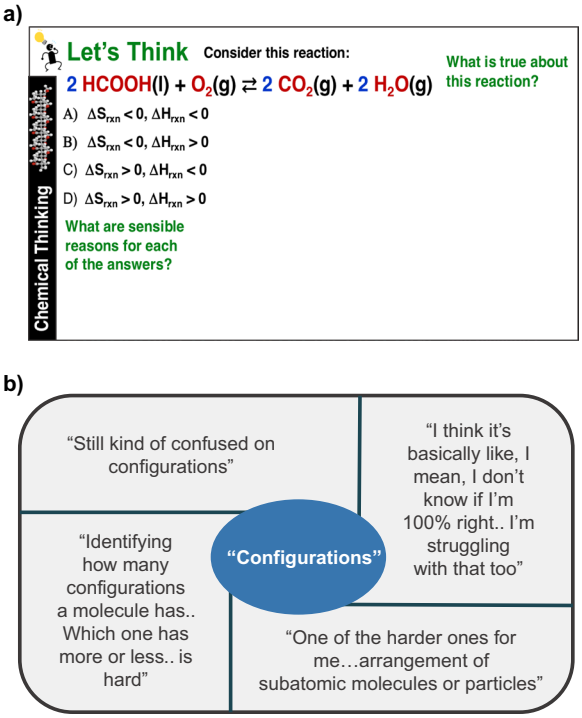

Fig. 5 **a** Question students and LA Cosog worked on. **b** Example quotes of the group's grappling (grey) with student Zara's idea (blue)

After the LA asked this question, two students, Zara and Zoe, grappled with the idea of configurations. Some quotes that show the group grappling with this idea are displayed in grey boxes in Fig. 5, surrounding the student idea of configurations in the central blue circle. Zara acknowledged that she was confused on the idea of configurations she mentioned earlier on and shared that she would not like to think through it further. Zoe joined the conversation to share some of her confusions, wonderings, and thoughts about configurations. Alongside acknowledging each other's struggle with and difficulty of the concept, the students added ideas, such as the arrangement of subatomic particles and the number of configurations. The LA's choice to center a student's idea gave the students the space and time to grapple with and make sense of one of their ideas further.

In summary, while all types of LA actions were associated with instances of grappling, there were differences in what the students grappled with revealed by paying close attention to whose ideas were picked up on by the students. Students grappled either with an LA's idea, a student's idea, or both. This demonstrates that centering students' perspective during dialogic facilitation also centers their perspective more often during their grappling following an LA's move, whereas centering LA's ideas in authoritative facilitation centers the LA's perspective more often during grappling.

Reaching closure

Reaching closure occurred when students left a current need and moved on to another. Across interactions, who (i.e., the LA or students) had the agency to decide the current need was sufficiently filled and could be moved on from varied. To compare across the different LA actions and how they were associated with differences in how students reached closure, a Sankey diagram is presented in Fig. 6. We found that dialogic actions are significantly more correlated with student-centered closure, (i.e., student satisfied with LA understanding, epistemologically, and group consensus) than authoritative actions, and authoritative actions are significantly more correlated with LA-centered closure (i.e., LA confirming correctness and LA explanation) than dialogic actions (χ^2 (4) = 114.36, $p < 0.001$) (Table 10 in the Appendix). To demonstrate the different manifestations of this impact qualitatively, we show two instances of reaching closure, i.e., one initiated by an authoritative move and one initiated by a dialogic move.

In the following authoritative example, closure was provided by the LA. Students were asked to think about two identical carts rolling down hills and sticking together differently. They were then asked what is true about the carts just before and just after the carts collide (Fig. 7).

After the students discussed their thoughts about the kinetic energy right before the carts collide, LA Dan wondered about the second case having two masses moving while the first one had only one mass moving. He asked the students about this, and student Airmak provided some reasoning that the LA confirmed:

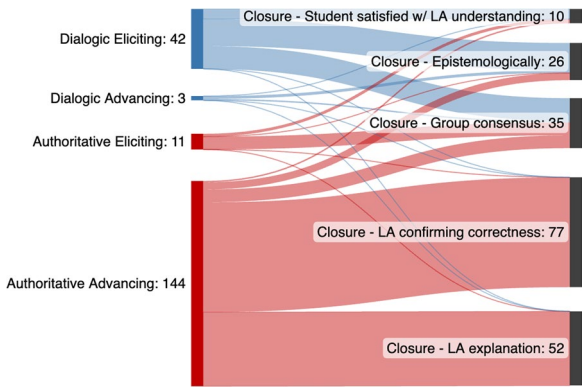

Fig. 6 The impact of different LA actions on how reaching closure manifested in student-centered (student satisfied w/ LA understanding; epistemologically; group consensus) and LA-centered (LA confirming correctness; LA explanation) ways. Dialogic actions (blue) were more often correlated with students having autonomy over deciding when a gap could be moved on from whereas authoritative actions (red) were more often correlated with LAs having autonomy over deciding when a gap could be moved on from

Airmak: Well, the way that I thought about it was, just, like I completely forget about the, or like didn't take into account the calculation for the final kinetic energy, because that's completely dependent on the initial potential energy. So then like just to do that calculation, it's mgh in the first case, and then mg one half h plus mg one half h in the second one, and then if you just solve for that, it ends up being the same.

LA Dan: Good, exactly.

In his action, the LA confirmed the correctness of the student's response. This short authoritative advancing move shared insight to the canonical correctness of the answer given by Airmak (authoritative) and gave the group the "okay" that they shared an idea that answered his question correctly and could thus move on (advancing).

After this utterance, the students moved on to the next part of the problem. This suggests that the LA had the authority to determine whether the current gap, i.e., gap 2, had been sufficiently discussed and that the group had "reached closure", rather than the students having that agency (Fig. 7).

While in the previous example, the LA closed a gap by confirming the correctness of students' reasoning, in other instances, students were the decision-makers. In the next example, a dialogic move made by the LA led to the group reaching consensus on their own. Students were tasked to think about what would happen to the capacitance of a capacitor under several different conditions when the distance between the plates is doubled (Fig. 8).

One student, Channah, started off the discussion of what happens to the capacitance by mentioning that the equation seemed to help people think about the relationship between capacitance and distance. LA Shin explicitly asked about the equation she was referring to:

LA Shin: Can anyone remind me about the equation you used?

In his question to the group, the LA picked up on the idea of the equation mentioned by Channah (dialogic) and asked the students to make the equation they were already thinking about explicit for the whole group (eliciting).

In what followed the LA's question, the student discussion led to closing the gap they were discussing (Fig. 8). Channah shared the equation with the group and used the relationships between variables in the equation to make a prediction about the capacitance. As she spoke, the group nodded, and three other group members shared that they agreed with her ideas about the relationship between distance and capacitance according to the equation. The last student to share in agreement, Jumbo, moved the group on to the next gap which evidences

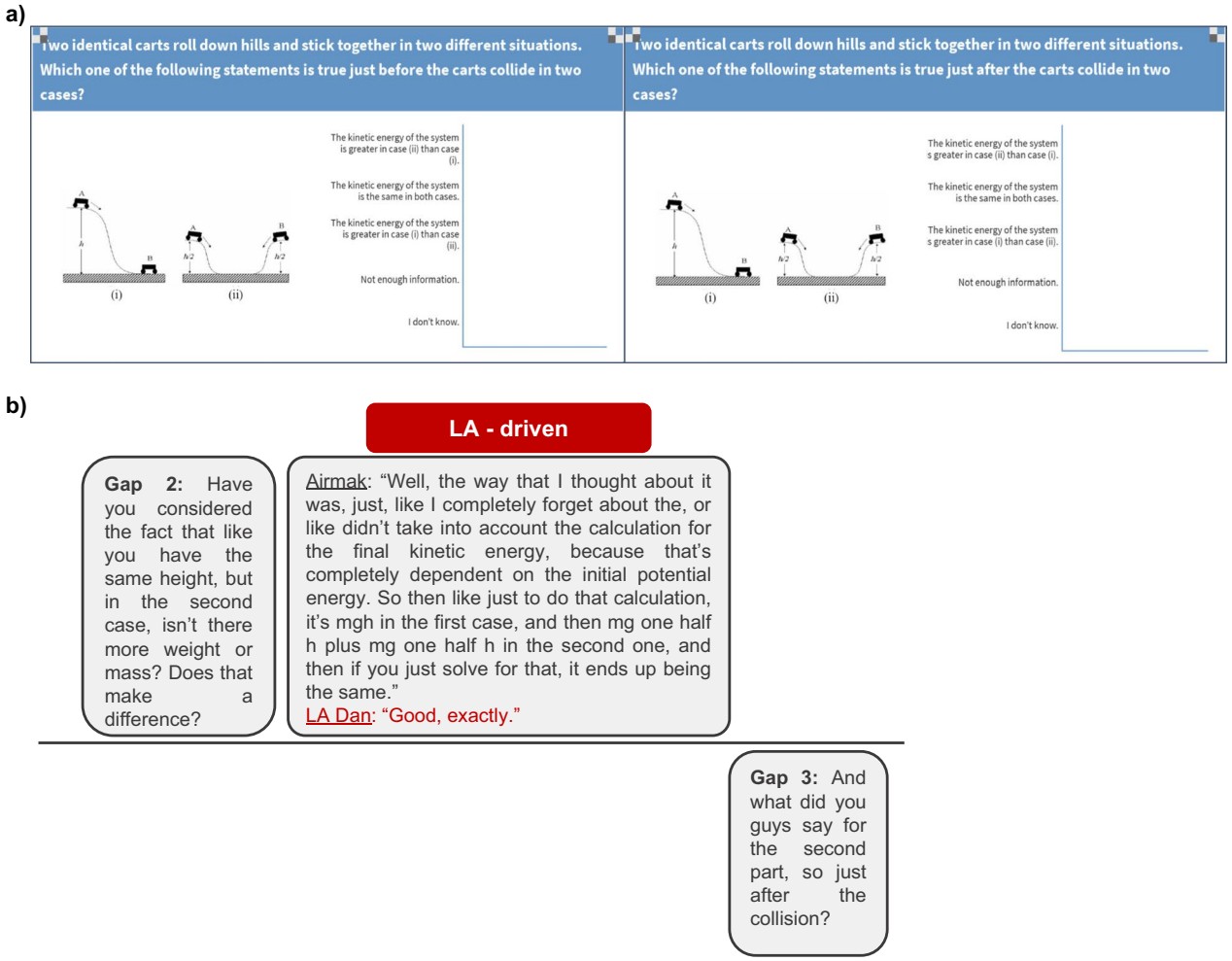

Fig. 7 **a** Question students and LA Dan worked on. **b** Example quotes from student Airmak and LA Dan embedded in a graphical display of how student learning progressed from gap 2 to gap 3. The graphic shows that the LA provided the last pieces towards gap 2 closing this gap (red) and the group moved on to gap 3

the students' autonomy in deciding gap 1 had been sufficiently addressed and could be moved on from.

In summary, while various types of LA actions were associated with reaching closure, there were differences amongst *who* decided a gap was closed and could be moved on from. Dialogic moves were more often followed by student-centered closure. This correlation likely occurred because the LA move allowed students to decide for themselves when a need was sufficiently addressed. Beyond group consensus discussed previously, other student-centered manifestations of this impact occurred when the students would indicate that they were satisfied with how the LA was following along or understanding their ideas to round out the gap. Other times, closure would play out epistemologically, meaning that although students were unable to meet their conceptual need, their need was still acknowledged and validated in some way, so that it felt okay for the students to move on to something else. Authoritative moves were more often followed by LA-centered closure likely because the autonomy remained with the LA to make decisions about when the need was sufficiently addressed. In addition to the LA confirming correctness to reach closure as seen in the example provided previously, LAs also provided explanations to the groups they were working with that determined closure was reached and a gap was sufficiently addressed.

Sharing ideas and reasoning

Students shared additional ideas and reasoning when they expanded upon their ideas, justified their ideas, or shared new ideas. Across interactions, the reason that students shared ideas differed, e.g., sometimes they

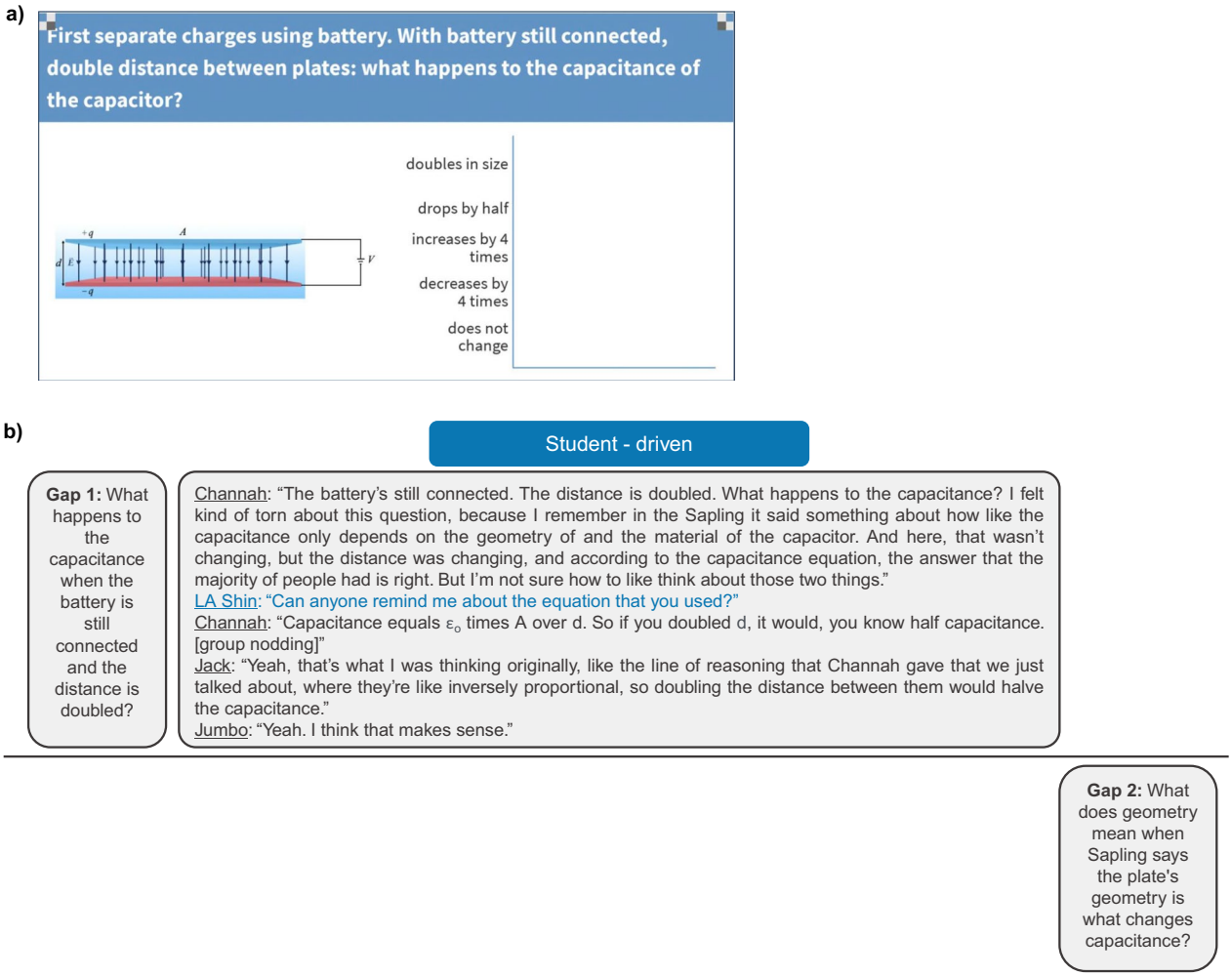

Fig. 8 **a** Question students and LA Shin worked on. **b** Example quotes from LA Shin and the group he worked with embedded in a graphical display of how student learning progressed from gap 1 to gap 2. The graphic shows that after the LA's question (blue), the students close the gap via group consensus before moving on to gap 2

