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RESEARCH

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Characterizing facilitation practices of learning assistants: an authoritative-to-dialogic spectrum

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Abstract

Background Learning assistants (LAs) increase accessibility to instructor–student interactions in large STEM lecture classes. In this research, we used the Formative Assessment Enactment Model developed for K-12 science teachers to characterize LA facilitation practices. The Formative Assessment Enactment Model describes instructor actions as eliciting or advancing student thinking, guided by their purposes and the perspective they center as well as by what they notice about and how they interpret student thinking. Thus, it describes facilitation practices in a holistic way, capturing the way purposes, perspectives, noticing, interpreting, and actions are intertwined and working together to characterize different LA actions. In terms of how perspectives influence actions, eliciting and advancing moves can be enacted either in authoritative ways, driven by one perspective that has authority, or in dialogic ways, driven by multiple perspectives. Dialogic practices are of particular interest because of their potential to empower students and center student thinking.

Results Our analysis of video recordings of LA–student interactions and stimulated recall interviews with 37 introductory physical science lectures' LAs demonstrates that instead of as a dichotomy between authoritative and dialogic, LA actions exist along a spectrum of authoritative to dialogic based on the perspectives centered. Between the very authoritative perspective that centers on canonically correct science and the very dialogic perspective that centers the perspectives of the students involved in the discussion, we find two intermediary categories. The two new categories encompass a moderately authoritative perspective focused on the LA's perspective without the claim of being correct and a moderately dialogic perspective focused on ideas from outside the current train of thought such as from students in the class that are not part of the current discussion.

Conclusions This spectrum further adds to theory around authoritative and dialogic practices as it reconsiders what perspectives can drive LA enactment of facilitation other than the perspective of canonically correct science and the perspectives of the students involved in the discussion. This emerging characterization may be used to give LAs and possibly other instructors a tool to intentionally shift between authoritative and dialogic practices. It may also be used to transition towards more student-centered practices.

Keywords Learning assistant, LA, Undergraduate science, STEM, Chemistry education, Physics education, Pedagogical actions, Facilitation practices, Authoritative discourse, Dialogic discourse

Introduction

While current STEM education research emphasizes the importance of dialogic facilitation practices that center students, their needs, and their ways of thinking, many K-12 and college classrooms over-proportionately use authoritative facilitation practices that highlight one

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correct way of thinking (e.g., Alkhouri et al., 2021; Chin, 2006; Coffey et al., 2011; Gehrtz et al., 2022; Kranzfelder et al., 2020; Lederman et al., 2013; Patchen & Smithenry, 2013; Rosebery et al., 2016; Roth, 2009; Russ et al., 2009; van Es & Sherin, 2002). Here, we understand authoritative facilitation as restricted facilitation centering one perspective as authority—often the perspective of canonical science/the instructor perspective—and dialogic facilitation as open facilitation acknowledging multiple perspectives as equal—including the student perspective (definitions adapted from Freire, 1968/2000; Mortimer & Scott, 2003). Interestingly, even when college STEM instructors use active learning strategies, they still mostly use authoritative discourse (Alkhouri et al., 2021; Kranzfelder et al., 2020). It is not surprising then that near-peer instructors such as learning assistants (LAs; Otero et al., 2010), who are trained to attend to student thinking but mostly experience authoritative discourse as students, also use authoritative discourse to facilitate student learning in small groups during interactive lectures. Thompson et al. (2020), for example, found that LA-*directed* facilitation, where LAs provide students with information from their perspective, was more common than LA-*guided* facilitation, where LAs create opportunities for students to share their ideas.

Our work is the first to apply theory around authoritativeness and dialogicity to the facilitation practices of LAs. We use this context to characterize a spectrum of authoritative-to-dialogic facilitation practices that expands theoretical understanding between authoritative and dialogic extremes. When used in training, this spectrum may support LAs and possibly other instructors to intentionally transition between authoritative and dialogic practices. Previous research has alluded to the existence of a spectrum between authoritative and dialogic extremes (Lee & Kim, 2016; Van Booven, 2015), however, this spectrum has yet to be investigated using the theoretical underpinnings of authoritativeness and dialogicity.

In the following sections, we review literature focused on LAs in general and LA facilitation practices in particular. We then turn to the Formative Assessment Enactment Model (FAEM) as one way of characterizing facilitation practices that we employed in our work before reviewing its focus on authoritativeness and dialogicity in more depth. While our study includes LA facilitation practices in the physical sciences only, our review is focused on broader STEM because LA implementation (e.g., Alzen et al., 2018b) and the prevalence of authoritativeness over dialogicity are relevant in all STEM disciplines (Alkhouri et al., 2021; Gehrtz et al., 2022).

Literature review: impact of LA implementation, LA roles, and LA facilitation practices

The LA model was developed at the University of Colorado Boulder in 2001 (University of Colorado Boulder, 2022) and has since been adopted by many different institutions (Learning Assistant Alliance, 2012–2023). LAs are undergraduate students who have taken the course before, are hired to facilitate student group discussions in active learning classrooms, and have weekly meetings that address the three main components of the LA model: practice, pedagogy, and content knowledge (Learning Assistant Alliance, 2012–2023; Otero et al., 2006, 2010). Practice is the time the LAs have in the classroom they support. Pedagogy is the opportunity for LAs to develop their pedagogical knowledge on teaching and learning practices through a pedagogy course (Top et al., 2018). Content knowledge is addressed by having content meetings with the instructional team. These content meetings do not only serve the aforementioned purpose of developing LAs' content knowledge, but instructors can also develop reciprocal relationships with their LAs by collaborating on the development of course content and instructional strategy (Davenport et al., 2018; Hamerski et al., 2021; Jardine, 2019, 2020; Sabella et al., 2016). In general, this model aims at improving the experience of students in college STEM classes and improving the professional development of LAs to foster better prepared future STEM teachers. The goals of this model are specifically (1) to improve STEM education and teacher education; (2) enlist future STEM teachers; (3) inform science faculty of education research/teacher education; and (4) shift traditional science department cultures towards researched-based teaching (Otero et al., 2006, 2010).

There are many benefits of having LAs in the classroom (Barrasso & Spilios, 2021). For example, LAs have been associated with a decrease in Ds, Fs, and withdrawals in STEM classes, especially amongst students marginalized by racism[1] (Alzen et al., 2018a, 2018b; Van Dusen & Nissen, 2020). This may be in part due to the increase in conceptual understanding as measured by concept inventories or higher-order reasoning skills that LAs support (Herrera et al., 2018; Miller et al., 2013; Otero et al., 2006, 2010; Sellami et al., 2017; Talbot et al., 2015; Van Dusen et al., 2015, 2016; White et al., 2016). LA prompts were also found to generate increased student discussion during clicker-questions (Knight et al., 2015) and encourage active learning via peer-to-peer interactions (Hernandez et al., 2021; Jardine & Friedman, 2017; Kornreich-Leshem et al., 2022). These peer-to-peer interactions are especially important for students marginalized by racism as

[1] The term "students marginalized by racism" is used in this paper to refer to students of color to lift up the inequities they experience through oppression in a racialized society.

they can be a starting point for students to build community within and beyond the classroom (Goertzen et al., 2013). Hernandez et al. (2021) proposed that a specific mechanism for this engagement with and buy-in to active learning could be through social support, specifically feedback, emotional support, and informational support. Students particularly benefit from the presence of LAs because of the increased sense of belonging and identity they provide (Kornreich-Leshem et al., 2022).

Before a more in-depth literature review on how LAs interact with students when they facilitate group discussions, i.e., the focus of our study, it is important to note that the benefits of having LAs in class go beyond the facilitation of student learning during class. Near-peer effects are crucial to the success of LAs (e.g., Hite et al., 2021; Jardine, 2020; Li, 2013; Winterton et al., 2020). For example, LAs can serve as role models for students and they can build community with undergraduate students (Hite et al., 2021; Winterton et al., 2020). Being positioned between faculty and students, LAs take on roles beyond facilitators of student learning. They can serve as informants for faculty, since they gather information by their approachability as near-peers (Jardine, 2020). They can also serve as faculty consultants and co-creators of instructional material based on their student perspective and on what they learn in the pedagogy course (Jardine, 2020). Thus, in the formative assessment system of an LA-supported class, there is a complex information flow mediated by the role of LAs: Faculty communicate expectations to LAs, LAs gather evidence from students, LAs respond to that evidence directly while also communicating it back to faculty instructors (Jardine, 2019). In this study, we focus on one part of this system, i.e., LAs gathering evidence from students and responding to this evidence directly during interactions with students.

The following studies describe LA facilitation practices during their interactions with students and emphasize different aspects of what LAs do. For example, Pawlak et al. (2020) characterized LA approaches during computational physics problem solving as "programming focus, learning physics via computation focus, computation as a tool focus, and shifting perceptions of learning focus" (p. 1), which suggest various ways LAs interpret the goals of the activity and enact facilitation to meet these goals. While this characterization incorporates the goals of the LA, other studies captured in detail what moves LAs used when interacting with students. In Knight et al. (2015), LA prompts were described by the type of utterance they used—e.g., reasoning, analogy/example, requesting information, and requesting reasoning. In a similar manner, Thompson et al. (201920202020) characterized LA actions on an utterance-by-utterance level—e.g., answering questions, directing resources, and validating students—all in the broader categories of LA-directed facilitation, LA-guided facilitation, advice, feedback, course-related talk, and non-course related talk. While these studies called attention to the technical moves an LA may use, research is warranted to understand LA moves holistically as they are enacted during LA–student interactions— guided by LAs' goals, in response to what LAs notice about student thinking, and depending on the perspective that is centered in the conversation. One model that offers the possibility to understand LA facilitation practices in these ways is the Formative Assessment Enactment Model (FAEM). This model was originally developed to characterize the formative assessment of experienced K-12 science teachers (Dini et al.,) and we adopted it for the characterization of LA facilitation practices.