tried to satisfy the LA's need for more reasoning simply because the LA asked for it, i.e., LA-centered sharing, and sometimes they shared ideas for the sake of having them and wondering about them, i.e., student-centered sharing. To compare across the different LA actions and how they were associated with differences in how students shared ideas and reasoning, a Sankey diagram is presented in Fig. 9. We found that dialogic actions are significantly more correlated with one way of student-centered sharing, (i.e., build on way of thinking/justify reasoning) than authoritative actions, and authoritative actions are significantly more correlated with LA-centered sharing (i.e., answer the LA question) than dialogic actions (χ^2 (3) = 95.45, $p < 0.001$) (Table 11 in the Appendix). For two other ways of student-centered sharing (i.e., share an alternative way of thinking and share a new idea/wondering), post-hoc testing showed no significant difference between authoritative and dialogic actions. Before exploring this nuance in more depth at the end of this section, we bring a qualitative example of each of the relationships that were significant.

When they discussed the following problem, a group of students shared reasoning to satisfy an LA need. The problem tasked students with thinking about the decomposition of ozone and writing the rate law for the reaction when given the energy diagram (Fig. 10).

LA Daisy noticed that the group seemed to know the answer to the problem but that no one spoke up much about it, maybe because they found the problem to be straightforward and not necessarily in need of extensive discussion. Thus, after students had talked about the slowest step in the mechanism being the first one, Daisy prompted one student who had not spoken yet to share her reasoning about the rate law:

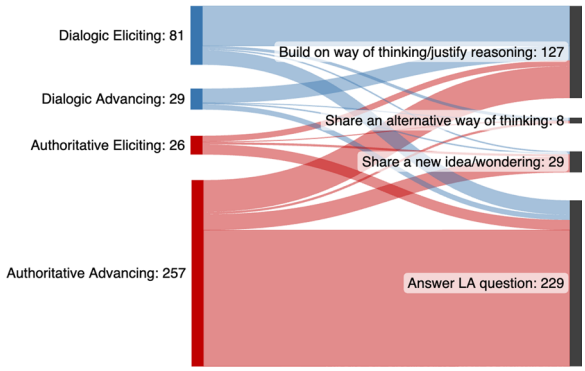

Fig. 9 The impact of different LA actions on how sharing reasoning and ideas manifested in student-centered (build on way of thinking/justify reasoning; share an alternative way of thinking; share a new idea/wondering) and LA-centered (answer LA question) ways. Dialogic actions (blue) were more often correlated with one way of student-centered sharing (build on way of thinking/justify reasoning) whereas authoritative actions (red) were more often correlated with LA-centered sharing (answer LA question). For two student-centered impacts (share an alternative way of thinking and share a new idea/wondering), post-hoc testing showed no significant difference between authoritative and dialogic actions

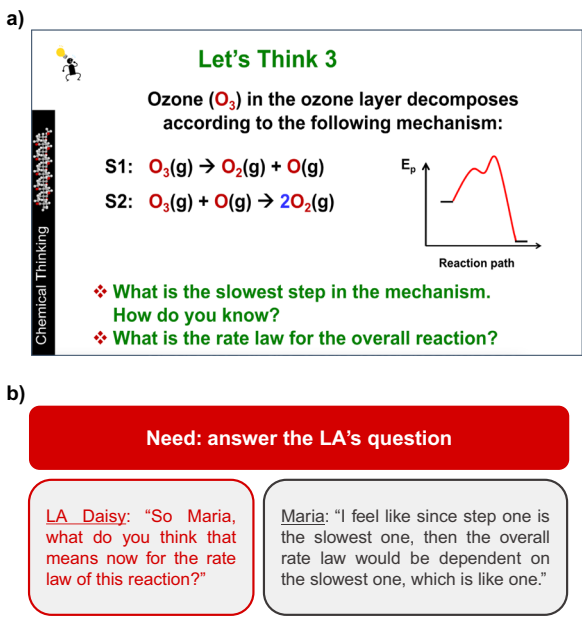

Fig. 10 **a** Question students and LA Daisy worked on. **b** Example quotes that show the LA's question (red) and student Maria's response (grey) to satisfy the LA's need

LA Daisy: So Maria, what do you think that means now for the rate law of this reaction?

When the LA asked what Maria was thinking about, the LA positioned this detail of the problem as central (authoritative) and invited the student to share thoughts she seemed to already have been thinking but not speaking about (eliciting).

In response, Maria provided reasoning (Fig. 10) that directly addressed the LA's question. Prompted by the LA, Maria said out loud what the logical next step of the reasoning was that the group had discussed previously: If step one is the slowest step (discussed previously), then the rate law is dependent on that step (logical next step). This exchange between the LA and student is a quick back and forth and Maria's response, presented with a neutral tone of voice, comes for the sake of satisfying the LA's need (i.e., to answer the LA's question).

In the example previously discussed, the quick exchange with a neutral tone of voice did not make it seem like Maria was actively engaging in that reasoning in the moment; rather she was just putting it out there because the LA had asked. Other times, sharing reasoning came in the form of students building on their own way of thinking in response to an LA move. As an example of this, we turn to a problem where students were asked to consider where in the human body cocaine is most readily absorbed by considering pH (Fig. 11).

The group spent most of their discussion up until this point talking about how they would need to look at how high the pH is, and that a high pH would lead to more absorption. Student Pumpkin shared that they thought it would be the rectum or the blood based on the given values. Making sure they could understand the reasoning behind the student's idea, LA Azari asked:

LA Azari: Because of the high pH?

LA Azari's clarifying question provided space for the student to share the thoughts that made them choose the rectum or blood (eliciting) indicating the LA was curious to hear where the student was coming from (dialogic).

In response to the LA's question, student Pumpkin confirmed their original idea, but then cut themselves off (Fig. 11) once they realized the problem provided students with a pK_b instead of a pK_a. In their response, Pumpkin built on their original line of reasoning by clarifying it to the LA and expanded on it by recognizing that there was a need to solve for the pK_a to fully answer the question.

In summary, while each type of LA action was associated with instances of sharing reasoning and ideas, there were differences in the needs students were trying to satisfy, e.g., answering the LA question or sharing an idea for the sake of having it and wondering about it. Authoritative moves were more often followed by LA-centered sharing. This likely occurred because the LA asked for specific information, so the students gave it to them. Dialogic moves were more often followed by one way of student-centered sharing of reasoning (i.e., building on students' own way of thinking and justifying their

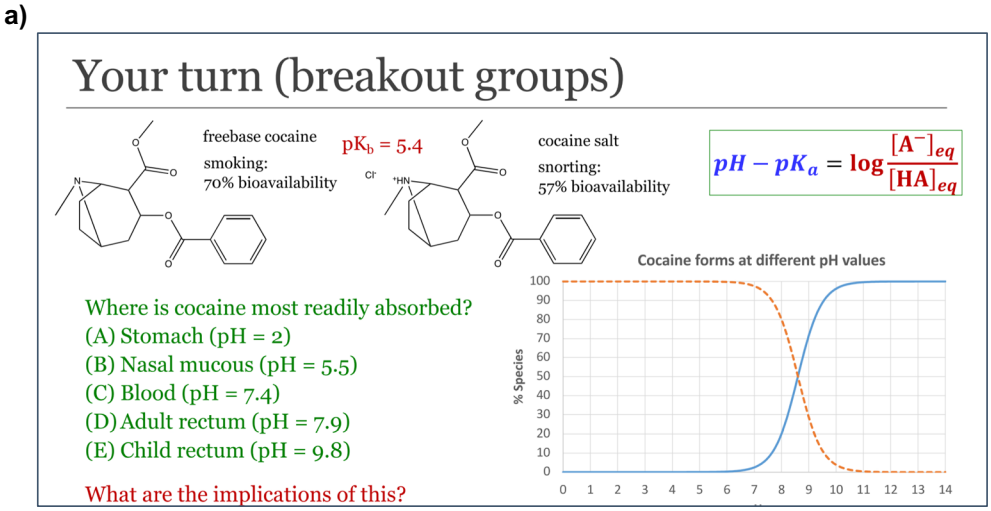

Fig. 11 **a** Question students and LA Azari worked on. **b** Example quotes that show the LA's question (blue) and student Pumpkin's response (grey) that shows them building on their own idea

reasoning) likely because dialogicity allowed them to focus on their own perspective and thus share for the sake of putting their own ideas into the discussion to progress in their learning.

In addition to building on their own way of thinking and justifying their reasoning, we found two other student-centered ways of sharing reasoning: share an alternative way of thinking and share a new idea or wondering, for which post hoc testing showed no significant difference between authoritative and dialogic LA actions (Table 11 in the Appendix). In the following, we exemplarily describe the impact of students sharing a new idea/wondering and why this impact might have resulted similarly often from both, authoritative and dialogic LA moves. Students sometimes shared a new idea or wondering in response to a dialogic LA move that checked in with students and gave them space to share more ideas. This occurred likely because the dialogic move explicitly gave them the space to do so. Other times, students also shared additional wonderings that would open new gaps for the group after an authoritative LA move, typically one that directed students to different parts of the problem or after an LA explanation to close out a gap. This occurred likely because the LAs authoritative contribution had brought the discussion to a moment of shift that the students used to bring in what they wondered about.

Revisiting

Revisiting occurred when students reconsidered an old, lingering need. An "old, lingering need" is one that was opened and moved on from without being resolved. Revisiting an old need either occurred using the insights students gained from other parts of the discussion (i.e., revisit an old need in light of new information) or by not explicitly drawing on other parts of the discussion (i.e., thinking through old need further). There is no difference between the student- vs. LA-centeredness of these two impacts. It is thus no surprise that the Sankey diagram presented in Fig. 12 does not show trends in terms of differences between those two impacts for dialogic and authoritative LA moves (χ^2 (1) = 3.26, $p < 0.8$) (Table 12 in the Appendix).

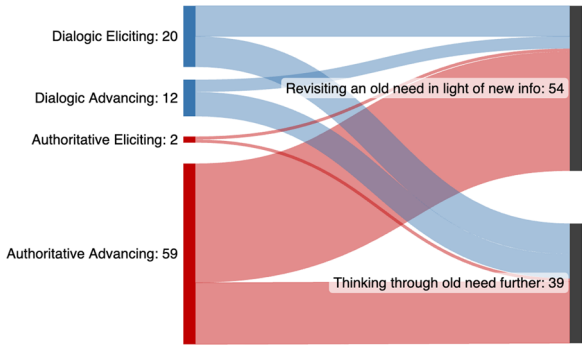

Fig. 12 The impact of different LA actions on how revisiting manifested. There are no trends in terms of differences between these two manifestations for dialogic (blue) and authoritative (red) LA actions

However, from a closer look at our qualitative analysis, we hypothesize that there might be differences between authoritative and dialogic moves with respect to who recognized the need to revisit, no matter whether the revisiting occurred with or without using new information. Paying attention to who held agency in revisiting revealed some differences that likely occurred because of the authoritative and dialogic nature of the LA actions. Based on patterns we see reoccurring in our data, we hypothesize that authoritative LA moves might more often be associated with the LA having agency in the decision to revisit, i.e., to reconsider in light of new information or to think through old needs further. This likely occurred because authoritative moves involved the LAs explicitly directing students to revisit old needs. Dialogic moves, however, might more often be associated with students taking the agency to revisit, i.e., to reconsider in light of new information or to think through old needs further. This could be because dialogic moves gave students the space to have this recognition on their own as the conversation was centered around the exploration of their ideas. Since we did not code for who had agency in revisiting but rather attended to it after we saw trends around student- and LA-centeredness emerge for other impacts, it would be beyond the scope of this study to make definitive quantitative claims about a relationship between authoritative and dialogic moves and agency in revisiting. More research is needed to investigate this hypothesized trend. Here we back up our hypothesis with qualitative data by showing two instances of revisiting, i.e., one initiated by an authoritative move and one initiated by a dialogic move.

In the following authoritative example, LA-centered revisiting occurred, as the LA's action positioned new ideas as relevant toward an old, lingering need. The students were asked to draw the energy diagram for a two-step reaction represented by colored sphere models of molecules (Fig. 13).