Conceptual framing: the formative assessment enactment model

In the model, formative assessment (FA) is broadly defined as any action done by an instructor to monitor and enhance student learning during their learning (Bell & Cowie, 2001). The FAEM describes instructors' facilitation practices as eliciting or advancing student thinking. When an instructor elicits student thinking, they find out about what the student is already thinking, while when an instructor advances student thinking, they move student thinking forward. Whether an instructor elicits or advances is guided by their noticing about students, their interpreting of student thinking, and their purposes developed in response to their observations (Fig. 1; Dini et al., 2020).

Grounded in sociocultural theory, the FAEM is contingent upon the idea that understanding and learning result from dialogue with others as well as within one's mind (Bakhtin, 1934/2017; Voloshinov, 1929/1986; Vygotsky, 1934/1987; Wertsch, 1991/1993). More specifically, FAEM builds upon Mortimer and Scott's (2003) characterization of teacher–student discourse as allowing for a univocal perspective, i.e., authoritative, versus a multivocal perspective, i.e., dialogic. Whether instructors employ eliciting or advancing actions in authoritative or dialogic ways is guided by their purposes (Fig. 1; Dini et al., 2020). Others have focused in on one part of the model and built upon it further by investigating teacher noticing and interpreting in more depth (Murray et al., 2020). In our work, we specifically focus on the authoritative and dialogic enactment of eliciting and advancing actions. To expand upon authoritative and dialogic enactment, our characterization of LA actions is holistically informed by how the noticing, interpreting, and purposes all influence LA actions. While our study is the first to adapt the FAEM to the LA context, previous research on LA actions in the classroom has

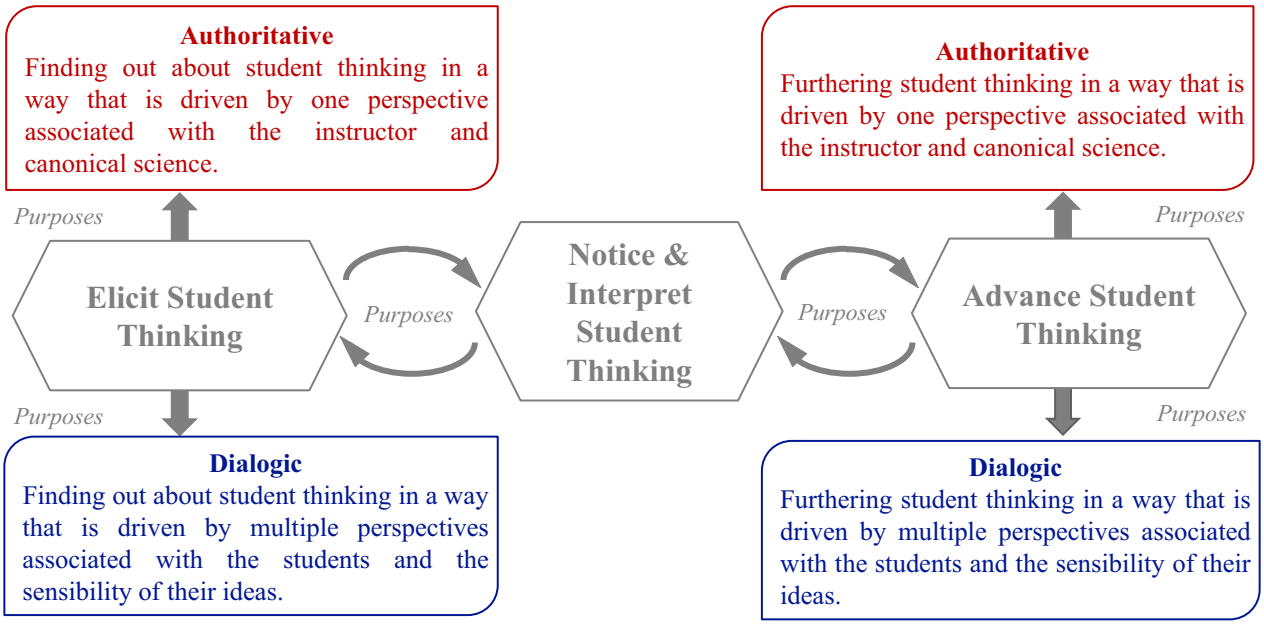

Fig. 1 The formative assessment enactment model (FAEM). The FAEM includes categories for teachers' actions (authoritative versus dialogic; eliciting versus advancing) while also recognizing and categorizing their observations (noticing and interpreting) and purposes when utilizing these actions (Dini et al., 2020). Figure adapted with permission from Murray et al. (2020). Copyright 2020 American Chemical Society

demonstrated that LA facilitation is closely connected to their noticing and interpreting behaviors and to their perceived roles (Thompson, 2019). Similarly, dialogicity and authoritativeness have not yet been used to study LA facilitation practices but have been employed to study college STEM teaching (Alkhouri et al., 2021). As well, these constructs are closely related to a study describing LA-*directed* facilitation (authoritativeness), where LAs provide students with information from their perspective, versus LA-*guided* facilitation (dialogicity), where LAs create opportunities for students to share their ideas (Thompson et al., 2020).

Theory and prior research on dialogicity and authoritativeness

Mortimer and Scott (2003) described teacher and student interactions using a communicative approach. Specifically, they described the dialogues of teachers and students along two dimensions: dialogic-authoritative and interactive-non-interactive. Dialogic communication is described as including multiple *points of view*, while authoritative communication has one *point of view*. Along the second dimension, interactive communication describes communication *between multiple people*, while non-interactive communication *excludes other people* from participating (Mortimer & Scott, 2003; Scott et al., 2006). This paper primarily focuses on the authoritative-dialogic dimension.

Authoritativeness has not only been associated with univocality but also with the perspective of the instructor and canonical science; in contrast, dialogicity has been associated with the students and the sensibility of their ideas (Dini et al., 2020; Mortimer & Scott, 2003; Scott et al., 2006). Note that in this frame, dialogic facilitation does not necessarily need to include multiple student points of view, but once a student perspective is centered in the discourse, this perspective combined with the instructor perspective makes the discourse multivocal (Dini et al., 2020). This understanding of authoritativeness and dialogicity has been used in various current STEM education studies in the K-12 context (e.g., Lehesvuori et al., 2019; Soysal, 2021; Soysal & Yilmaz-Tuzun, 2021) and at the college level (Alkhouri et al., 2021). While the communicative approach emphasizes the univocality of authoritativeness and the multivocality of dialogicity, Freire's understanding of dialogic education draws attention to power highlighting that true dialogue acknowledges all voices as equals without one voice imposing knowledge on another (Freire, 1968/2000). Power dynamics are important to consider in STEM classrooms, as instructors of all kinds including LAs—even if less so than other instructors—are positioned as more adjacent to power than students. Combining understandings of dialogicity and authoritativeness in the literature and intentionally emphasizing the unequal versus equal power aspect in authoritative

versus dialogic discourse, we define authoritative facilitation as restricted facilitation centering one perspective as authority and dialogic facilitation as open facilitation acknowledging multiple perspectives as equal.

In STEM education, dialogic discourse has been emphasized for its central role in student learning (Bielik & Yarden, 2016; Lederman et al., 2013; Patchen & Smithenry, 2013). As outlined before, the importance of dialogic discourse has been detailed by Freire (1968/2000), suggesting the power of dialogic actions to empower learners and combat oppressors (Freire, 1968/2000). Thus, dialogic facilitation practices have the potential to contribute to equity of individuality, which occurs when teaching interventions improve the learning outcomes of students from groups marginalized by different forms of oppression such as sexism or racism (Van Dusen & Nissen, 2019). Different types of dialogic facilitation practices include asking clarifying questions, reflecting, rebroadcasting student thoughts, and prompting for elaboration (Dini et al., 2020). Dialogic facilitation practices support students as autonomous builders of sense and knowledge (Cherbow & McNeill, 2022; Kaya & Ahi, 2022; Kim, 2021; Oh et al., 2022; Soysal, 2021; Soysal & Yilmaz-Tuzun, 2021). Further, these facilitation practices encourage collaboration between peers to build communal understanding of science (González-Howard & McNeill, 2019). These benefits are particularly useful for overcoming language barriers in the classroom (Adams et al., 2015; Axelsson & Jakobson, 2020; Langman & Fies, 2010; Salloum & BouJaoude, 2020, 2021).

The necessary tension between authoritative and dialogic discourse has been described by multiple researchers, specifically noting how both types of exchanges foster one another in an overall conversation (Lehesvuori et al., 2019; Scott et al., 2006). However, K-12 and college instructors more frequently employ authoritative facilitation strategies (Alkhouri et al., 2021; Coffey et al., 2011; Kranzfelder et al., 2020; Russ et al., 2009), which are associated with limiting, alienating, and even oppressing student thinking if they are not employed in balance with dialogic practices (Chin, 2006; Roth, 2009). Traditional science education tends to center "unitary language and cultural centralization"—in other words, authoritative perspectives (van Eijck & Roth, 2011). As such, teachers tend to use authoritative discourse when their goal is for students to appropriate canonical content from the teacher or from the textbook (Alkhouri et al., 2021; Kayima & Mkimbili, 2021; Oh et al., 2022; Semeon & Mutekwe, 2021). This purpose can be in tension with more overarching and inclusive goals of drawing on student experiences, incorporating multicultural perspectives into science, and accepting different ideas as true (Kervinen et al., 2020; van Eijck & Roth, 2011). It is therefore important to investigate the spectrum between authoritative and dialogic extremes that has been found in prior research (Lee & Kim, 2016; Van Booven, 2015).