When LA Billu joined the group, the students shared their initial thoughts of what their energy diagram would look like before moving on to discussing enthalpy and activation energy as two components that would help them with their diagram. The group worked together across the whole interaction to reach consensus about the change in enthalpy and the activation energy for each reaction step. The LA recognized that these new ideas would be helpful towards thinking about their original diagram (lingering need). Thus, the LA asked:

LA Billu: Okay. So how would you configure your EP graph [potential energy diagram] based off of that [enthalpy and activation energy reasoning] then?

In this move, the LA explicitly referenced the consensus the group came to in the moments immediately before and leveraged this to point the group back towards the diagram (advancing) because he wanted them to answer the problem (authoritative). This authoritative advancing move directed students to use an idea they had recently established to explicitly revisit a lingering need.

In response to the LA's question, the students reconsidered the drawing of the diagram their group made at the very beginning of the interaction (Fig. 13). One student, Desiree, described in detail that they would need to adjust the curves in the diagram to be aligned with what they discussed regarding activation energy for both steps in the reaction. Following the LA's recognition of the relevance to revisit the energy diagram after the group's discussion about activation energy, the group was able to revisit a lingering need and make sense of it further.

While in the previous instance the LA was the one who recognized the relevance of new ideas towards an old need, in other cases, the students recognized this relevance after an LA move. As an example of this, we turn to a problem where students were asked to think about where the force is biggest when looking at the negative x direction of a potential energy function (Fig. 14).

In the beginning of their discussion, two students, Music and Fox, were discussing their reasoning for answer choices D and A. When talking through his reasoning for D, Music spoke about a hypothetical situation where he could roll a ball along the path and reasoned that at D it would move to the left the fastest, but wondered if this could translate to the greatest force. The group moved on to discuss Fox's reasoning for A, when LA Potatoes followed up on Music's reasoning:

LA Potatoes: And so you think that like for D, it's the one that moves fastest to go left? Or did I get that completely wrong?

In this move, the LA repeated back her understanding of the students' reasoning (dialogic) to clarify if that was

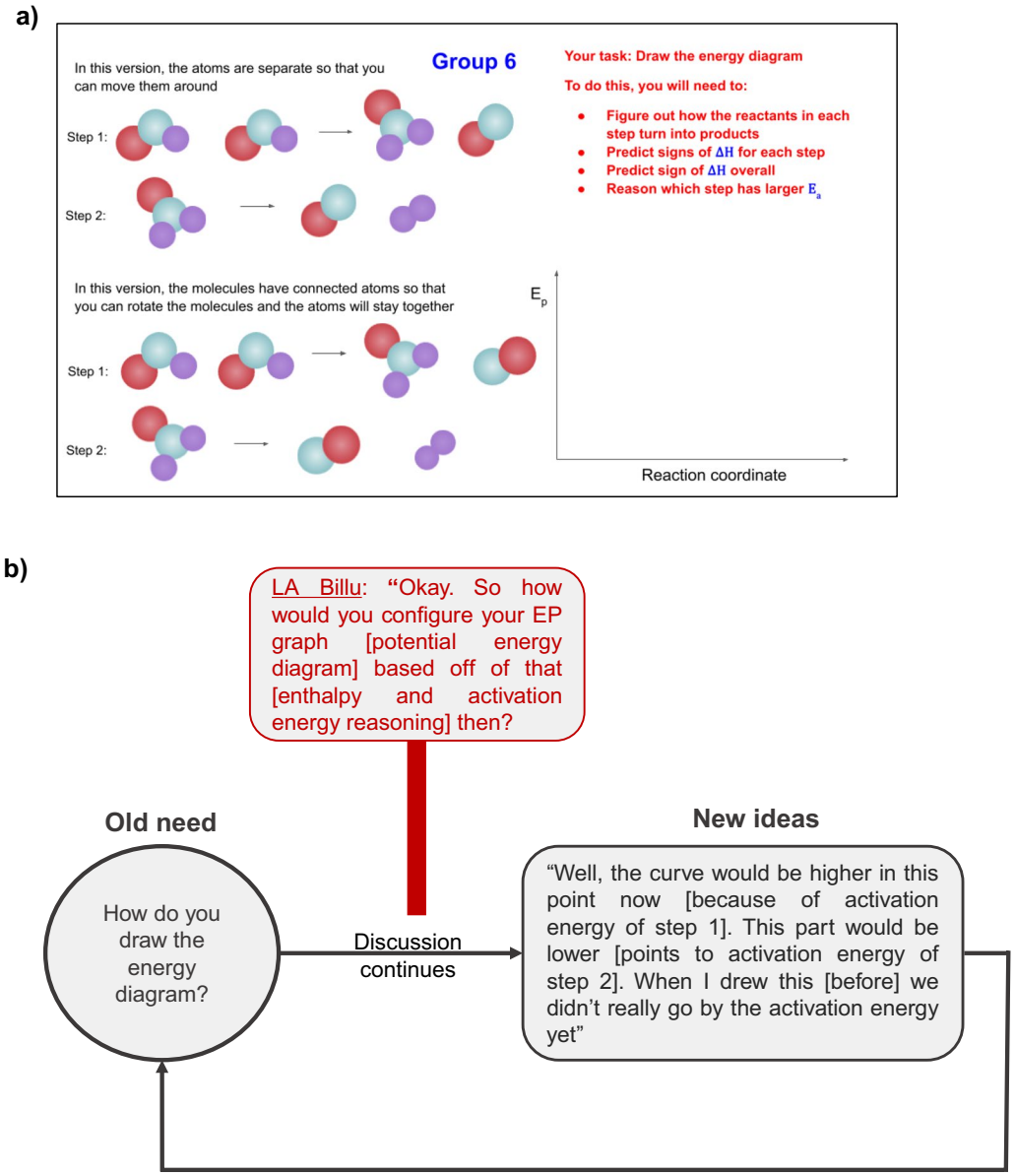

Fig. 13 **a** Question students and LA Billu worked on. **b** Example quotes to show the old need (grey circle) and relevant new ideas used to revisit this need (grey square). The LA question (red) prompted the students to use these new ideas towards their old need

what the student meant (eliciting). While this dialogic eliciting move was the LA's attempt at making sure she understood the student's idea for answer choice D, the LA did not explicitly direct the student to reconsider his answer choice.

In what followed the LA action, Music confirmed that the LA understood his original reasoning correctly but also recognized that based on that idea, he no longer thought D was the answer that aligned with his idea (Fig. 14). Following the LA's clarification question, the student realized that his idea about the quickest movement to the left would align with answer choice C, revisiting the lingering need (to choose an answer to the problem) on his own.

Socioemotional impacts

Beyond conceptual actions and impacts, our analysis revealed five socioemotional actions: talking to one student, validation/acknowledgement, inviting/inclusive language, bring in quiet student, empathizing/vulnerable (Table 6 in the Appendix); and five socioemotional impacts: less participation, dominance

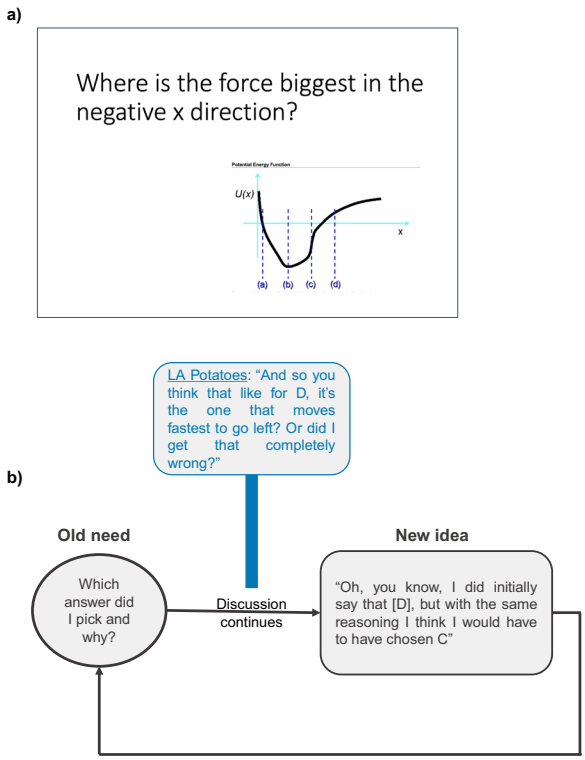

Fig. 14 **a** Question students and LA Potatoes worked on. **b** Example quotes to show the old need (grey circle) and relevant new ideas used to revisit this need (grey square). The LA question (blue) prompted the student to clarify his thought, which led the student to recognize the relevance of his new idea towards his old need

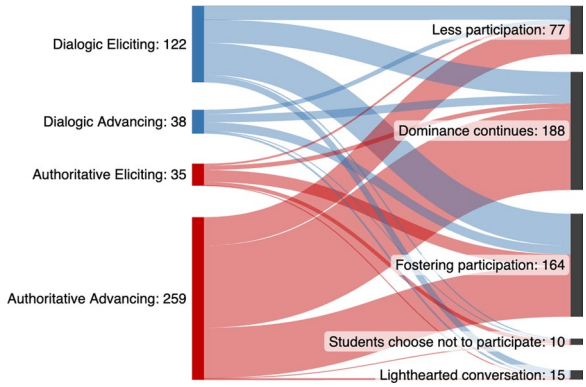

Fig. 15 The socioemotional impacts of authoritative and dialogic LA actions. The flows demonstrate that authoritative and dialogic LA actions have a variety of socioemotional impacts (less participation, dominance continues, fostering participation, students choose not to participate, and lighthearted conversation). Specific trends observed are that authoritative actions were more often correlated with dominance continues than dialogic actions, and dialogic actions were more often correlated with lighthearted conversation than authoritative actions

continues, fostering participation, students choose not to participate, and lighthearted conversation (Table 7 in the Appendix). Because dialogic actions include multiple perspectives, one might expect that dialogic actions would foster more participation amongst students, whereas one might expect authoritative actions to limit participation. However, we found that across authoritative and dialogic actions, the only significant relationships were with dominance continuing and lighthearted conversation (χ^2 (4) = 25.24, $p < 0.001$) (Table 13 in the Appendix). More specifically, authoritative actions were significantly more correlated with dominance continues than dialogic actions, whereas dialogic actions were significantly more correlated with lighthearted conversation than authoritative actions (Fig. 15).

We were curious if these correlations might have resulted from the dialogic and authoritative character of the actions, or if they might be better explained by a socioemotional action component layered on top of the authoritativeness and dialogicity. Therefore, we investigated the relationship between authoritative and dialogic actions with socioemotional actions, which resulted in no significance (χ^2 (4) = 4.72, $p < 0.32$) (Table 14 in the Appendix, Fig. 16). This shows that the correlations between authoritative actions and dominance continuing and between dialogic actions and lighthearted conversation cannot be explained with a socioemotional action component layered on top of the authoritativeness and dialogicity, making it more likely that the correlations come from the authoritative and dialogic character. Furthermore, this investigation of the relationship between authoritative and dialogic actions and socioemotional actions shows that an LA can layer any socioemotional action on top of authoritative and dialogic actions.

We further tested for socioemotional actions and their impacts and found that talking to one student was significantly more correlated with dominance continues than bringing in a quiet student and inviting/inclusive language and that brining in a quiet student and inviting/inclusive language was significantly more correlated with fostering participation than talking to one student (χ^2 (16) = 119.2, $p < 0.001$) (Table 15 in the Appendix). We also found significant relationships between talking to a quiet student and students not choosing to participate and being empathetic/vulnerable and lightheartedness (χ^2 (16) = 119.2, $p < 0.001$) (Table 15 in the Appendix). While further research is needed to understand why for example the relationship between talking to one student and dominance continues is significant while the relationship with less participation is not significant, there is a clear pattern in participation dynamics that spans across multiple socioemotional actions (i.e., talking to one student, bring in quiet student, and inviting/inclusive language) and impacts (i.e., dominance continues and fostering participation): Participation

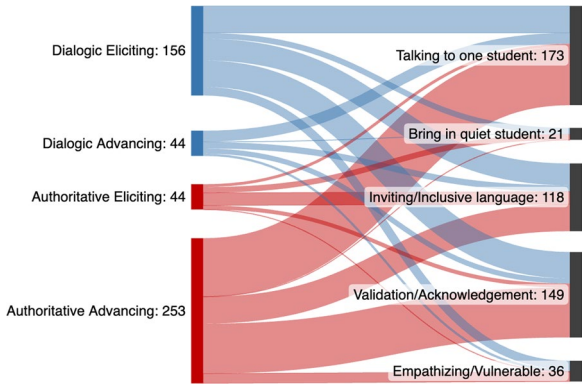

Fig. 16 Dialogic and authoritative actions and their socioemotional components. The flow demonstrates that all LA actions can have socioemotional components to them, and there are no significant differences between which LA actions (i.e., dialogic and authoritative) have which socioemotional components

more often increased after LA moves that aimed at drawing students in and dominance continued more often after LA moves that singled one student out (Table 15 in the Appendix, Fig. 17). To demonstrate how these differences manifest in our data, we show two examples, i.e., one where participation increased after an LA used inclusive language and one where dominance continued after an LA talked to one student.

In the following example, we build on the interaction presented in the methods between LA Maria and a group of students. In this example, students were asked to think about a reactions' rate, directionality, and pH at three points: equilibrium, at the disturbance, and after the disturbance (Fig. 18).

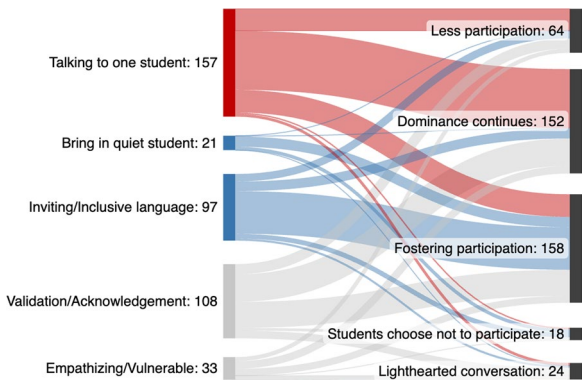

Fig. 17 Socioemotional actions and their socioemotional impacts. There is one significant trend that spans across multiple socioemotional actions and impacts: Talking to one student (red) was more often correlated with dominance continuing while bringing in a quiet student and using inviting/inclusive language (blue) were more often correlated with fostering participation

After the group discussed the equation for Q (Table 3), they focused on the pH and students Moon and Pink mostly dominated the discussion space by sharing more than the rest of their group. Moon and Pink both shared many wonderings that moved the group slightly away from discussing the pH, which was one of the main foci of this question. Amid these two students going back and forth with one another, the LA asked:

LA Maria: *What did you guys end up deciding for pH?*

In this move, LA Maria used inviting and inclusive language (bolded) to invite all students into the discussion around pH. Using this language directed her question towards the whole group. Following this LA action, a shift in participation occurred from just Moon and Pink to all four students in the group discussing the pH with one another (Fig. 18).

While in the previous instance the LA's action was followed by an increase in student participation, after other LA actions, a student or a small subset of students who were already dominant continued to participate more. Dominance continues occurred when one student or a small subset of students were persistently more dominant in sharing their thoughts than their peers. One example of this occurred in an interaction where students were tasked with thinking about two loops carrying current in opposite directions and asked if the loops will attract or repel each other (Fig. 19).

The students were using two different right-hand rules to think about the magnetic field of the loops. Student Josephine was grappling with how to use the second right hand rule and engaged in a back and forth with student Noor about it. They worked together collaboratively to develop Josephine's understanding of how to use the second right-hand rule, and the conversation shifted to privilege Noor's way of knowing in Gap 2. LA Shin seemed to be actively trying to understand what Noor was describing, and followed up with her by bringing in his own question to try to make sense of the right-hand rule:

LA Shin: So if you [?] the current is going this way, so if you look at the left loop, it's like this right? But then what if it like goes like this? So what's going to happen? [arm movements] [laughs] It's also hard for me.

In this move, the LA explicitly talked to Noor using "you" to address her and inquires about her thoughts on the first right-hand rule. Before this move, the dynamic of the conversation shifted from the students having a back and forth amongst each other about the second right-hand rule to Noor's ideas being centered. In what followed this move, student Noor's ideas and participation continued dominating the space after being leveraged by the LA, leaving little room for others to participate during the back and forth between her and the LA (Fig. 19).

Fig. 18 **a** Question students and LA Maria worked on. **b** Example quotes embedded in a graphical display of how the learning progressed through gaps 8, 9 and 5 in one part of the interaction. Note that gap 5 had already been talked about in an earlier part of the interaction not displayed here. Some details of student quotes have been reduced for space as the conceptual content is not the focus of this example. The figure shows two students (Moon and Pink) contributed to the discussion before the LA move that used inclusive language, and four students (Moon, Pink, Daisy, and Kehlani) contributed to the discussion after

Discussion

Building on our previous characterization of LA facilitation practices (Carlos et al., 2023) and our analytical tool for studying in-the-moment learning during LA–student interactions (Karch, Maggiore, et al., 2024), our work here is the first to connect these two fields of study investigating the impact of LA moves on how learning progresses in the moment of interaction. Post hoc studies of student success in LA-facilitated courses (Herrera et al., 2018; Van Dusen & Nissen, 2017; Van Dusen et al., 2015) are important for furthering our understanding of the impact of the LA model on the holistic, whole-course

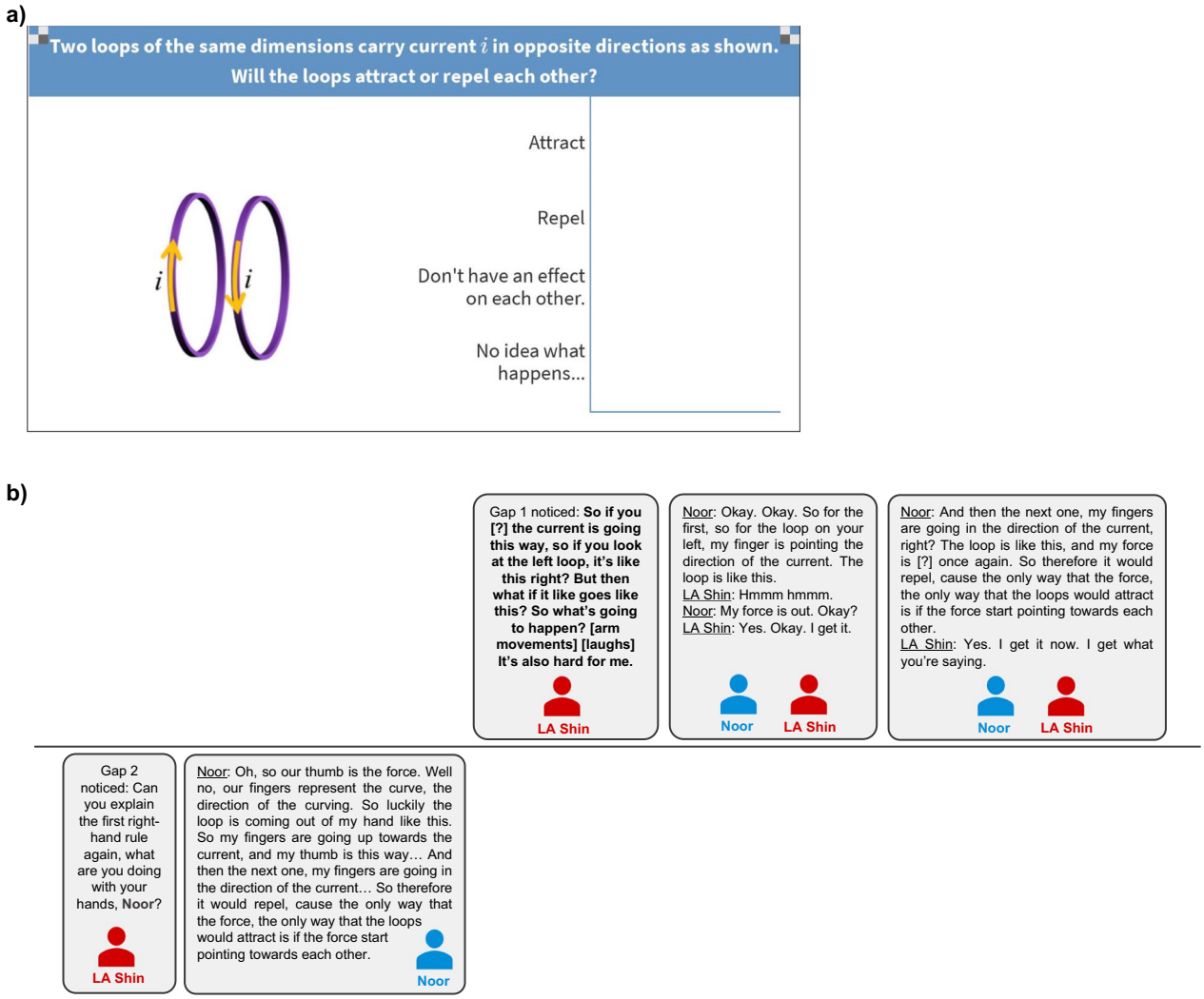

Fig. 19 **a** Question students and LA Shin worked on. **b** Example quotes embedded in a graphical display of how the learning progressed through gaps 2 and 1 in one part of the interaction to the bottom. Note that gap 1 had already been talked about in an earlier part of the interaction not displayed here. Some details of student quotes have been reduced for space as the conceptual content is not the focus of this example. The examples shows that one student Noor was the only one who contributed to the discussion at this point, and following the LA move that addressed her specifically (bolded), the conversation remained between the LA and Noor exclusively

level. Our study deepens understanding of this prior work by zooming into the moment of LA–student interactions to see what and how students learn throughout the semester, expanding our knowledge of the impact of LAs from the macro scale of the course to the micro scale of interactions. The culmination of these day-to-day interactions inform the findings of generalized, whole-course studies, so understanding what goes on during these interactions is productive towards optimizing LA facilitation and better understanding how students are engaging in their learning. While prior work connected LA facilitation to a characterization of student discussion patterns during LA–student interactions (Knight, et al., 2015), our work shows a detailed account of the progression of student disciplinary learning. More specifically, we demonstrate how the perspectives centered during LA facilitation impact the way students' needs are met and how disciplinary meaning is transformed.

Our study expands existing theory on authoritativeness and dialogicity (Mortimer & Scott, 2003) in two major ways. The first contribution becomes clear when considering our finding that dialogic and authoritative LA facilitation are both associated with all ways of student in-the-moment learning: grappling, reaching closure, sharing reasoning, and revisiting. While prior work has focused on differences between the impact of

authoritative and dialogic facilitation (Chin, 2007; Knight, et al., 2015), we found a major similarity. Knowing that both authoritative and dialogic facilitation can induce all ways of in-the-moment learning can help instructors who base their facilitation on one end of the authoritative-to-dialogic spectrum of facilitation (Carlos et al., 2023) to diversify their facilitation across the spectrum without the fear of losing major components of learning. The second contribution becomes clear when considering our finding that dialogic and authoritative facilitation are more correlated with either student-centered or LA-centered manifestations of these impacts on student in-the-moment learning. Theory on authoritativeness and dialogicity tells us that authoritativeness centers one perspective while dialogicity centers multiple perspectives during facilitation (Mortimer & Scott, 2003). While it is assumed that this difference in facilitation connects to a difference in the impact on students, our study separates the characterization of what the facilitator, i.e., LA, does from what the students do and empirically validates that authoritative facilitation is more correlated with LA-centered learning and dialogic facilitation is more correlated with student-centered learning.

The different ways authoritative and dialogic facilitation impact how in-the-moment learning manifests are especially important when considering the context in which LAs practice and what is most productive in the moment of interaction within their context. In the example with LA Billu, he worked in a course where the instructor valued students bringing in their own chemical thinking and following multiple causal steps through towards applying it to the problem at hand. Thus, when the LA noticed that the students' discussion about activation energy was relevant towards their conceptualization of the energy diagram, he directed them to use these new ideas to revisit their lingering need (i.e., to draw the potential energy diagram). This key observation helped the group adjust their original energy diagram relative to the new ideas they discussed and was productive toward the goal of students applying their chemical thinking towards the question during small group discussions. In this example, a dialogic move that aimed to draw out even more reasoning about activation energy might not have been as productive towards the goals of the interaction compared to the authoritative move made by LA Billu. In other instances, however, dialogic moves can be more productive for learning goals. For example, in the interaction between LA Cosog and students, they were situated in a class where the instructor valued confusions and wanted students to work through these during small group discussions. Thus, when the LA heard Zara's confusion about configurations, he took it as an opportunity to center her idea and invite the students to think through it further. The resulting impact of this action was that multiple students resonated with Zara's confusion and grappled with their thoughts and struggles, which aligned with the goals the professor had for the small group discussions. In this example, an authoritative move where the LA explained the concept of configurations to the group might not have been as productive towards the goals of the interaction compared to the dialogic move made by LA Cosog.

Our future work will further explore the context LAs work in, and how various factors beyond their noticing and purpose drive their actions. Towards developing a model to describe the different drivers of LA actions, we will consider the entire Activity System (Engeström, 1999) and more specifically how the instructor's goal, modality, tools, rules, and division of labor of the course influence the LA purpose and thus the LA actions in LA–student interactions.

In addition to the conceptual impacts of LA actions, our work is the first to investigate the relationship between socioemotional LA actions and impacts on student in-the-moment learning on the interactional level. Though it has been shown that LAs positively influence students' attitudes and increase engagement in the courses they work in (K. Clements et al., 2023; T. Clements et al., 2022), and that LAs offer a variety of different social supports during their practice (Donis et al., 2024; Hernandez et al., 2021), there is no previous work exploring the ways various socioemotional LA actions engage students in the moment. Our research demonstrates that all LA facilitation (i.e., authoritative and dialogic eliciting and advancing actions) can include socioemotional components including, but not limited to, decisions about whom the LA talks to, what language they use, and how they express emotions. Our research shows that small socioemotional additions to LA actions such as using inclusive language or addressing one specific student are very impactful, often influencing students' participation levels. LAs can thus intentionally make choices around socioemotional actions in their facilitation to induce these outcomes. The fact that LA moves often combine conceptual with socioemotional actions warrants deep reflection by LAs. For every student idea that an LA picks up on, the LA should be aware that they are not just centering that idea, but possibly also the student who brought forth the idea. LAs may decide to pick up on an idea because it seems beneficial for students' conceptual learning, but they may also be making an intentional decision to center or de-center a particular student in the discussion. At times, this can mean that LAs need to make compromises between productive disciplinary ideas and more equitable discussion, for example when a student dominating the discussion brings in an idea

the LA thinks could be beneficial. The LA then needs to weigh the possible conceptual benefit of picking up on that idea against the possible socioemotional downside of dominance continuing.

Exploring the relationship between conceptual actions and socioemotional impacts, we found that centering multiple perspectives in dialogic facilitation did not automatically correlate with more participation and centering one perspective in authoritative facilitation did not automatically correlate with less participation (there was a significant relationship between authoritative facilitation and dominance continuing, but not between authoritative facilitation and less participation or dialogic facilitation and fostering participation). Rather, socioemotional actions added on to either dialogic or authoritative facilitation had their own impacts on student participation. This finding aligns with the communicative approach where teachers' dialogue is characterized along two separate dimensions: dialogic-authoritative and interactive-non-interactive (Mortimer & Scott, 2003; Scott et al., 2006). The fact that the socioemotional component of facilitation is separate from the conceptual component becomes specifically important for LAs working in contexts with learning goals set by the instructor. Within different contexts, certain learning goals set by instructors may be better aligned with LAs using mostly authoritative facilitation, mostly dialogic facilitation, or some combination of both. Our findings show that regardless of which facilitation LAs should use to align with the goals of their course, they can incorporate socioemotional components to their practice and thus support students to fully and comfortably participate in whatever kind of learning is prioritized in a specific class context.