Some progress towards this end has been made. For instance, Martin and White (2005) described dialogic language as being able to both expand and contract the scope of the conversation while still referencing multiple external voices. Further, Van Booven (2015) characterized a "'middle ground' between maximal authoritativeness and dialogicity" (p. 1182), which they identified as separate from typical authoritative moves based on the "moderate cognitive, structural, and epistemological diversity" in student responses (p. 1196). However, researchers have yet to characterize this spectrum using the theoretical underpinnings of authoritativeness and dialogicity—in other words, using the perspective the instructor enacts in light of the power differentials between perspectives. One study that begins this work is from Tee et al. (2022), who characterize a spectrum from mono-voiced (non-interactive), mono-perspectival (authoritative) over multi-voiced (interactive), mono-perspectival (authoritative) to multi-voiced (interactive), multi-perspectival (dialogic). While this work mixes the two separate dimensions of the communicative approach (Mortimer & Scott, 2003) to create a spectrum, we focus on the dialogic-authoritative dimension alone and use the perspectives centered to characterize a continuum.

In the present study, we developed this spectrum in the context of LAs. The practices of LAs provide a specifically rich context for studying the spectrum between maximal authoritativeness and dialogicity because LAs do not have the pressure to run the classroom at the same time as facilitating student learning like TAs, K-12 teachers, or professors, so they can focus more on the substance of student thinking and student needs. They are closer in experience to the students they interact with, which may allow them to relate to students better and reduce the power differential between instructor and students (Winterton et al., 2020). While TAs, K-12 teachers, and professors often develop experience in teaching without much training in facilitation practices early on or without continuous training, LAs receive this training through the pedagogy course they take concurrent to their first semester of being an LA and thus might not fall into standard authoritative patterns as easily.

Purpose of the study and research question

In the current study, we use theory, LA–student interaction data, and interviews with LAs to reconsider what perspectives can drive facilitation other than the canonically correct scientific perspective and the perspective of the interacting students. Thus, our research answers the following question: Which perspectives do LAs center

Table 1 Demographics of the undergraduate population and the LAs in the study sample at the two universities

	University A		University B	
	University undergraduate population %	LAs in study sample %	University undergraduate population %	LAs in study sample %
Students who identified as American Indian, Alaska Native, Black, African American, Native Hawaiian, Other Pacific Islander, Asian, Latino, Latinx, Hispanic, Hispanic of any race, Cape Verdean, two or more races, self-described race, Non Resident Alien, and/or International	64	67	47	64
Students who identified as white and did not identify with any of the social constructs on top	36	33	53	36
Students who identified as non-binary, female, or self-described gender	58	58	54	60
Students who identified as male	42	42	46	40

For the racial/ethnic makeup of the undergraduate student populations, we relied on categories and numbers provided by the two universities. While for the demographics of the LAs collected for our study, we separated race, ethnicity, and international status, those were not separated by the universities with regard to the demographics of the students. This means for example that for the undergraduate student population, a student was not able to select that they identify as Black and Hispanic or Asian and International, while LAs in our study were able to make those kinds of selections. To make numbers between the two universities and the LAs in our study as comparable as possible, we decided to display aggregated percentages for all students who identified at least with one marginalized social construct vs. students who only identified as white or male. To be transparent in what social constructs we aggregated we listed all social constructs included in the aggregation. While it might seem as if we doubled some terms, such as including "Hispanic" and "Hispanic of any race," we did this intentionally to include all the different language choices used by the different universities and the research team as these were the actual choices the students could self-identify with. We also acknowledge that the two universities and our research team opted for different language choices, some more marginalizing (e.g., "Non Resident Alien") while others are more justice-oriented (e.g., "International"). Lastly, we acknowledge that it would have been more respectful to use the term "First Nations" instead of the colonizing term "American Indian/Alaska Native," but this more justice-oriented language was neither used by any of the two universities nor by our research team

when using authoritative and dialogic ways of eliciting and advancing? In addition to bolstering theory around authoritative and dialogic discourse, this approach can also open new possibilities for LAs, and possibly other instructors, to navigate the tension between authoritativeness and dialogicity.

Methods

This study is part of a larger ongoing project to develop a model of LA facilitation practices in large introductory physical science lectures. The project uses a sociocultural perspective (Vygotsky, 1934/1987) to model different dimensions of LA facilitation practices, i.e., the nature of LA facilitation during LA–student interactions as they relate to LA purposes (this study), student in-the-moment learning that occurs during these interactions (Karch & Caspari-Gnann, 2022; Walsh et al., 2022), and the integration of these interactions into the whole class system (under development). Different frameworks are used to develop the different dimensions of the model: FAEM is used to model the nature of LA–student interactions as they relate to LA purposes; practical epistemology analysis (Wickman, 2004; Wickman & Östman, 2002) is used to model in-the-moment learning during these interactions, and cultural historical activity theory (Engeström, 1987, 2001) is used to model the integration of these interactions into the whole system. Before combining the frameworks to present a comprehensive model of LA facilitation practices, we are developing each dimension independently. The study presented here uses FAEM as a framework and is solely focused on the nature of LA facilitation during LA–student interactions as they relate to LA purposes.

We used narrative inquiry as the primary methodology for this study. We created narratives to organize LA facilitation experiences that foreground the voices of the LAs, the researchers, and the sociocultural settings in which this research occurred (Moen, 2006). Aligned with a narrative research process, video recordings and stimulated recall interviews were collected and an ongoing interpretative process including theoretical, LA, and researcher perspectives was employed to select what to include in the narratives, how to tell the LA facilitation story, and how to interpret it further through the lens of dialogicity and authoritativeness.

Research context

The study included 37 introductory chemistry and physics LAs at a public, highly diverse university (University A) and a private, majority white university (University B) in the Northeastern USA. Table 1 compares the ethnic/racial makeup, sex, and gender distribution of the undergraduate population at each university with the ethnic/racial makeup, sex, and gender distribution of the LAs in our study sample. In our LA study sample, we aimed to have the same representation of student identities marginalized by racism, sexism, or genderism as in the undergraduate student population at the respective university or to overrepresent these marginalized identities

Table 2 Classes, number of LAs and students who participated in the study, and LA pedagogical training

University	Class	Modality	Semester	Number of LAs enrolled in study	Number of students enrolled in study	Pedagogical training: length instructor main mode of facilitation training
A	Chemistry 2	Virtual	Fall 2020	4	96	1-h pedagogy course PhD candidate in chemistry education Video and transcript analysis
A	Chemistry 1	Virtual	Spring 2021	2	36	Same as previous
A	Chemistry 1	Virtual	Spring 2021	1	50	Same as previous
A	Chemistry 2	In-person	Fall 2021	1	80	1-h pedagogy course Faculty in a different STEM discipline than chemistry Video and transcript analysis
A	Chemistry 1	Hybrid	Spring 2022	2	28	1-h pedagogy course Member of dean of students' office Video and transcript analysis
A	Chemistry 1	In-person	Spring 2022	2	51	Same as previous
B	Chemistry 2	Virtual	Fall 2020	5	129	2-h pedagogy & content training Course instructor who is also STEM education research faculty Mock facilitation
B	Chemistry 2	In-person	Fall 2021	5	113	2-h pedagogy course & 1 week of dialogic/authoritative facilitation training prior to start of semester STEM education research faculty Video & transcript analysis & mock facilitation
B	Physics 1	Virtual	Fall 2020	4	112	Asynchronous feedback throughout semester & pedagogical meetings early in semester Course instructor who is also STEM education research faculty Video & transcript analysis
B	Physics 2	Virtual	Spring 2021	3	40	Same as previous
B	Physics 1	In-person	Fall 2021	3	82	2-h pedagogy course Course instructor who is also STEM education research faculty Video & transcript analysis
B	Physics 1	In-person	Spring 2022	5	26	2-h pedagogy course STEM education research faculty Video & transcript analysis & mock facilitation

The displayed pedagogy courses were offered during the semesters the LAs participated in the study. For new LAs, they took this course concurrent with their first semester of being an LA, and often this overlapped with the semester they participated in the study. For returning LAs, this course is not necessarily reflective of their pedagogical training, as they had taken a pedagogy course in an earlier semester. Individual information on the specifics of when each LA was trained/their histories in the LA program was not collected

in order to give them more voice in our study.[2] The Institutional Review Boards of both involved institutions approved this study.