In the prior sections, we discussed implications of our findings for LA practice, i.e., one part of the LA model. Insights from our work across the conceptual and socioemotional planes of LA practice can further inform LA training within the other two parts of the LA model—the pedagogy course and weekly instructional team meetings (Otero et al., 2010). We see three interconnected points LAs can be trained on based on our findings: (1) how to use authoritative and dialogic facilitation intentionally, (2) how to incorporate socioemotional components in their facilitation, and (3) to recognize how they can adjust their practice to align with the outcomes they want for students. We see an opportunity in the pedagogy course for expanding training around points (1) and (2), especially because teaching LAs about different questioning styles and mindfulness are already goals of the pedagogy course (LA Alliance, 2024). Instructors can provide LAs with a "tool kit" of different actions (i.e., the actions from our codebook seen in Tables 4 and 6). LAs can first be introduced to the conceptual actions in Table 4 and the class can discuss how to make informed decisions around the various types of actions they can take within authoritative and dialogic facilitation. Similarly, LAs can be introduced to the socioemotional actions in Table 6 and the class can discuss the language choices made by LAs, how they can be intentional about open or closed wording, and nonverbal cues they can use to support students to participate fully and comfortably. Further, all these actions can be introduced alongside their impacts (Tables 5 and 7) on student learning, both conceptually and socioemotionally, so that LAs can use these insights for intentional use in their facilitation. We see an opportunity in the weekly preparation meetings in combination with the pedagogy course for training around point (3). The meetings with the instructional team provide opportunities for course instructors to be transparent about their expectations for LA–student interactions and more specifically about what they hope for students to be discussing in class. Being intentional and transparent with expectations for LAs' roles and student learning during these meetings will give LAs an explicit understanding of the instructors' goals that they should work towards and carry out in their own, unique ways. Having a tool kit provided from the pedagogy course and expectations clearly communicated from the weekly preparation meetings, we imagine LAs will have the necessary means to engage in cycles of reflexive practice: LAs look at the different impacts and think about which ones best align with the goals for their interactions; then they look back to see which actions are associated with those impacts; they attempt to carry these actions out during their practice; and lastly they reflect on the impact of their actions by comparing them back to the goals within their own context. Through this reflexive practice to tailor their facilitation toward the goals within their context, the "tool kits" become more directly applicable to their context and their facilitation practices become more intentional and productive towards their goals.

The outcomes of our study were made possible via the intentional use of two different frameworks. Relying on the theoretical constructs of authoritativeness and dialogicity (Dini et al., 2020; Mortimer & Scott, 2003), allowed us to characterize LA facilitation (Carlos et al., 2023). The constructs of gaps, pieces, and relations (Wickman, 2004; Wickman & Östman, 2002) allowed us to characterize in-the-moment learning during LA–student interactions (Karch & Caspari-Gnann, 2022; Karch, Maggiore, et al., 2024). However, only the combination of these two frameworks allowed us to go

beyond a description of separate phenomena of facilitation and learning towards an investigation of how one influences the other. This speaks to the strength of combining complementary frameworks towards a deeper understanding of instructional phenomena.

Limitations

We chose to analyze LA–student interactions on the level of individual LA moves to characterize the microcosms of the impacts that each move had on student in-the-moment learning. Conducting our analysis in this way provided multiple advantages. It allowed us to track learning closely on the level of conceptual ideas and how they were picked up and developed moment to moment. Thus, we captured in-the-moment learning as a process, which allowed us to see nuanced shifts that occurred after LAs intervened during interactions. We recognize that analyzing the data in this way did not show us the impact a combination of LA moves had on a larger scale of the whole interaction. Yet, we made sure that our moment-to-moment interpretations of the impacts of individual LA moves aligned with our more holistic understanding of the entire interaction developed when watching the video and reading the transcript as a whole prior to the moment-to-moment analysis.

Within our theoretical and analytical bounds, we were able to capture conceptual learning as it differed related to the perspectives centered by LAs on an interactional level. We also were able to capture socioemotional aspects of in-the-moment learning as they emerged from the data by focusing on what socioemotional pieces LAs brought in and whose voices were heard. When we set out to investigate our research question within the broader goals of the research study, we did not intentionally set out to investigate socioemotional aspects of learning. The sociocultural frameworks that informed the study were selected prior to engaging in analysis, and thus before we noticed the important role of socioemotional impacts of LA moves in the data. While analyzing how systems of oppression function in interactions between LAs and students should be part of a comprehensive analysis of learning (Philip et al., 2018; Suárez et al., 2023), our work only tapped into those aspects that could be directly observed on the level of the interaction such as an increase in participation or the dominance of one student continuing. What we were not attending to was how any imbalances in participation related to systems of oppression in society such as racism or sexism as this would have required an additional critical frame that our analysis was not set up for. We recognize that presenting our results in this way, while still beneficial to know and use to train LAs, does not capture the way systems of oppression exist and impact all LA–student interactions. These interactions exist within systems that have pre-existing rules and norms that privilege certain ways of being and knowing over others, which marginalizes some students more than others. More work is needed to understand how systems of oppression impact LA facilitation and student learning on a moment-to-moment basis.

Conclusion

Our study shows that dialogic and authoritative LA facilitation impact student learning as it occurs in the moment of LA–student interactions in the same four major ways: students grapple with ideas, reach closure, share reasoning, or revisit earlier needs. Depending on whether LA facilitation is authoritative or dialogic, these impacts manifest more often in LA-centered or student-centered ways. Our study further reveals that LAs add socioemotional aspects to authoritative and dialogic facilitation that impact student participation during LA–student interactions. Together these findings are relevant to multiple areas of the field. Our findings expand knowledge on authoritativeness and dialogicity as we demonstrate empirically that authoritative moves are more often correlated with LA-centered learning and dialogic moves are more often correlated with student-centered learning. Our findings further expand knowledge about LA implementation. We add an interaction-level understanding to the existing classroom-level knowledge about LA implementation improving conceptual and socioemotional student outcomes. With respect to the study of LA facilitation and student in-the-moment learning, our study adds the link between the two through describing the impact of one on the other. This connection between LA facilitation and their impact can contribute to LA reflexivity and intentionality. If an LA knows how authoritative and dialogic moves typically impact student learning, then they can be more intentional about using moves that align with the intended learning goals of their context. Similarly, if LAs know they can layer socioemotional aspects onto their facilitation no matter whether it is dialogic or authoritative, they can contribute to student engagement and comfort in any learning space where they have the opportunity to interact with students.

Appendix

See Tables 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15.

Table 4 Conceptual action codes, definitions, and examples

Action codes	Action subcodes	Definition	LA quote examples
Dialogic Eliciting	Inviting students to respond to a topic or idea	This move occurs when the LA asks students how they are thinking about an idea or topic in a way that invites more thoughts into the space. This move does not limit the scope of the students' responses because the LA opens the space for students to share what they are already thinking (eliciting) about a student idea or a topic that is being discussed by students (dialogic). This typically occurs when an LA checks in about whether there is group consensus or not around an idea or when an LA checks in to see how other students are thinking about an idea	"Yeah, absolutely. Absolutely. So what does everybody else think about that?"
	Clarifying	This move occurs when an LA clarifies something that was shared by the students. The LA centers ideas from the students' discussion (dialogic) and aims to make these thoughts more explicit (eliciting). This typically occurs when an LA restates students' explicit ideas back to clarify if they understood them correctly, adds implicit ideas explicitly to find out if that is what the student meant, or asks questions about something they are not sure they understood	"Yeah, so just so I can like understand, you're saying that the momentum is zero at the beginning and zero at the end? Or is that not what you're saying?"
	Asking students to repeat ideas	This move occurs when the LA asks the student to repeat back what they had said so the LA can follow along. The LA follows up on students' ideas (dialogic) and asks them to talk again about what they have already discussed (eliciting). This typically occurs when an LA misheard the student or when the LA had a hard time hearing the student	"For the second one. Can you just repeat what you said about the answer? I want to make sure I'm understanding."
Dialogic Advancing	Opening space for students to expand upon an idea	This move occurs when an LA invites the students to explore or expand upon one idea that they mentioned. The LA focuses on a student's idea (dialogic) and asks them to explore beyond what they have already reasoned about, expanding their discussion (advancing). This typically occurs when an LA explicitly asks the students to talk more about an idea or when they ask them follow-up questions to go beyond the level of reasoning they have already discussed	"I was going to ask about Peppa744's first point about pressure, volume, and temperature affecting the electrochemical cell to increase the voltage. So how does pressure how would that affect the voltage?"

Table 4 (continued)

Action codes	Action subcodes	Definition	LA quote examples
	Asking for justification of an idea	This move occurs when an LA asks students to justify or provide additional reasoning for an idea they mentioned. The LA asks students to think about their own ideas (dialogic) further by providing new justification (advancing). This typically occurs when an LA asks for justification because they think this will help the students think through a confusion or when an LA is curious to hear how or why a student thought of an idea	"Case two. Why do you think it's case two?"
	Looking for a relationship between two ideas	This move occurs when an LA notices that two ideas are related to one another and inquires further about their connection. The LA calls attention to multiple student ideas (dialogic) so that the group can think about their relationship, something they have not done yet (advancing). This typically occurs when an LA explicitly asks about a connection between two ideas or when an LA just states two ideas into the conversation space to make these explicit to students. These ideas can be similar or contrasting	"How do you guys like think that those [two different ideas] relate? Do you see them as being equal in this scenario?"
	Asking students to think about outside reasoning	This move occurs when an LA notices that there is the opportunity to bring in outside ideas and asks the students about these. The LA includes other ideas (dialogic) so that the group can think about ones they have not yet (advancing). This typically occurs when an LA brings in other reasoning from student groups or asks the group to think about other answer choices they have not yet thought about	"Okay, great. That make sense. I am wondering what you all thought of the other responses. So I think one of them was that the current moves from left to right. And so, and then there is also, like the current moves from right to left, and then people also, some people thought that there is no current. So I guess I'm wondering, first, why do you think people would say that there is no current? What do you think their ideas were?"
Authoritative Eliciting	Focusing in on a specific detail	This move occurs when an LA picks up on one idea specifically and inquires further about it. The LA calls attention to one idea that they are positioning at the center (authoritative) to learn more about it or see how the students already thought about it (eliciting). This typically occurs when an LA asks students to share detailed thoughts, usually in a way that feels like they want to see how the students are thinking and if it is correct	"So before we proceed, can someone tell me the two types of intermolecular forces that we've just learned?"
	Inquiring about student's problem-solving process	This move occurs when an LA asks about the detailed steps in a student's problem-solving process. The LA wants to check over this process (authoritative) to learn more about how the students already thought through this (eliciting). This typically occurs when an LA knows that students must have engaged in a problem-solving process, and the LA asks questions about it to find out more details or to correct the student	"So if it's okay, Canyon123, do you think you can summarize real quick what you did with the pK_B and how did you place that on the graph and what does it tell you?"

Table 4 (continued)

Action codes	Action subcodes	Definition	LA quote examples
	Seeking agreement	This move occurs when an LA picks up on one idea on purpose and asks if other students agree with this idea. The LA wants to uncover more students' thinking (eliciting) around one specific idea they purposefully center as correct or more important than others (authoritative). This typically occurs when an LA explicitly names an idea as correct or implicitly selects a correct idea and asks for group consensus around that idea	What do other people think? Do people agree or disagree with Cola777?
Authoritative Advancing	Prompting additional reasoning to move towards the canonically correct understanding	This move occurs when an LA inquires further into students' answers or ideas to make sure the students can justify their canonically correct understanding. The LA wants to help students develop the correct line of reasoning (authoritative), so they push them towards discussing more details they have not yet (advancing). This typically occurs when an LA asks students questions about the concepts they are discussing	"And why do the fluorine's have an impact on our stability here?"
	Asking students about a new (LA) idea in relation to LA need	This move occurs when an LA brings in their own ideas to the group discussion and asks students to think about them. The LA positions their idea at the center of the discussion (authoritative) and asks students to make sense of it or share any thoughts they may have about it (advancing). The idea the LA brings in or inquiries about is relevant to a need the LA has. These needs can include wanting students to continue discussing, wanting students to engage further with a concept, or being curious about how students think about something	"Okay. You're saying no, but you've walked, hopefully. This campus is on a hill, so you've walked up a hill. Is the situation different if you're walking up a hill? Especially right now in the winter when it's icy, maybe, or sliding a little bit as you go up the hill? Any difference on the work or the friction being done?"
	Confirming correctness or correcting	This move occurs when an LA confirms that students' answers, ideas, or problem-solving steps are correct or when an LA works to correct student reasoning. The LA focuses on the correct reasoning (authoritative) and moves the students forward from one part of the problem to another (advancing). This typically occurs when an LA explicitly corrects students, asks correcting questions, or provides confirmation of correctness	"Is it being broken or formed? Two NOs are joining to form. Do you see that?"

Table 4 (continued)

Action codes	Action subcodes	Definition	LA quote examples
	Directing students to use an idea they have established to explicitly revisit a lingering gap/confusion	This move occurs when an LA asks the students to take new information to revisit an old need they had. The LA tells students that these new pieces connect to the lingering gap (authoritative) and prompts them to discuss this old gap or confusion in a way they have not yet (advancing). This typically occurs when an LA takes specific ideas mentioned by students and leverages them to direct students to discuss a gap that is lingering or a previous confusion expressed by students	"So if we go with what Tessa517 was saying, which hydrogen would that, would make that, would that make more acidic on this structure?"
	Asking students about a new (LA) idea in relation to student need	This move occurs when an LA introduces their own idea into the conversation as they think it will relate to a student need. The LA asks about their idea (authoritative) in conversation with the students' confusion to encourage more group sense-making about a new connection (advancing). This typically occurs when an LA picks up on a student need, e.g., a student confusion or a student wondering, and asks about their own idea that they think relates to this need	"Beyond like the whole like memorization level, maybe it would help to think about it in a little bit of like, like picture it a little. What about like the number of molecules, and what about it being a gas makes it, makes you guys think that it's more entropically favored?"
	Contributing to student discussion by providing LA insight	This move occurs when an LA introduces a new idea in a way that contributes to students' sense making. The LA provides their own ideas (authoritative) to help the students discussion progress forward (advancing). This typically occurs when an LA provides an explanation about a concept or when an LA shares their own thoughts about how to solve a problem	"Right. So if it's exactly one, then you know it's that one. If it's close to one, you couldn't be sure until you graph all of them and then see which one is closest."
	Directing students' attention towards a specific part of the problem	This move occurs when an LA directs the students' attention towards a different part of the problem than what they are already discussing. The LA aims for students to address all parts of the problem (authoritative) to progress forward in their discussion of the activity (advancing). This typically occurs when the LA asks students explicitly about a different part of the question or when the LA directs students to talk about something new that the LA thinks is relevant to the problem at hand	"So we did the left hydrogen on the right structure, and what about the structure on the left?"

Table 4 (continued)

Action codes	Action subcodes	Definition	LA quote examples
	Providing logistical insight into the problem	This move occurs when an LA shares more insight into the problem students are working on. The LA takes on an instructional role in the sense that they provide students with additional insight to the problem (authoritative) so that the group can move forward to discussing the content (advancing). This typically occurs when an LA provides clarification on what the question is asking, when the LA helps students understand their task, when the LA shares how they go about solving this type of problem, or when the LA provides any other logistical insight	"So basically, the question is, because H_2 are like hydrogen, like the question says, is one of the products, right? And so it's basically asking how much hydrogen can you produce. So it kind of, it relates to limiting reagent, because the limiting reagent is going to like determine the maximum amount of hydrogen that can be produced if that makes sense."

The quotes provided are from LAs and demonstrate one way each action could occur

Table 5 Conceptual impact codes, definitions, and examples

Impact codes	Impact subcodes	Definition	Example quotes and background
Increase grappling	With new LA idea(s)	Grappling of this kind occurs when students work towards making sense of an idea introduced by the LA. It is typically an idea they have not thought about explicitly yet, and they are working to understand it and incorporate it into their reasoning for the first time. It is typical for this type of grappling that students ask questions about the LA idea, express confusion about the LA idea, or think critically about the LA idea	The group discussed the concept of complexity, and the LA asked about his own idea of the complexity of the reactants [$HCOOH + O_2$] versus the products [$CO_2 + H_2O$] either as a whole or as individual molecules. The student replied, "That's kind of what I'm confused about in the reaction cause I feel like this molecule [HCOOH] would be more complex than like either of these [$CO_2 + H_2O$], but then at the same time O_2 is not … so like how do you determine which one is more important?"
	With LA & student idea(s)	Grappling of this kind occurs when students work towards making sense of an idea introduced by the LA in combination with their own ideas. These are typically ideas they have not thought about together yet, and they are working to understand them and incorporate them into their reasoning for the first time. It is typical for this type of grappling that students ask questions about the LA and student ideas, express confusion about the LA and student ideas, or think critically about the LA and student ideas	Students discussed the concentration and number of molecules of H_3O^+ in a problem. The LA noticed that the students were discussing concentration and number of molecules as if they were the same, and asked the group how they think about the difference between these two things. Following this, the group worked to think about their original idea of concentration and number of molecules being the same and the LA's idea that there was a difference. One student shared, "I guess I get a little bit confused on that. I didn't necessarily think there was a difference at first between the concentration and the net amount, but that could change things. It's a possibility."
	With student idea(s)	Grappling of this kind occurs when students work towards making sense of an idea introduced by another student or one of their own ideas. It is typically an idea they have not thought about explicitly in depth yet, and they are working to understand it and incorporate it into their reasoning for the first time. It is typical for this type of grappling that students ask questions about the student idea, express confusion about the student idea, or think critically about the student idea	The students were discussing if and how they could use the force vectors in the dot product to calculate work, and the LA followed up to ask about their idea. One student replied, "Um, I think I was just trying to like memorize when the vectors were, like what orientation the vectors had to be in for it to be zero. But I think I memorized it incorrectly, and then now I'm like confused, cause I'm trying to think about—"

Table 5 (continued)

Impact codes	Impact subcodes	Definition	Example quotes and background
Reach closure	Epistemologically	This type of closure occurs when a student need is recognized as existing by the LA, but the idea is moved on from and not discussed further. This typically occurs when an LA provides encouragement that the group is making progress, when an LA acknowledges students struggling with a concept, or when an LA acknowledges that students did not receive an answer to their question or time to finish discussing	Students were going back and forth with many ideas and did not come to any conclusions. The LA acknowledged that they had good reasoning in any case, and says, "Okay. Sounds like we have a better understanding, at least" to which the student replied, "That's what I'm saying."
	Student satisfied with how LA understands them	This type of closure occurs when students' express agreement with how the LA understands them. This typically occurs when an LA repeats back or clarifies what the students said, and the group agrees that the LA was following along and understanding them correctly so the group can move on to think about other ideas	The students were discussing two separate, opposing arguments. The LA repeated back these ideas to see if she was following both by asking, "so it seems like you guys are sort of torn, whereas in the first scenario, if the PE is all translated to KE, it seems as though it would be equal, because you have half the height twice. So then it would be like half mgh plus half mgh equals mgh, which is the same as scenario one. So I think that's one argument. And then if I'm understanding you guys correctly, the other one is that if you're starting from a higher height, like is it a way that the acceleration sort of acts on that longer time that would change the velocity more, which would lead to a bigger KE? Is that the other argument?". The students affirmed, "yeah. Yes."
	LA confirming correctness	This type of closure occurs when the LA confirms that students are correct. This typically occurs when the LA is satisfied with the students' response so the group can move on to think about other ideas	The student worked to balance an equation, and once she stated the coefficients that she came up with, the LA confirmed by saying, "you're right!" and "that's all there is to the problem."
	LA explanation	This type of closure occurs when insight from the LA is shared that rounds out a gap. This typically occurs when an LA provides an explanation, insight into the problem-solving process, or answers a student question so the group can move on to think about other ideas	The group discussed the way molecules would collide effectively in a problem where molecules were represented by colored spheres. The LA addressed their question about the collision by explaining, "Yeah. The purple on this guy, that I have highlighted on the top [clicks on the purple atom of the first molecule in the top step 1], right, becomes more strongly attracted to this group of atoms. So when it slides, it ends up sticking onto that guy [moves the same purple atom to the second molecule onto the blue atom]. It's a different shape, but you know what I mean? I mean, cause that one probably moves over and makes room. That guy gets stuck there."

Table 5 (continued)

Impact codes	Impact subcodes	Definition	Example quotes and background
	Group consensus	This type of closure occurs when students reach agreement about an idea. This consensus might only be explicit for a few members of the group and implicit for others. If no one outwardly disagrees, pragmatically the group has reached consensus, so the group can move on to think about other ideas	The LA wondered if all students agreed with student Cheki's idea, and one student said, "Yeah, it makes a lot of sense." So, the LA followed up with another student, and they said, "That was a good example, that Cheki said."
Share ideas & reasoning	Share an alternative way of thinking	This occurs when there is already one line of reasoning about a specific topic and students share other ways of thinking about this. This typically occurs when students share a different but related line of reasoning, or when students share an opposing line of reasoning that contrasts the current idea	Students were addressing the acidity of two different protons on hydroxyl groups on a molecule. They were mainly discussing electronegativity as the reason for induction. Following the LA's question that inquired about more thoughts, one student shared a different idea, "I think that might also be something to do with the double, the fact that for the hydroxyl group on the left side, that carbon is attached, is double bonded to an alkyl group, versus the hydroxyl on the right side, there's no double bond affiliated with that hydroxyl group. So I think that could contribute more to like the withdrawing impact of the alkyl group."
	Build on the same way of thinking/justify way of thinking (includes repeating back ideas)	This occurs when there is an idea being discussed and students continue to build on that same idea. This typically occurs when students expand upon, build upon, or justify an earlier thought, share additional insight to where they were coming from, explain why they said something, or share more about their problem-solving process	The group was considering how the direction of a ball moving horizontally would change after a sideways hit from a mallet. Throughout their discussion, they hinted at there being three vectors horizontally and one vector downward, so the LA followed up on this and asked the group how they would account for the three to one vector ratio. Following the LA's question, one student talked about vector addition explicitly, "I think that if you're trying to think about it in terms of vector addition, you could deal with that by like my instinct is just to make the magnitude of this vector greater" and the group continued to reason about vector addition
	Share a new idea or wondering	This occurs when students share a new idea or wondering and they leave the current gap to explore this new idea. This typically occurs when a student asks a question about an idea they have for the first time	The LA suggested the students consider a different argument, one about the multi-particle level, while discussing entropy and enthalpy. One student in the group started wondering about when to look at this level. "So is a multi-particle, like you should always look at that first?"
	Answer LA question (stepwise manner)	This occurs when a student directly answers the LA's question only. This typically occurs when students respond to questions with short, simple answers in a Socratic manner	The LA was working to correct the students' drawing of a molecule and asked how many bonds carbon can make, to which two students responded, "four."

Table 5 (continued)

Impact codes	Impact subcodes	Definition	Example quotes and background
Revisit/reconsider earlier need	Reconsider an old need in light of new information	This occurs when the students revisit a lingering gap in the discussion and work towards discussing it again using the insight they have gained from the other parts of their conversation. This typically occurs when either an LA directs students to do so, or students recognize the relevance of new ideas towards lingering needs	The group finished discussing which direction a reaction will proceed towards and reached a consensus that it would be product-favored. The LA followed up and asked, "So – [pause] Yeah. What does that tell you then about the potential energy in this diagram?" to which multiple students gave responses including, "It's pretty low.", "Yeah. The difference between the potential energy of the two sides, like the reactants and the products, is quite different, especially compared to step one. So are you redrawing it?", "Yeah. I'm just redrawing it to accommodate that."
	Think through an old need further	This occurs when the students re-notice a previously opened gap and attend to it further in a way that does not explicitly draw on pieces they have used for other gaps throughout the conversation. This typically occurs when either an LA asks students to do so or when students go back towards an old need on their own	Students discussed a problem that had two cases and they were asked to think about which one had more torque and angular acceleration. Student Graph shared a thought that the group quickly moved away from. Later in the discussion, the LA asked, "Wait, so Graph, you're saying that intuitively, you thought case one, like this was like one of your first thoughts that you mentioned. Intuitively you thought case one would have more, were you saying torque or angular acceleration?". The group then worked to address this need for the rest of the conversation
Students do not engage with the move	No student response	This occurs when the group does not engage with the LA utterance	Student Ellie was not participating as much as others, and when they did contribute to the discussion the LA followed up on this contribution by asking, "Could you explain that a little more, Ellie?" to which the student did not respond because others were talking over them

The examples provided give some context into the LA–student discussion needed to follow the progression of learning, alongside relevant LA and student quotes to demonstrate the impact.

Table 6 Socioemotional action codes, definitions, and examples

Action codes	Definition	LA quote examples
Purposefully bring quiet student(s) in	The LA intentionally invites students who have not been as vocal in the discussion to contribute to the conversation in some capacity. This typically occurs when an LA centers these students either explicitly with their language or implicitly with the direction of their attention, inviting these students to participate	"And Lavender and Lemon you guys both agree?"
Talking to one student	The LA attempts to hear more of one student's thought. Rather than directing their comment or question to bring in a quiet student, these moves are typically directed towards one student that is participating vocally in the discussion. This typically occurs when an LA says the student's name explicitly to address them and invite their thoughts in or follows up on an idea mentioned by one student to hear more about it or clarify their understanding of it	"JC, you said step one reached transition state. What do you mean by that?"
Validation/acknowledgement	The LA shares their gratefulness and appreciation for the students' participation. This move signifies that the LA is listening to the students' contributions to the discussion and that they value the students' ideas. The LA often uses aesthetic pieces that epistemologically recognize students' needs, their contributions to these needs, and their participation. This often occurs when an LA confirms correctness of the students' responses and includes some sort of addition beyond the confirmation of correctness, e.g., "exactly", "cool", "that totally makes sense", or any other time an LA uses this type of language in their utterance	"That's so fair. Thanks for sharing."
Empathizing with students/vulnerable	The LA relates to the students and their struggles. This typically occurs when an LA resonates with students' expression of confusion or doubt by sharing their own struggles as a student or by recognizing the difficulties students are facing	"I will fully admit I am [confused] as well."
Inviting/inclusive language	The LA attempts to hear more of a group's thoughts. This typically occurs when an LA addresses more than one student or the whole group to share their thoughts using open and inclusionary language, e.g., "anyone,""you all."	"So what's going on with the far-right carbon? Can anybody tell me?"
Create space that allows for rejection/no participation	The LA creates an environment where it is explicitly known to the group that they have the agency to not participate or contribute anything to the current discussion if they do not feel comfortable doing so. This typically occurs when an LA provides the students with a choice of whether they want to continue with the same topic being discussed or if they want to change the ideas centered in the conversation	"Does anyone want to take a stab at that? If not, it's fine."

The quotes provided are from LAs and demonstrate one way each action could occur

Table 7 Socioemotional impact codes, definitions, and examples

Impact codes	Definition	Example quotes and background
Less participation	Less students participating is a shift in who is sharing or contributing their ideas into the discussion. This occurs when a discussion involving multiple students or the whole group turns into a discussion involving fewer students, or when one student becomes the sole participant and the discussion now centers around their ideas and contributions	Three students, Sun, Water, and Bean were discussing how they thought different molecules would orient and how they would collide. LA Ruthie joins into the discussion and provides an explanation to the group to round out their ideas about the collision. Following this LA move, Water takes over the conversation sharing their ideas as the main participant
Students choose not to participate	Students choosing not to participate is when students actively choose to not share thoughts or contribute to the discussion in any verbal capacity. This occurs either when students do not speak or say they would not like to share after an attempt by the LA to bring them explicitly into the discussion	Students were working on a two-part problem, where they were asked to compare kinetic and potential energy of two different carts going down a ramp from different heights. Almost all students in the group were collaborating in their sense-making, besides one student, Acadia. The LA asked, "Acadia, do you happen to have any thoughts on this? No worries if not." The student responded, "No, not really."
Fostering participation	More students participating or collaborating is when there is more participation from someone or from multiple students in the group who were not participating right before this point in the interaction. This occurs when a non-dominant student speaks or when any additional group member(s) speaks. Other times this impact is seen through collaboration—that is when students shift towards working with one another opposed to just talking back and forth with the LA	Students were discussing if the friction force of the road a car is driving up with constant speed does work on the car. One student, Bank, starts the discussion by sharing their thoughts and shared a counter example to further back up their thoughts. The LA turned to the group and asked, "Wow. Okay. I like a lot that you kind of like thought about a counterexample and then tried to negate it as well all at one. What about you? Do you agree with this, or do you want to try and find another counterexample?" In response, student Kiwi shared that they agreed with some parts of Bank's reasoning, but not all, and went on to share their own ideas. Bank joined in and the students went back and forth with one another to discuss their ideas
Dominance continues	Dominance continues when a small subset of students in a group continue to present their ideas to the group/LA and hold the most space in the group discussion relative to the other students in the group. This occurs when a student or two are at the center of the discussion and continue talking compared to the majority of the group who is listening	Students were discussing what would happen to the electromagnetic field (EMF) if they moved a magnet into and out of a solenoid. One student, Yzma, was sharing a lot of their ideas to the group. The LA followed up on one of their ideas and asked, "Okay, so what I'm hearing, and I just want to know if I'm echoing you [Ymza] correctly, is like you're saying that…" to which Ymza continued sharing reasoning
Lighthearted conversation	Lighthearted conversation is when the discussion amongst the group shifts from being only content centered to being more relaxed, laid-back, and friendly. This occurs when there is laughter, giggling, smiling, and making jokes with one another	Students were comparing the difference in torque between two cases where the force around the rotation axis was different. After discussing the equation for torque to help them think through the question, the group turned their attention to student Vega who had a drawing to show her reasoning. The group turns their attention to the drawing and the LA says, "Yes. It's [the drawing] beautiful. Incredible [group all laughs]."