Data collection occurred over the span of four semesters: fall 2020, spring 2021, fall 2021, and spring 2022. Two semesters were in virtual, interactive, LA-supported Zoom lectures. The other two semesters were conducted in similar classes, but in an in-person setting at the same universities. All professors teaching with LAs in chemistry and physics at the two institutions were invited to participate and consented to the data collection in their courses. The professors recruited LAs that they were working with to participate in the study. All LAs who decided to participate received a $500 stipend for their participation in the study. Students were recruited via announcement in lecture and through their course management system. At the discretion of their professor, students who participated in the study either received a small amount of extra credit, maximum 2% of their final course grade, or a $10 stipend. All participants gave consent via an online Qualtrics form. All data are de-identified and all participants have been given a codename. Table 2 outlines the number of LAs and students that participated in each class in addition to the pedagogical training the LAs were offered during the semester concurrent to their LA position. The pedagogical training column includes

[2] There was no specific focus on this group of students in the study other than ensuring their representation in the research study.

the weekly length of the pedagogical training, who led the training, and the main mode of facilitation training. In all trainings, emphasis was placed on student-centered facilitation, but dialogicity and authoritativeness was not introduced specifically in most trainings (unless mentioned otherwise in Table 2). LAs had different amounts of pedagogy training and the content of each training was slightly different depending on the individual pedagogy instructor. In addition to their varied pedagogy training, LAs had a mixture of experience levels, with some being new LAs and others having one or two semesters of prior experience. LAs were mostly juniors and seniors and were mostly all STEM majors who were not majoring in the subject they were an LA for, with a few exceptions. This variety in LA pedagogy training, experience levels, year in school, and major is especially important in informing our results as our spectrum is representative of a wide range of facilitation practices from a diverse group of LAs. Further, the variety contributes to the validity of our study as "the analysis is more valid, the more it can be applied to related sorts of data" (Gee, 1999, p. 95).

Data collection

Data sources for this study were video recordings of LA–student interactions and interviews with the LAs. Since LA facilitation practices were the focus of our study, the participating LAs recorded their interactions with students from their point of view. In Zoom lectures, they were given recording privileges to record their breakout rooms. In in-person lectures, they recorded their interactions using their cell phones mounted to their chest with a harness. For each course, we asked the LAs to record all their interactions with students during three lectures, roughly one at the beginning, one in the middle, and one at the end of the semester. When data collection occurred specifically depended on a few factors such as the syllabus, exams, holidays, instructor preferences, but some general guidelines applied to data collection in all courses: the first data collection was at the end of week 2 the earliest. The third data collection was the latest 10 days before the end of the semester. There needed to be at least 10 days between each data collection. For most courses, data collection 1 was in weeks 3–5, data collection 2 in weeks 6–10, and data collection 3 in weeks 11–14. This allowed us to investigate a variety of LA practices with a variety of student groups. For each lecture, the number of interactions an LA had with students ranged from one to 10. While the average number of student interactions an LA had per lecture was three with an average length of five to seven minutes each, interactions typically lasted longer if an LA had fewer interactions, up to 20 min, and interactions were often rather short if an LA had many interactions, as short as 20 s. Table 3 shows the lengths of different interactions and their quantity in our data set. Only interactions used for data analysis were counted (see next paragraph and data analysis section for more details on selection of interactions).

Table 3 Length of interactions and quantity in the data set

Length of Interaction (min)	Quantity in the data set
0:00–1:00	4
1:01–3:00	35
3:01–5:00	51
5:01–7:00	52
7:01–9:00	56
9:01–11:00	17
11:01–13:00	6
13:01–15:00	3
15:01 +	3

Within the two weeks following each recorded lecture, members of the research team conducted one-on-one, semi-structured Zoom interviews with the LAs. During these interviews, the LAs watched a maximum of three recordings of their interactions with students for stimulated recall (Meade & McMeniman, 1992). If more than three video clips were collected, we selected the clips shown based on audio/video quality, variety in the interactions, and focus of the discussion on class content (i.e., selection criteria established in our prior research; Caspari-Gnann & Sevian, 2022; Dini et al., 2020).

The goal of including these video clips was to situate the LA's thinking towards what it was in the moment of lecture. Notably, stimulated recall interviews can give deep insight into the connections subjects make between their implicit understandings (e.g., of their role and purposes) and their actions (Meade & McMeniman, 1992). In general, we asked the LAs about how the lecture went and how they perceived the roles of different people in the classroom (LAs, students, professor). Specific to our analysis, we asked LAs about what they noticed during their interactions, what their purposes were, and how they would describe their actions. Table 4 shows the semi-structured interview protocol used by interviewers with questions created explicitly to relate to the FAEM (Dini et al., 2020) displayed in bold. Other questions in the interview protocol were inspired by cultural historical activity theory (Engeström, 1987, 2001) and were core to other parts of the larger project, although LA responses to these questions also often pertained to the analysis for the present study and were thus included for comprehensive analysis. Follow-up questions were asked to further explore ideas that seemed salient to the LAs. Various members of the research team conducted

Table 4 Semi-structured interview protocol used for LA interviews

Purpose of interview portion	Example questions
Ask these questions in the beginning about the entire lecture	
Open beginning	How did the lecture go? What strikes you about it? (Alternative: How do you feel about it?)
LAs' overall purposes for interactions	**What was your overall purpose in interacting with the students during this lecture?**
Watch video clip of LA–student interaction, then ask questions, do this for each video clip selected for the interview	
LAs' noticing & interpreting	**What do you know about the students in this interaction and what did you notice about them when you had the interaction?** **Follow-up (if they don't talk about student reasoning): What did you notice about the students' thinking?** **What were you responding to with your statements?**
LAs' in-the-moment purposes for interactions	**Why did the students work on this problem; what was the purpose?** **So, what did you do and why did you do it?**
LAs' interpretations of in-the-moment learning	What do you think the students learned during this interaction?
LAs' perceptions of rules and contradictions	How did you decide what group to interact with? How did you decide when to jump in? What do you think the professor and the students expected of the interaction? (Possible follow-up: Where did you know these expectations from?) Does this match up with what you think is best for learning?
LAs' perceptions of division of labor and contradictions	What do you see as your role in this interaction? What about the students? (If interviewees ask what we mean by role: You know like in a play different people have different roles, and it's kind of like that in the lecture, everybody has different roles.)
LAs' perception of the integration of this interaction into the whole class	What do you think students get out of the breakout room that is different from the lecture? And what do they get from the lecture that is different from the breakout rooms? What is your role in facilitating that?
Ask these questions in the end after you have shown all selected video clips	
Open end	Anything else you wanted to share?

Instructions of when to ask questions are inserted in italics. Bold font is used to highlight questions that relate specifically to the formative assessment enactment model (FAEM)

the interviews. Interviewers were undergraduate students (including the first author of this paper), a graduate student (second author of this paper), a postdoc, and a professor (corresponding author of this paper), all of whom received intensive training in how to conduct these interviews to ensure high quality and comparability across interviews. We had a maximum of 90 min for each interview.

Data analysis

Overview

A professional transcriptionist transcribed the interaction recordings and Zoom automatically generated transcripts of the interviews. Members of the research team read transcripts of the interaction recordings and interviews carefully while listening to the recordings and corrected any mistakes that occurred. Interactions used for analysis were only those the LAs were interviewed on because LAs' video-recorded practices and their reflections on their practice in the interview were crucial for analysis. To characterize which perspectives drove LA facilitation practices, our process of data analysis involved multiple steps for every LA–student interaction. First, we used the interaction recording and the LA interview to write a narrative describing the LA facilitation during a given interaction (Moen, 2006). Structuring this narrative was guided by the FAEM (Dini et al., 2020). Second, we coded this narrative with theory-driven codes, such as authoritative and dialogic eliciting and advancing. Third, we used "thinking with theory" (Jackson & Mazzei, 2013) to further distinguish different perspectives that guided LA facilitation within the broader categories of authoritative and dialogic eliciting and advancing. Figure 2 shows our complete data analysis process. Further details for every step of this process alongside a description of our consensus process involving multiple coders (Saldaña, 2013) are given below.

Narrative writing

The challenge of our data analysis aligned with that of narrative research where "the challenge for the researcher is to examine and understand how human actions are related to the social context" (Moen, 2006, p. 56). Guided by the FAEM, the actions under investigation in our work