The examples provided give some context into the LA–student discussion needed to follow the progression of learning, alongside relevant LA and student quotes to demonstrate the impact

Table 8 Chi-squared and post-hoc test results for authoritative and dialogic LA actions and conceptual impacts

	χ^2	df	p-value	Authoritative	Dialogic	Critical threshold
Conceptual Impact	22.20	4	*p* < .005	St. res. (Obs. freq.)	St. res. (Obs. freq.)	−2.81
Increase grappling				0.95 (86)	−0.95 (27)	
Reach closure				1.86 (155)	−1.86 (45)	
Share ideas and reasoning				−0.24 (283)	0.24 (110)	
Revisit an earlier need				−1.71 (59)	1.71 (32)	
Do not engage				**−4.05** (2)	**4.05** (9)	

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and conceptual impacts. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for authoritative and dialogic actions and increase grappling, reach closure, share ideas and reasoning, revisit an earlier need, and do not engage. Bolded values are those that are significant based on our selected significance value of p < .05 (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Table 9 Chi-squared and post-hoc test results for authoritative and dialogic LA actions and increase grappling

	χ^2	df	p-value	Authoritative	Dialogic	Critical threshold
Increase Grappling	**74.71**	2	*p* < .001	St. res. (Obs. freq.)	St. res. (Obs. freq.)	−2.64
Grappling with student idea				**−8.56** (4)	**8.56** (23)	
Grappling with student and LA idea				2.18 (32)	−2.18 (4)	
Grappling with LA idea				**5.31** (50)	**−5.31** (0)	

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and increase grappling. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for authoritative and dialogic actions and grappling with student idea, grappling with student and LA idea, grappling with LA idea. Bolded values are those that are significant based on our selected significance value of p < .05 (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Table 10 Chi-squared and post-hoc test results for authoritative and dialogic LA actions and reach closure

	χ^2	df	p-value	Authoritative	Dialogic	Critical Threshold
Reach Closure	**114.36**	4	*p* < .001	St. res. (Obs. freq.)	St. res. (Obs. freq.)	
Student satisfied with LA understanding				**−3.70** (3)	**3.70** (7)	−2.81
Epistemologically				**−7.63** (5)	**7.63** (21)	
Group consensus				**−4.07** (18)	**4.07** (17)	
LA confirming correctness				**6.03** (78)	**-6.03** (0)	
LA explanation				**4.52** (52)	**−4.52** (0)	

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and reach closure. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for authoritative and dialogic actions and student satisfied with LA understanding, epistemologically, group consensus, LA confirming correctness, LA explanation. Bolded values are those that are significant based on our selected significance value of p < .05 (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Table 11 Chi-squared and post-hoc test results for authoritative and dialogic LA actions and share ideas and reasoning

	χ^2	df	p-value	Authoritative	Dialogic	Critical Threshold
Share Ideas and Reasoning	**95.45**	3	*p* < .001	St. res. (Obs. freq.)	St. res. (Obs. freq.)	
Build on way of thinking/justify reasoning				**−9.48** (52)	**9.48** (75)	−2.73
Share an alternative way of thinking				−1.40 (4)	1.40 (4)	
Share a new idea/wondering				1.77 (25)	−1.77 (4)	
Answer LA question				**8.45** (202)	**−8.45** (27)	

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and share ideas and reasoning. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for authoritative and dialogic actions and build on way of thinking/justify reasoning, share an alternative way of thinking, share a new idea/wondering, answer LA question. Bolded values are those that are significant based on our selected significance value of p < .05 (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Table 12 Chi-squared test results for authoritative and dialogic LA actions and revisit an earlier need

	χ^2	df	p-value	Authoritative	Dialogic
Revisit an Earlier Need	3.26	1	*p* < .8	Obs. freq	Obs. freq
Revisit an old need in light of new info				40	21
Thinking through old need further				14	18

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and revisit an earlier need. This result was not significant based on our significance value of p < .05, so further post-hoc testing was not necessary. Observed frequencies (Obs. freq.) are reported on the right side of the table

Table 13 Chi-squared and post-hoc test results for authoritative and dialogic LA actions and socioemotional impacts

	χ^2	df	p-value	Authoritative	Dialogic	Critical Threshold
Socioemotional Impact	**25.24**	4	*p* < .001	St. res. (obs. freq.)	St. res. (obs. freq.)	
Less participation				−0.05 (48)	0.05 (29)	−2.81
Dominance continues				**3.24** (138)	**−3.24** (50)	
Fostering participation				−1.47 (99)	1.47 (65)	
Students choose not to participate				0.35 (7)	−0.35 (3)	
Lighthearted conversation				**−4.24** (2)	**4.24** (13)	

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and socioemotional impacts. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for authoritative and dialogic actions and less participation, dominance continues, fostering participation, students choose not to participate, lighthearted conversation. Bolded values are those that are significant based on our selected significance value of p < .05 (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Table 14 Chi-squared test results for authoritative and dialogic LA actions and socioemotional actions

	χ^2	df	p-value	Authoritative	Dialogic
Socioemotional Actions	4.72	4	*p* < .32	Obs. freq	Obs. freq
Talking to one student				107	66
Bring in quiet student				10	11
Inviting/inclusive language				69	49
Validation/acknowledgment				94	55
Empathizing/vulnerable				17	19

The left side of the table shows the omnibus chi-squared test results calculated in R for authoritative and dialogic LA actions and socioemotional actions. This result was not significant based on our significance value of p < .05, so further post-hoc testing was not necessary. Observed frequencies (Obs. freq.) are reported on the right side of the table

Table 15 Chi-squared and post-hoc test results for socioemotional LA actions and socioemotional impacts

	χ^2	df	p-value	Talking to one student	Bring in quiet student	Inviting/ inclusive language	Validation/ acknowledgment	Empathizing/ Vulnerable	Critical Threshold
Socioemotional Impact	**119.20**	16	$p < .001$	St. res. (obs. freq.)	St. res. (obs. freq.)	St. res. (obs. freq.)	St. res. (obs. freq.)	St. res. (obs. freq.)	
Less participation				2.20 (32)	−2.01 (0)	−1.26 (11)	−0.50 (15)	0.46 (6)	−3.09
Dominance continues				**6.01** (86)	−**3.10** (1)	−**5.16** (14)	0.13 (40)	−0.40 (11)	
Fostering participation				−**5.55** (33)	**3.24** (15)	**6.01** (62)	−0.70 (38)	−0.95 (10)	
Students choose not to participate				−2.38 (2)	**4.50** (5)	1.60 (7)	−0.37 (4)	−1.27 (0)	
Lighthearted conversation				−2.19 (4)	−1.16 (0)	−1.29 (3)	2.28 (11)	**3.19** (6)	

The left side of the table shows the omnibus chi-squared test results calculated in R for socioemotional LA actions and socioemotional impacts. The right side of the table shows the results from the post-hoc tests using the calculating residuals method; standardized residuals (St. res.) calculated in R for socioemotional actions (i.e., talking to one student, bring in quiet student, inviting/inclusive language, validation/acknowledgment, and empathizing/vulnerable) and less participation, dominance continues, fostering participation, students choose not to participate, lighthearted conversation. Bolded values are those that are significant based on our selected significance value of $p < .05$ (omnibus test) and the Bonferroni-adjusted p-value for the critical threshold (post-hoc test). Observed frequencies (Obs. freq.) are reported in parenthesis next to the standardized residuals

Abbreviations

STEM Science, technology, engineering, and mathematics
LA Learning assistant
FAEM Formative assessment enactment model
PEA Practical epistemology analysis

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Author contributions

ICG initiated and designed the overall study. NMM designed the specific investigations presented in this manuscript. NMM, KLL, and ICG all contributed to data collection. All authors engaged in data analysis. NMM, KPP, and ICG interpreted the findings. NMM wrote this manuscript and ICG revised it. All authors read and approved the final manuscript.

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Availability of data and materials

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

Declarations

Ethics approval and consent to participate

Ethical approval was received from the Tufts University Institutional Review Board (IRB # 00000765) and the University of Massachusetts – Boston Institutional Review Board (IRB # 2020176). Participants provided electronic consent via an online Qualtrics form.

Consent for publication

N/A. Consent was provided via the IRB-approved consent process, no identifiable information is included.

Competing interests

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References

Alzen, J. L., Langdon, L. S., & Otero, V. K. (2017). The learning assistant model and dfw rates in introductory physics courses. *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2017.pr.004

Alzen, J. L., Langdon, L. S., & Otero, V. K. (2018). A logistic regression investigation of the relationship between the learning assistant model and failure rates in introductory STEM courses. *International Journal of STEM Education, 5*(1), 56. https://doi.org/10.1186/s40594-018-0152-1

Auby, H., & Koretsky, M. D. (2023). Analysis of learning assistants beliefs of status and their role as status interventionists. *American Society for Engineering Education Annual Conference & Exposition, Baltimore, MD.* https://doi.org/10.18260/1-2-42655

Barrasso, A. P., & Spilios, K. E. (2021). A scoping review of literature assessing the impact of the learning assistant model. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-020-00267-8

Beasley, T. M., & Schumacker, R. E. (1995). Multiple regression approach to analyzing contingency tables: post hoc and planned comparison procedures. *The Journal of Experimental Education, 64*(1), 79–93. https://doi.org/10.1080/00220973.1995.9943797

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education, 85*(5), 536–553. https://doi.org/10.1002/sce.1022

Breland, H., Clark, C. M., Shaked, S., & Paquette-Smith, M. (2023). The benefits of participating in a learning assistant program on the metacognitive awareness and motivation of learning assistants. *CBE—Life Sciences Education, 22*(3), 30. https://doi.org/10.1187/cbe.22-08-0156

Campbell, J. L., Quincy, C., Osserman, J., & Pedersen, O. K. (2013). Coding in-depth semistructured interviews: problems of unitization and intercoder reliability and agreement. *Sociological Methods & Res., 42*, 294–320.

Cao, Y., Smith, C., Lutz, B., & Koretsky, M. (2018). Cultivating the next generation: outcomes from a learning assistant program in engineering. *ASEE Annual Conference & Exposition, Salt Lake City, UT*. https://doi.org/10.48550/arXiv.1807.04838

Caravez, D., De La Torre, A., Nissen, J., & Van Dusen, B. (2017). Longitudinal associations between learning assistants and instructor effectiveness. *arXiv Preprint*. https://doi.org/10.48550/arXiv.1711.05834

Carlos, C. M. L., Maggiore, N. M., Dini, V., & Caspari-Gnann, I. (2023). Characterizing facilitation practices of learning assistants: an authoritative-to-dialogic spectrum. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-023-00429-4

Chin, C. (2007). Classroom interaction in science: teacher questioning and feedback to students' responses. *International Journal of Science Education, 28*(11), 1315–1346. https://doi.org/10.1080/09500690600621100

Clements, K. A., Zepeda, C. D., Leich Hilbun, A., Todd, T., Clements, T. P., Johnson, H. J., Watkins, J., Friedman, K. L., & Brame, C. J. (2023). "They have shown me it is possible to thrive within STEM": incorporating learning assistants in general chemistry enhances student belonging and confidence. *Journal of Chemical Education, 100*(11), 4200–4211. https://doi.org/10.1021/acs.jchemed.2c01224

Clements, T. P., Friedman, K. L., Johnson, H. J., Meier, C. J., Watkins, J., Brockman, A. J., & Brame, C. J. (2022). "It made me feel like a bigger part of the STEM community": incorporation of learning assistants enhances students' sense of belonging in a large introductory biology course. *CBE-Life Sciences Education*. https://doi.org/10.1187/cbe.21-09-0287

Close, E. W., Close, H. G., & Donnelly, D. (2013). Understanding the learning assistant experience with physics identity. *In AIP Conference Proceedings, 1513*(1), 106–109. https://doi.org/10.1063/1.4789663

Close, E. W., Conn, J., & Close, H. G. (2016). Becoming physics people: development of integrated physics identity through the learning assistant experience. *Physical Review Physics Education Research*. https://doi.org/10.1103/PhysRevPhysEducRes.12.010109

Conn, J., Close, E. W., & Close, H. G. (2014). Learning assistant identity development: is one semester enough? *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2014.pr.010

Creswell, J. W., & Miller, D. L. (2000). Determining validity in qualitative inquiry. *Theory into Practice, 39*(3), 124–130. https://doi.org/10.1207/s15430421tip39032

Davenport, F., Amezcua, F., Sabella, M. S., & Van Duzor, A. G. (2017). Exploring the underlying factors in learning assistant-faculty partnerships. *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2017.pr.021

Dini, V., Sevian, H., Caushi, K., & Orduña Picón, R. (2020). Characterizing the formative assessment enactment of experienced science teachers. *Science Education, 104*(2), 290–325. https://doi.org/10.1002/sce.21559

Donis, K., Aikens, M. L., Swamy, U., Delgado, M., Gillespie, M., Graves, P., & Eddy, S. L. (2024). Learning assistants and instructors provide social support that influences student engagement differently in undergraduate active leaning chemistry courses. *Journal of Chemical Education, 101*(8), 2989–3002. https://doi.org/10.1021/acs.jchemed.3c01137

Engeström, Y. (1999). Activity theory and individual and social transformation. In Y. Engeström, R. Miettinen, & R. L. Punamäki (Eds.), *Perspectives on Activity Theory* (pp. 19–38). Cambridge: Cambridge University Press.