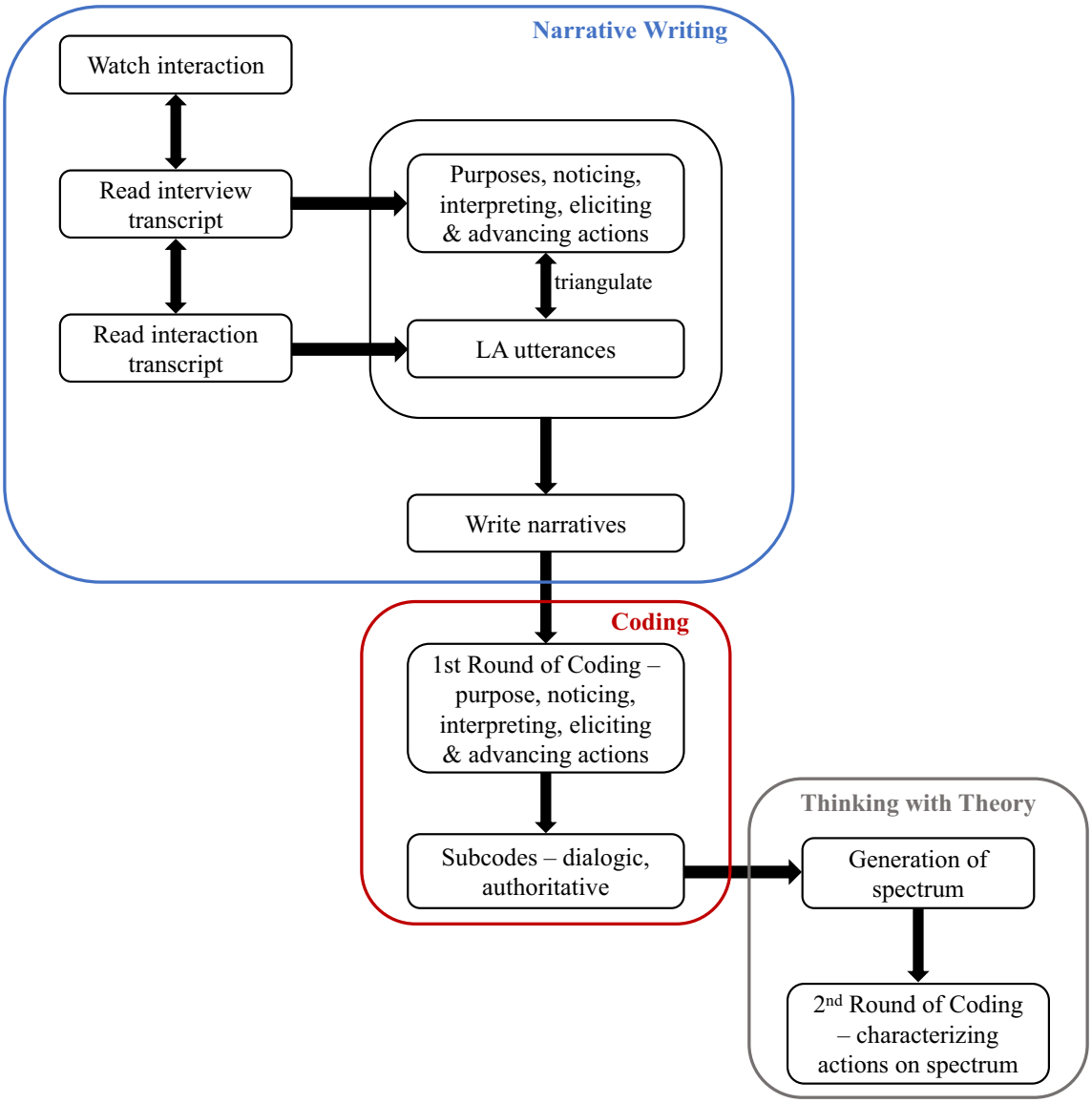

Fig. 2 Data analysis process

were LA eliciting and advancing actions enacted in the video-recorded LA–student interactions and described by the LAs in their interviews. The aspects of the social context we captured were the purposes for the LAs' actions and what the LAs noticed about and how they interpreted students' thinking, as described by the LAs in their interviews. "The narrative as a unit of analysis provides the means" (Moen, 2006, p. 56) for relating human actions to the social context, in our study relating LA purposes as well as noticing and interpreting to eliciting and advancing actions. Thus, our narratives described LA facilitation holistically revealing how the LAs acted upon their noticing and interpreting to pursue their purposes.

To construct the narratives, interaction videos as well as transcripts of both interaction videos and LA interviews were considered, going back and forth between the data sources. The reasons for triangulating interaction and interview data were to ensure that we did not interpret the LA actions (in the recorded LA–student interaction) out of the context of what the LA perceived and intended to do (described in the interview) and to ensure that the LA was reflecting on something (in their interview) that was a part of their interaction (in the recorded LA–student interaction). Thus, we abstracted from and summarized specific LA utterances in the LA–student interaction and the LA interview when writing narratives.

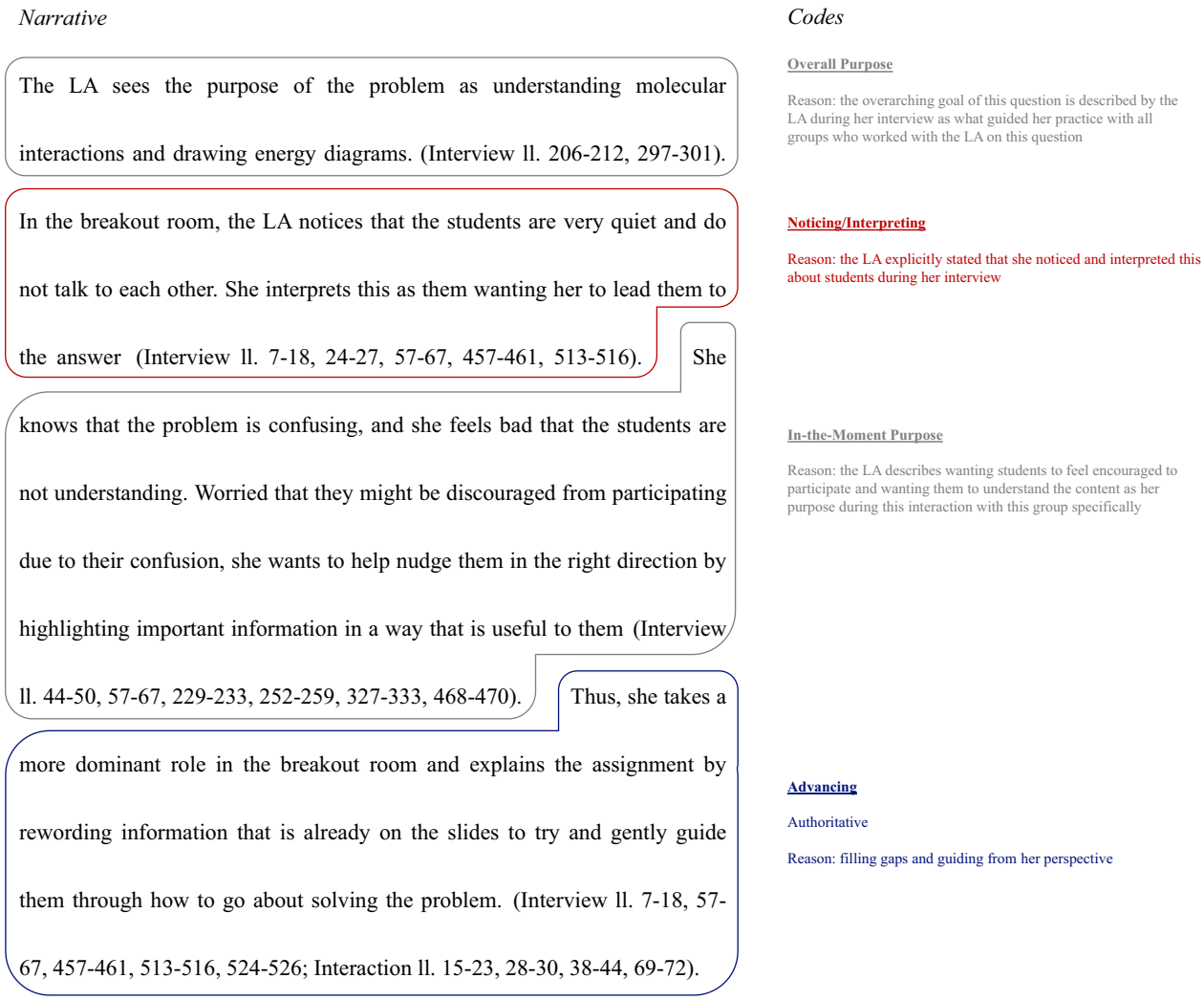

Fig. 3 Example narrative and coding

Figure 3 displays an example narrative. The action part of the narrative (see example of an advancing action in Fig. 3) encompasses a description of what LAs did through use of their language in the recorded LA–student interaction. These eliciting or advancing actions were described in a way that summarized the LA utterances in the LA–student interaction choosing wording that closely aligned with how the LA described their own actions in the interview. The purpose part of the narrative included anything the LA said (in their interview) about how they viewed their role as an LA both in general and specific to the interaction they were reflecting on, what the LA hoped to achieve, what the LA wanted for students, and why the LA did what they did during the interaction. Often, the purpose part of the narrative was split into two parts, an overall purpose that referred to the LAs overarching goals applicable to all groups and an in-the-moment purpose that was contingent on what the LA noticed about the specific group they were working with (Dini et al., 2020). The noticing and interpreting part of the narrative included anything the LA said (in their interview) about what they observed and how they understood what they observed regarding group dynamics and/or student thinking.

The connections between LA purposes, noticing, and interpreting with LA actions represented in the narrative were established from the LA interviews. Sometimes the LAs made these connections directly, e.g., by saying that they did something to achieve a certain goal. In other instances, the connections were inferred from what the LAs were describing, e.g., when the sentiment of a hope they had for students aligned with their action.

The example in Fig. 3 demonstrates how the narrative writing achieved the goal of foregrounding the relation between action, purposes, noticing, and interpreting, i.e., due to the LA *noticing* that the group she was working with was quiet and *interpreting* this as them needing support, she wants (*in-the-moment purpose*) to move their thinking in the right direction and support their participation which she enacts (*action*) by gently guiding them through how to solve the problem. We aimed at capturing this complexity of LA facilitation in a way that condenses the raw data (LA–student interaction and LA interview) but represents it very closely. Preserving this complexity of the data in this stage of analysis was important for the process of thinking with theory, where we did not look back at the LA interview but worked with the holistic narratives directly.

During the narrative writing process, we were intentional about how to divide between different narratives. We divided one interaction into more than one narrative if it included more than one of the following actions: dialogic eliciting, authoritative eliciting, dialogic advancing, authoritative advancing. One interaction was captured in a single narrative if all LA utterances in the interaction were part of the same action.

Coding based on FAEM and dialogicity and authoritativeness as analytical framework

We used FAEM and theory on dialogicity and authoritativeness outlined in the introduction (see also Table 6 in the Appendix for definitions) as our analytical framework to code portions of the narrative. Actions described in the narrative were coded as either eliciting or advancing and either authoritative or dialogic. While Dini et al. (2020) coded actions utterance-by-utterance, we coded multiple lines that fell under the same narrative informed by the information from the interview. As outlined before, this holistic narrative-based approach to coding, where one action often summarized multiple LA utterances in the LA–student interaction, allowed us to capture the context of the LAs' actions, in line with the sociocultural theory that guides FAEM itself (Bakhtin, 1934/2017; Moen, 2006; Vygotsky, 1934/1987). We coded the purpose as being overall (applicable to all groups), in-the-moment (applicable to a specific group), or both (Dini et al., 2020). We also coded for noticing and interpreting. An example of a coded narrative is provided in Fig. 3 and a table of codes used in this paper is provided in Table 5. Table 6 in the Appendix contains all codes and their definitions, including subcodes for noticing, interpreting, and purposes that were relevant for the larger project but not for the work presented in this paper, alongside example narrative portions and interaction quotes.

Table 5 Codes and subcodes used in this paper

Codes	Subcodes
Purpose	Overall In-the-moment
Noticing and Interpreting	–
Eliciting	Authoritative Dialogic
Advancing	Authoritative Dialogic

Consensus process for narrative writing and coding

For the first half of the data, i.e., a total of 19 LAs, the process of narrative writing and coding was guided by the first author. She analyzed the entire data set of 1 or 2 LAs per week including all interactions on all three recording days and all three interviews for each LA. Using a random number generator, we determined one whole recording day out of the three for each LA, i.e., one third of the data, for which narrative writing and coding were independently done for all interactions by the third author for the physics LAs (the third author has the most experience in physics education) and by the corresponding author for the chemistry LAs (the corresponding author has the most expertise in chemistry education). In addition, one of the researchers watched only the recordings of the interactions for which no second researcher did independent analysis, read the narratives and coding done by the first author and gave feedback on the analysis. We discussed analysis in weekly meetings in which we compared the independent analyses done by the two researchers and discussed the feedback given on the additional narratives coded by the first author. During our discussions, we reached consensus, and the first author revised narratives and codes based on these discussions. For the second half of the data, i.e., a total of 18 LAs, the same process was guided by the second author, while the first author did the independent analysis for all 18 LAs, and the corresponding author joined the weekly discussion meetings for 8 of the 18 LAs. We determined that this was the best consensus process (Saldaña, 2013) because one LA seemed to have repetitive narratives, so analyzing one day for each LA independently covered more variety than if we would have randomly chosen any recording day from any LA. It was most useful to independently analyze entire recording days instead of individual interactions because the interviews were about multiple interactions and to understand the LAs' thinking about one interaction one had to read it in the context of the entire interview. The additional process of giving feedback on analyses based on only watching interaction recordings and not reading interviews contributed another layer to the consensus process during which we

could check that our interpretation of the LA facilitation as recorded was not biased but enriched through the triangulation with the interview data. The weekly coding process, weekly discussion meetings, and when necessary, revision of previous narratives and coding based on these discussions in combination all ensured consistent application of the narrative writing process and coding scheme.

Process of the second round of data analysis—thinking with theory

During the first round of data analysis, patterns emerged around LA actions that we coded as authoritative because they centered one perspective as authority and as dialogic because they centered multiple perspectives as equal; in some cases, the LA took neither the perspective of canonically correct science often associated with authoritative actions, nor the perspective of the students present in the discussion group often associated with dialogic actions. Through "thinking with theory", meaning that we used the underlying theory on dialogicity and authoritativeness, the data collected for this study, and our own experiences plugged into one another (Jackson & Mazzei, 2013), we developed two intermediary categories to encompass these remaining actions, while still recognizing the original definitions of authoritative/dialogic as centering one perspective as authority/multiple perspectives as equal. These intermediary categories were labeled as moderately authoritative and moderately dialogic. They are described to great extent in the results section of this paper alongside differentiating them from the most authoritative and most dialogic ways of how LAs enacted eliciting and advancing actions. These new codes were developed by the first, third, and corresponding author during the discussion meetings of the first round of data analysis based on the data of 19 LAs and then applied to the entire data set.

To categorize LAs' actions again using these more nuanced codes, the first author went through all the interactions and coded all narratives more specifically using the new codes in a second round of data analysis. This process included re-reading the previously established narrative and the LA utterances during the interaction that pertained to this narrative before characterizing them using one of the possible codes created through thinking with theory. We made distinctions based on the types of perspectives focused on in the conversation and supported by the purposes stated by the LA in their interviews. This coding was aided by the holistic nature of the narrative as the purposes connected to the LA actions often helped distinguish which perspective was employed. If there was more than one of the new codes present in one narrative, we made a note of which utterances during the interaction corresponded to which code.

Consensus process for thinking with theory

To ensure consistency of the applied codes, a similar consensus process as in the first round of data analysis including the first and second author as independent coders and weekly discussion meetings were employed. The only difference was that instead of randomly choosing one recording day for each LA for independent analyses, we chose two interactions from any recording day for each LA for independent analyses, i.e., one that felt intuitively most productive for student learning and one that felt intuitively least productive for student learning. To make decisions about which interactions felt most and least productive, all interactions LAs were interviewed on were watched and evaluated. One determining factor was student engagement—if students were productively engaging in conversation with one another, whether it was on content or something else, this was considered more effective. If students had been passively involved and not engaged in dynamic conversation or the interaction reflected highly structured turn-taking amongst the group, this was considered less effective. Another determining factor was the LA role in the interaction and how they were responding to student thoughts— if the LA created more space for student reasoning and helped the conversation become dynamic, this was considered more effective. If the LA interrupted the flow of conversation or if every student contribution was initiated and responded to by the LA, this was considered less effective. We made the decision to focus on these two interactions because we realized as part of our research in the larger project that choosing the most and least productive interaction for one LA best represented the variety of LA facilitation that the LA demonstrated.

Results

While the existing literature recognizes the existence of a spectrum from authoritative to dialogic actions, to our knowledge the results of our study represent the first incident of characterizing this spectrum with the perspectives centered in the conversation. In the literature, authoritative actions are often associated with the canonically correct perspective, while dialogic actions are often associated with the perspectives of the students participating in a discussion. Our analysis showed that this understanding presented in the literature was limiting as two new categories emerged from our analysis. The two new categories encompassed the ability for an LA to take up one perspective without limiting the perspective to being canonically correct and the ability for an LA to introduce new perspectives to the students without

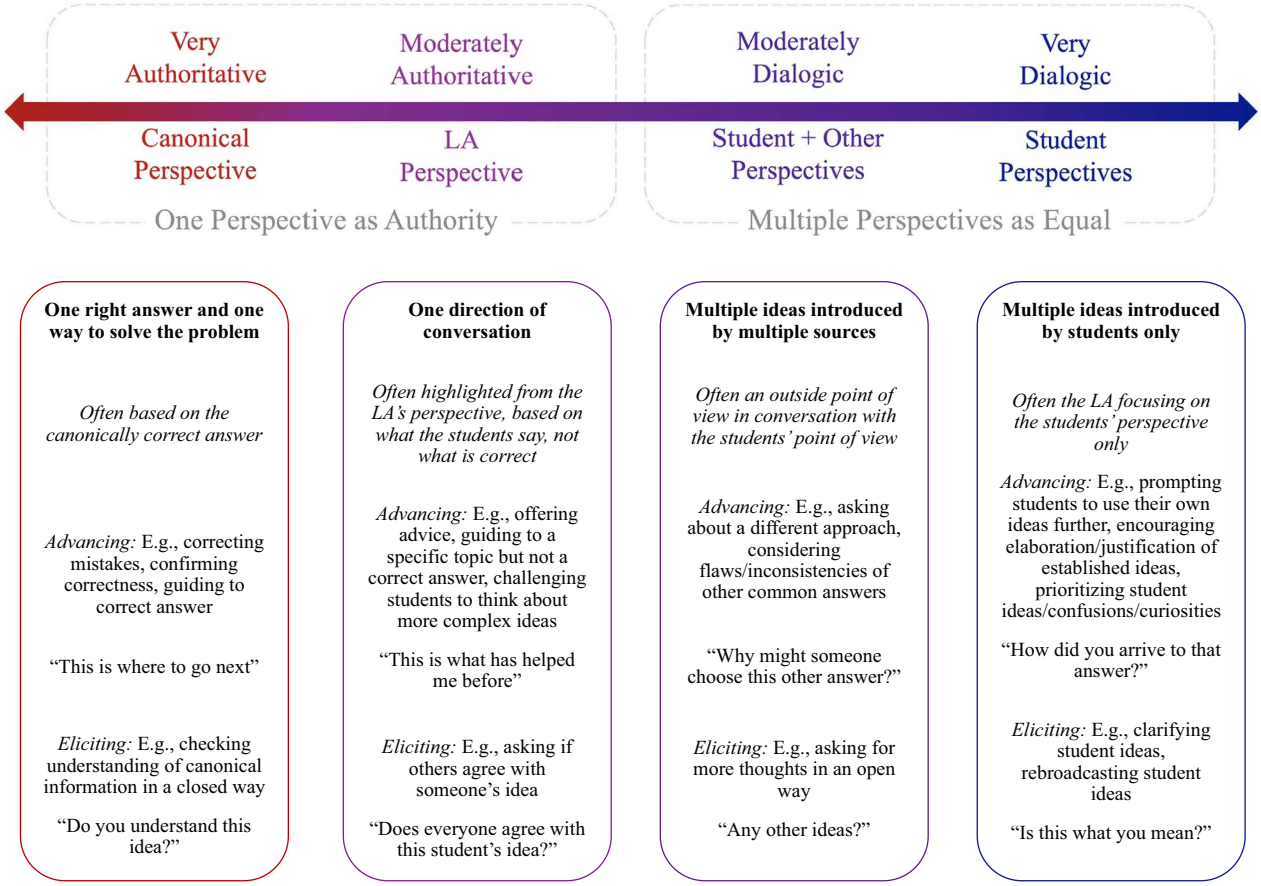

Fig. 4 The authoritative-to-dialogic spectrum. The perspectives are displayed from highest power differential between the LA perspective and the students' perspectives to lowest power differential

focusing completely on the students in the group. These two intermediate categories were called "moderately authoritative" and "moderately dialogic", respectively. The original extremes of the perspective of canonically correct science and the perspective of the students present became "very authoritative" and "very dialogic", respectively (Fig. 4).