Ferrari, B. A., Dees, J. A., Armstrong, N. A., & Kittleson, J. M. (2023). Exploring peer learning assistants' impact on student performance and perceptions in an undergraduate biology course. *Journal of College Science Teaching*. https://doi.org/10.1080/0047231X.2023.12315862

Flaherty, A. A. (2020). A review of affective chemistry education research and its implications for future research. *Chemistry Education Research and Practice, 21*(3), 698–713. https://doi.org/10.1039/c9rp00200f

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the USA, 111*(23), 8410–8415.

Freire, P. (2000). *Pedagogy of the oppressed* (M. B. Ramos, Trans.; 30th anniversary ed). Continuum.

Goertzen, R. M., Brewe, E., Kramer, L. H., Wells, L., & Jones, D. (2011). Moving toward change: institutionalizing reform through implementation of the learning assistant model and open source tutorials. *Physical Review Special Topics - Physics Education Research*. https://doi.org/10.1103/PhysRevSTPER.7.020105

Hamerski, P. C., Irving, P. W., & McPadden, D. (2021). Learning assistants as student partners in introductory physics. *Physical Review Physics Education Research*. https://doi.org/10.1103/PhysRevPhysEducRes.17.020107

Hernandez, D., Jacomino, G., Swamy, U., Donis, K., & Eddy, S. L. (2021). Measuring supports from learning assistants that promote engagement in active learning: evaluating a novel social support instrument. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-021-00286-z

Herrera, X., Nissen, J., & Van Dusen, B. (2018). Student outcomes across collaborative-learning environments. *In Physics Education Research Conference Proceedings*. https://doi.org/10.48550/arXiv.1808.07076

Hill, C. J., Barrasso, A. P., & Spilios, K. E. (2023). A mixed-methods analysis of perspectives toward learning assistant-faculty relationships. *Journal of College Science Teaching*. https://doi.org/10.1080/0047231X.2023.12290703

Hite, R., Johnson, L., Velasco, R. C. L., Williams, G. B., & Griffith, K. (2021). Supporting undergraduate STEMM education: perspectives from faculty mentors and learning assistants in calculus II. *Education Sciences*. https://doi.org/10.3390/educsci11030143

Indukuri, S., & Quan, G. M. (2022). Characterizing the feedback that learning assistants give to faculty. *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2022.pr.Indukuri

Jackson, A. Y., & Mazzei, L. A. (2013). Plugging one text into another. *Qualitative Inquiry, 19*(4), 261–271. https://doi.org/10.1177/1077800412471510

Jardine H. E. (2019). *Instructional Partnerships Between Science Faculty and Undergraduate Teaching and Learning Assistants: Implications for Formative Assessment* [Doctoral dissertation, University of Maryland]. https://drum.lib.umd.edu/handle/1903/22109

Jardine, H. E. (2020). Positioning undergraduate teaching and learning assistants as instructional partners. *International Journal for Students as Partners, 4*(1), 48–65. https://doi.org/10.15173/ijsap.v4i1.4032

Karch, J. M., & Caspari-Gnann, I. (2022). Student in-the-moment learning in LA-facilitated interactions in undergraduate chemistry and physics courses. *Presentation at NARST 95th Annual International Conference,* Vancouver, BC.

Karch, J. M., Maggiore, N. M., Pierre-Louis, J., Strange, D., Dini, V., & Caspari-Gnann, I. (2024). Making in-the-moment learning visible: the development of a framework to identify and compare various ways of learning through continuity and discourse change. *Science Education, 108*(5), 1292–1328. https://doi.org/10.1002/sce.21874

Karch, J. M., Mashhour, S., Koss, M. P., & Caspari-Gnann, I. (2024). Expansive learning in the learning assistant model: how instructors' goals lead to differences in implementation and development of LAs' practices. *International Journal of STEM Education*. https://doi.org/10.1186/s40594-024-00496-1

Kiste, A. L., Scott, G. E., Bukenberger, J., Markmann, M., & Moore, J. (2017). An examination of student outcomes in studio chemistry. *Chemistry Education Research and Practice, 18*(1), 233–249. https://doi.org/10.1039/c6rp00202a

Knight, J. K., Wise, S. B., Southard, K. M., & Dirks, C. A. (2013). Understanding clicker discussions: student reasoning and the impact of instructional cues. *CBE-Life Sciences Education, 12*(4), 645–654. https://doi.org/10.1187/cbe.13-05-0090

Knight, J. K., Wise, S. B., Rentsch, J., & Furtak, E. M. (2015). Cues matter: learning assistants influence introductory biology student interactions during clicker-question discussions. *CBE-Life Sciences Education*. https://doi.org/10.1187/cbe.15-04-0093

Koretsky, M. D., Montfort, D., Nolen, S. B., Bothwell, M., Davis, S., & Sweeney, J. (2018). Towards a stronger covalent bond: pedagogical change for inclusivity and equity. *Chemical Engineering Education, 52*(2), 117–127.

Kornreich-Leshem, H., Benabentos, R., Hazari, Z., Potvin, G., & Kramer, L. (2022). The cognitive and affective roles of learning assistants in science, technology, engineering, and mathematics college classrooms: an exploration of classroom experiences and students' metacognitive awareness and disciplinary identity. *Science Education, 106*(3), 545–572.

LA Alliance (2024). Retrieved September 14, 2024, from https://www.learningassistantalliance.org/

Lumivero (2020). *NVivo* (Version 13, 2020 R1). www.lumivero.com

Maggiore, N. M., Karch, J. M., & Caspari-Gnann, I. (2023). Facilitation Practices of Learning Assistants in a Synchronous Hybrid Course. *Presentation at NARST 96th Annual International Conference*, Chicago, IL.

McHenry, N., Martin, A., Castaldo, A., & Ziegenfuss, D. (2009). Learning assistant program- faculty development for conceptual change. *International Journal of Teaching and Learning in Higher Education, 22*(3), 258–268.

Meade, P., & McMeniman, M. (1992). Stimulated recall—an effective methodology for examining successful teaching in science. *Australian Educational Researcher, 19*(3), 1–18.

Miller, P. M., Carver, J. S., Shinde, A., Ratcliff, B., & Murphy, A. N. (2013). Initial replication results of learning assistants in university physics. *In AIP Conference Proceedings, 1513*(1), 30–33. https://doi.org/10.1063/1.4789644

Mooring, S. R., Mitchell, C. E., & Burrows, N. L. (2016). Evaluation of a flipped, large-enrollment organic chemistry course on student attitude and achievement. *Journal of Chemical Education, 93*(12), 1972–1983. https://doi.org/10.1021/acs.jchemed.6b00367

Mortimer, E., & Scott, P. (2003). *Meaning making in secondary science classrooms*. United Kingdom: Open University Press.

Otero, V., Finkelstein, N., McCray, R., & Pollock, S. (2006). Who is responsible for preparing science teachers? *Science, 313*(5786), 445–446. https://doi.org/10.1126/science.1129648

Otero, V., Pollock, S., & Finkelstein, N. (2010). A physics department's role in preparing physics teachers: the Colorado learning assistant model. *American Journal of Physics, 78*(11), 1218–1224. https://doi.org/10.1119/1.3471291

Pak, A., Mangini, M., Green, C., & Sikorski, T. R. (2018). Talk moves, argumentation, and questioning patterns in LA-supported group problem solving. *In Physics Education Research Conference Proceedings., 305*, 1842–2590.

Philip, T. M., Bang, M., & Jackson, K. (2018). Articulating the "how", the "for what", the "for whom", and the "with whom" in concert: a call to broaden the benchmarks of our scholarship. *Cognition and Instruction, 36*(2), 83–88. https://doi.org/10.1080/07370008.2018.1413530

Ponterotto, J. (2015). Brief note on the origins, evolution, and meaning of the qualitative research concept thick description. *The Qualitative Report*. https://doi.org/10.46743/2160-3715/2006.1666

R Core Team. (2024). *R: A language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing.

Roth, W.-M., & Lee, Y.-J. (2007). "Vygotsky's neglected legacy": cultural-historical activity theory. *Review of Educational Research, 77*(2), 186–232. https://doi.org/10.3102/0034654306298273

Sabella, M. S., Van Duzor, A. G., & Davenport, F. (2016). Leveraging the expertise of the urban STEM student in developing an effective LA Program: LA and instructor partnerships. *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2016.pr.067

Saldaña, J. (2013). *The Coding Manual for Qualitative Researchers* (2nd ed.). SAGE: Washington DC.

Schick, C. P. (2018). Trying on Teaching: transforming STEM classrooms with a learning assistant program. *Strategies Promoting Success of Two-Year College Students ACS Symposium Series, 1280*, 3–27. https://doi.org/10.1021/bk-2018-1280.ch001

Scott, P. H., Mortimer, E. F., & Aguiar, O. G. (2006). The tension between authoritative and dialogic discourse: A fundamental characteristic of meaning making interactions in high school science lessons. *Science Education, 90*, 605–631. https://doi.org/10.1002/sce.20131

Sellami, N., Shaked, S., Laski, F. A., Eagan, K. M., & Sanders, E. R. (2017). Implementation of a learning assistant program improves student performance on higher-order assessments. *CBE-Life Sciences Education*. https://doi.org/10.1187/cbe.16-12-0341

Sempértegui, T. S., Bebergal, J. L., & Adelmann, B. J. (2022). Piloting the learning assistant (LA) Model in a Large lecture general chemistry course. *Learning Assistance Review (TLAR), 27*(1), 79–114.

Sharpe, D. (2019). Chi-square test is statistically significant: now what? *Practical Assessment, Research, and Evaluation*. https://doi.org/10.7275/tbfa-x148

Sherin, M. G., & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of Technology and Teacher Education, 13*(3), 475.

Stuopis, I. R. (2023). *Learning assistants in undergraduate mechanical engineering: goals, discourse, and community* [Doctoral dissertation, Tufts University].

Stuopis, I., & Wendell, K. B. (2023). *Work in Progress: using the formative assessment enactment model to characterize instructor moves in a learning-assistant supported mechanics course*. Baltimore, MD: American Society for Engineering Education.

Suárez, E., Quan, G., Hammer, D., & Atkins, L. (2023). Learning in interaction: interacting scales of research. In L. Heron (Ed.), *The international handbook of physics education research learning physics* (pp. 13–32). New York: AIP Publishing LLCMelville New York.

Talbot, R. M., Hartley, L. M., Marzetta, K., & Wee, B. S. (2015). Transforming undergraduate science education with learning assistants: Student satisfaction in large-enrollment courses. *Journal of College Science Teaching, 44*(5), 24–30.

Theobald, E. J., Hill, M. J., Tran, E., Agrawal, S., Arroyo, E. N., Behling, S., Chambwe, N., Cintron, D. L., Cooper, J. D., Dunster, G., Grummer, J. A., Hennessey, K., Hsiao, J., Iranon, N., Jones, L., 2nd., Jordt, H., Keller, M., Lacey, M. E., Littlefield, C. E., & Freeman, S. (2020). Active learning narrows achievement gaps for underrepresented students in undergraduate science, technology, engineering, and math. *Proceedings of the National Academy of Sciences of the USA, 117*(12), 6476–6483. https://doi.org/10.1073/pnas.1916903117

Thompson, M. M., & Garik, P. (2015). The effect of learning assistants on student learning outcomes and satisfaction in large science and engineering courses. *Presentation at NARST 88th Annual International Conference,* Chicago, IL.

Thompson, A. N., Talbot, R. M., Doughty, L., Huvard, H., Le, P., Hartley, L., & Boyer, J. (2020). Development and application of the action taxonomy for learning assistants (ATLAs). *International Journal of STEM Education*. https://doi.org/10.1186/s40594-019-0200-5

Top, L. M., Schoonraad, S. A., & Otero, V. K. (2018). Development of pedagogical knowledge among learning assistants. *International Journal of STEM Education, 5*(1), 1. https://doi.org/10.1186/s40594-017-0097-9

Van Dusen, B., Langdon, L., & Otero, V. (2015). Learning assistant supported student outcomes (LASSO) study initial findings. *In Physics Education Research Conference Proceedings*. https://doi.org/10.1119/perc.2015.pr.081

Van Dusen, B., & Nissen, J. (2017). Systemic inequities in introductory physics courses: the impacts of learning assistants. *In Physics Education Research Conference Proceedings*. https://doi.org/10.48550/arXiv.1711.05836

Van Dusen, B., & Nissen, J. (2020). Associations between learning assistants, passing introductory physics, and equity: A quantitative critical race theory investigation. *Physical Review Physics Education Research*. https://doi.org/10.1103/PhysRevPhysEducRes.16.010117

Van Es, E. A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Of Technology and Teacher Education., 10*(4), 571–596.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes*. Harvard: Harvard University Press.

Watts, F. M., & Finkenstaedt-Quinn, S. A. (2021). The current state of methods for establishing reliability in qualitative chemistry education research articles. *Chemistry Education Research and Practice, 22*(3), 565–578. https://doi.org/10.1039/d1rp00007a

Wertsch, J. V. (1993). *Voices of the mind: sociocultural approach to mediated action*. Harvard: Harvard University Press.

White, J.-S.S., Van Dusen, B., & Roualdes, E. A. (2016). The impacts of learning assistants on student learning of physics. *In Physics Education Research Conference Proceedings*. https://doi.org/10.48550/arXiv.1607.07469

Wickman, P.-O. (2004). The practical epistemologies of the classroom: A study of laboratory work. *Science Education, 88*(3), 325–344. https://doi.org/10.1002/sce.10129

Wickman, P.-O. (2006). *Aesthetic experience in science education: learning and meaning-making as situated talk and action*. Oxfordshire: Routledge.

Wickman, P.-O., & Östman, L. (2002). Learning as discourse change: A sociocultural mechanism. *Science Education, 86*(5), 601–623. https://doi.org/10.1002/sce.10036

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