Describing each perspective starting with the most authoritative perspective, the canonical perspective is authoritative because it centers and privileges one point of view, typically delivered by the LA, due to its assumed correctness. Next is the LA's perspective. The LA's perspective is authoritative, because only one person's point of view is valued, but it does not claim to be the only or correct point of view, which allows for more exploration of ideas during the conversation. The third perspective shifts towards the dialogic end of the spectrum because more than one point of view is centered. This perspective highlights ideas and voices from outside the current train of thought (e.g., other students in the group, other students in class, the problem's answer choices, etc.) when brought into conversation with the voices of students in the group. Thus, the LA still exerts some authority in drawing students' attention to other perspectives than their own, making it only moderately dialogic. Finally, there is the most dialogic perspective—that of the students participating in the discussion in that moment. This is the most dialogic because it focuses completely on those participating in the learning through dialogue.

Here, we describe the four possible perspectives that LAs center when advancing or eliciting, each falling along our proposed spectrum of authoritative to dialogic (Fig. 4). To help illustrate this spectrum, we introduce two examples for each point on the spectrum and use them to elaborate on the spectrum in more depth. For advancing and then eliciting, we give an example from chemistry and physics classrooms for very authoritative, moderately authoritative, moderately dialogic, and very dialogic moves.

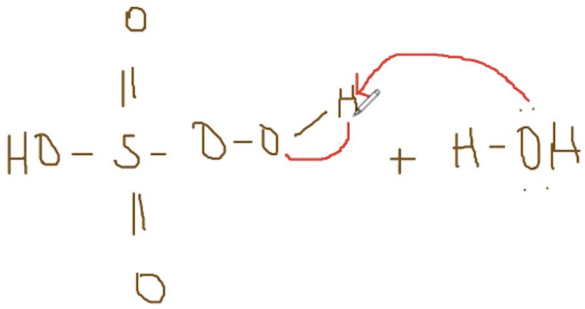

Fig. 5 Students drawing of an incorrect arrow pushing mechanism

Advancing spectrum

Very authoritative advancing

When LAs used authoritative advancing actions, they often took the perspective of canonical correctness to guide their utterances. As a result, many LAs moved student discussion towards a complete and correct answer using hints, directive questions, and corrections. In the following example, a group of chemistry students drew an arrow pushing mechanism for the reaction between H_2SO_5 and H_2O. Within H_2SO_5, they incorrectly drew an arrow from the H to the O rather than from the bond to the O (Fig. 5).

LA Keap noticed that the students incorrectly drew the arrow, specifically noting that the students did not pay attention to the movement of electrons. As a result, LA Keap drew their attention to this mistake: *"Where, like between the O and the H, where are the electrons that bind those two like atoms?"* Here, LA Keap hinted to the students that they should correct their arrow pushing mechanism by referencing ideas emphasized in class. This action was an advancement towards a different, more canonically correct answer compared to the answer the students had originally. In taking this advancing action, the LA narrowed the scope of the conversation such that there was limited space to explore other ideas.

While LA Keap chose to hint towards the students' mistake with a more general content-related question, other LAs chose to correct students more directly. In a physics lecture, LA Shin and a group of students discussed a problem involving the use of the right-hand rule—a visual tool that uses the curling of the right hand to determine the direction of magnetic force in a current-carrying loop (Fig. 6A). During the discussion, student Noor concluded that the two loops would repel because her thumbs (and thus the forces) pointed in the opposite direction when she did the right-hand rule for both loops sequentially (Fig. 6B). Another student, Josephine, had a difficult time following along with Noor's explanation because she used the right-hand rule with both her right and left hand (Fig. 6C).

Seeing that Josephine was struggling with the right-hand rule, and that no other student pointed out the misuse of her left hand to represent one loop and her right hand to represent the other, LA Shin decided to intervene: *"Josephine, I think you're using your left hand."* Though the LA generally believed that he should not be

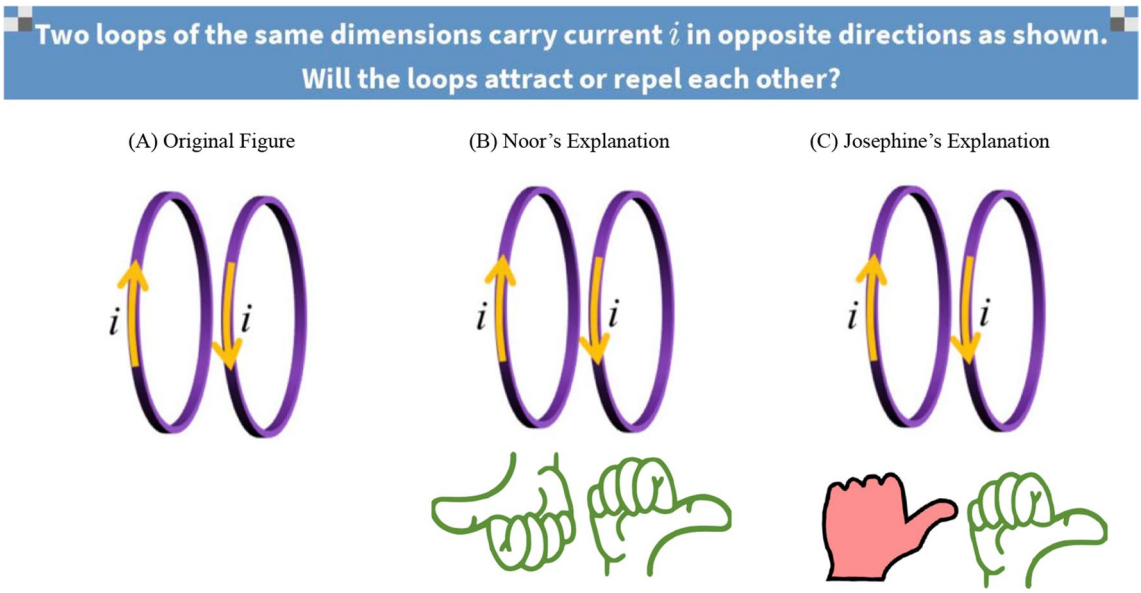

Fig. 6 The problem LA Shin and students worked on. **A** LA Shin and his group discussed the displayed physics problem. **B** Noor demonstrated her thought process using the right-hand rule. **C** Josephine tried to follow Noor's thinking, but incorrectly used her left hand while using the right-hand rule

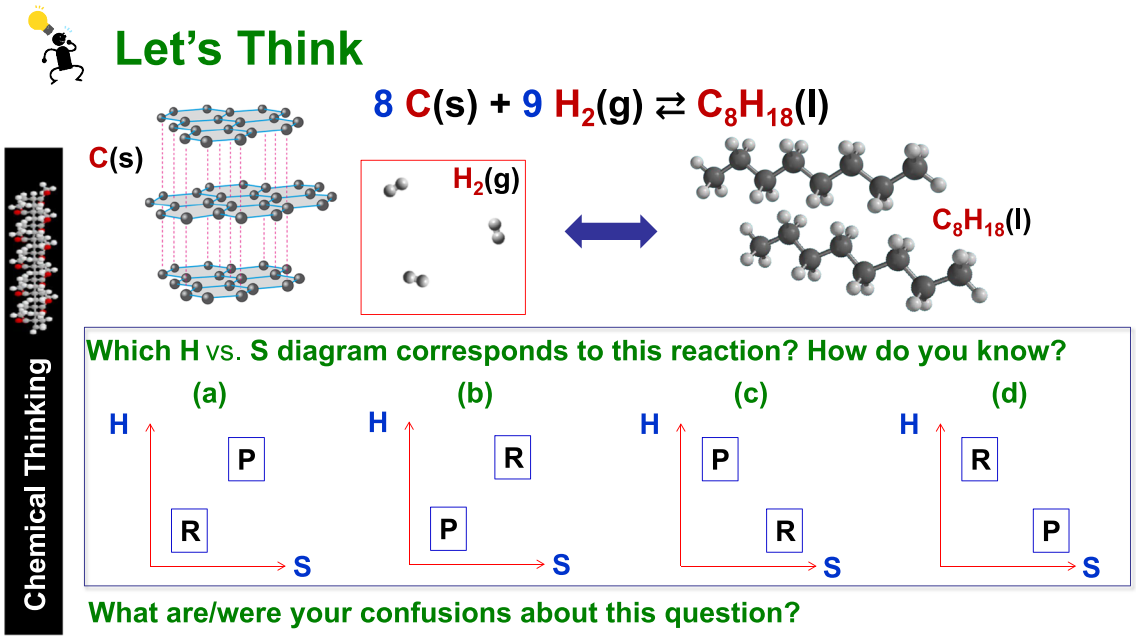

Fig. 7 The problem LA Jennie and students worked on. It is focused on making relative predictions about enthalpy (H) and entropy (S) of reactants (R) and products (P) based on the given chemical equation and structural information

directing students in this way, he thought that pointing out the mistake in this situation was appropriate because it was not a deep conceptual issue. This clarification allowed Josephine to continue following along with Noor. LA Shin advanced the conversation by directly adjusting Josephine's approach to the problem so that it was canonically correct. As was the case with LA Keap, he narrowed the scope of the conversation so that Josephine would use a canonically correct method of solving the problem.

Moderately authoritative advancing

Not all authoritative moves centered the canonically correct answer. When using moderately authoritative moves, LAs would often give students advice, guide students to different topics without focusing on correctness, or make scenarios more complex for students to discuss further. For instance, in a chemistry lecture, a group of students discussed the entropy of a reaction with their LA (Fig. 7). The students struggled with remembering the hierarchy of importance when it came to comparing different factors that make a reaction entropically favored. Specifically, the LA noticed that students were bringing in ideas about the phase changes, number of molecules, the molecule complexity, and number of configurations but not coming to a consensus on what the different ideas meant for the change in entropy. Thus, to focus the students more on one topic at a time, the LA suggested:

LA Jennie: Well maybe let's take a look at like the multi-particle level first. So what do you, let's consider the multi-particle like level there.

In response, two students gave two arguments related to multi-particle entropy.

Noosa: Okay. So looking at the multi-particle first, then it would be (b) [negative entropy], I guess, if that's like the phases. Like there would be way more configurations for gas [on the reactant side], and there's like a ton of moles.

Callum and Jisoo: Yeah.

Callum: Yeah, and there's just more moles in general [on the reactant side], which is the other multi-particle part of it, just more particles.

Noosa: Okay. So yeah, then we can say that entropy is positive.

Jisoo: Yeah.

Noosa: So. Oh no no. Sorry, that it's negative. So it would be (b).

The LA then took the conversation a step further by asking the students to elaborate more on these initial ideas. In response, the students not only justified their answer for negative entropy, but also clarified their

confusion about considering both multi- and single-particle level factors in entropy:

LA Jennie: 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?

Noosa: Well, cause there's like so much, like we know that solids are really stable, like held together in space and like more continuous, whereas gases have a lot more like variability to move around and reconfigure. So especially if there's more gases, they're likely to be more possible configurations, which would make it more entropically stable.

Callum: Yeah. And it makes sense that like the multi-particle level is more important than the single molecule level, because if you like add more molecules, they can go to any point in space, versus if you have a complex molecule, it can just kind of like configure itself in different ways. But it's not like when you add a whole extra like group of particles, I feel like that opens a lot more possibilities.

Overall, the LA advanced the conversation by aiding the students to resolve their confusions about the hierarchy of importance in factors related to entropy. Rather than directly telling the students which factors were more important to consider, she encouraged them to picture their ideas to further develop and explore their thoughts. This rendered the utterances moderately instead of very authoritative, as the LA directed the conversation by offering her perspective of which factors to consider first and giving advice about picturing ideas (beyond memorization) rather than giving a canonically correct explanation.

In another example, a group of physics students discussed the prompt "The earth pulls down on me and the floor pushes up on me. Must those forces be equal and opposite?" By the time LA Aadegil joined the conversation, the students, Alice, Max, and Cat, appeared to have reached a consensus on their answer:

Alice: We said that, um, we said yes, because in order for us to like not feel some sort of like movement or like force against us, it would have to be equal to like be keeping us along the floor, like keeping us in the same spot. And like the forces would have to cancel out so that we wouldn't move.

Max: And with every force exerted from one object onto another, a matching force is exerted back in the opposite direction. And if the only two things interacting are like you, your body, and the ground, then it's just like back and forth.

Cat: Yeah. And I was just relating that to like how when we're walking on earth, we don't really feel the effect of gravity necessarily. And so, but like we do know that it exists, and we know that there is a force coming down on us. So that force must be experiencing a force back at it from the ground like the normal force to cancel it out. So that's like, that's how I kind of reasoned that.

In his interview, LA Aadegil talked about how he noticed that the students settled on an answer. He wanted to challenge the basis of the students' answer not because of its canonical correctness but rather because of their convergence on one answer, so he asked them about a more complex scenario:

LA Aadegil: Yeah. I think you guys have parsed this pretty well, and you have like of course your lived experience, and then you brought up Newton's third law, Max, which is, I think, one of the, a big thing here. So my question to you guys is, so earth, the gravitational force of earth is coming from where?

Alice: Um, the core?

Maxine: Yeah.

LA Aadegil: So does it make a difference that, like, does it make a difference to you guys that you're not interacting with where the force is coming from, if that makes sense? So like if each, like you're saying, each force is a polar opposite force between two objects, right?

Alice: Hmm hmm.

LA Aadegil: So, but if I'm on like, like right now I'm on the 4th floor of a building. The force between me and the floor, is that, do you still say that's the polar opposite to the force of the earth and the core, even though like I'm not standing on the ground level?

Together, these utterances constituted the LA's attempt to advance the conversation and refine their understanding by having them consider a more complex scenario he came up with. As he stated in his interview, his actions were driven by his desire to challenge the students. Therefore, in contrast to Shin and Keap's very authoritative advancing guided by the canonical perspective, this example and the example of Jennie illustrate moderately authoritative advancing guided by the LA's perspective.

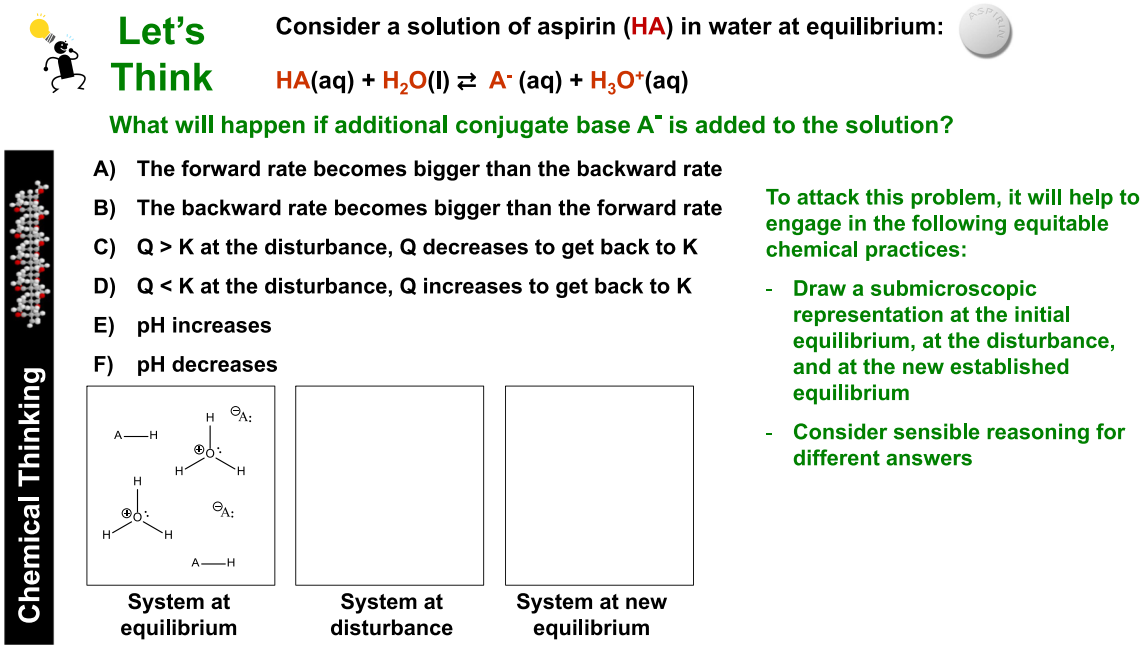

Fig. 8 The problem LA Rain and students worked on. It is focused on using kinetic and thermodynamic thinking as well as thinking on the submicroscopic level to make predictions about pH changes after disturbance of an acid–base equilibrium

Moderately dialogic advancing

Other interactions showed LAs similarly aiming to challenge student ideas by using ideas from other outside sources. For example, in many of the classes in our study, student groups summarized their small group discussions on online discussion boards during lecture. LAs sometimes used perspectives posted by groups other than the group they were interacting with and brought those additional outside ideas into the discussion. For multiple-choice problems, some LAs brought in other outside ideas by referencing another answer choice the group had not chosen. Because these actions included multiple voices and ideas, we consider them dialogic. However, since they did not rely solely on the voices and ideas of students present in the discussion, we categorize them as moderately dialogic. When LA Rain and a group of chemistry students discussed a multiple-choice equilibrium question with multiple answers, the group settled on three answers very quickly: B, C, and F (Fig. 8).

The LA noted the students had not talked about all the answer choices explicitly. Thus, the LA asked the group the following question: "*So can you guys think of any reasons why D would work, if at all? I know some of you picked it. Like was there a rationale behind it?*" In response, one student, Chantel, said: "*I mean, you could think of D as in, there's already, there's more products on that side, so to meet that like regulation of product, balance out the H.*" Chantel implied that because A^- was being added, answer choice D could be justified by balancing out the H. This answer choice was logical to the LA, so she asked: "*But then what makes C more correct?*" In this case, the two utterances together acted as a dialogic move because the LA encouraged the students to compare other logical answers to their selected answer, thus allowing the conversation to contain multiple perspectives. The specific questions that the LA asked did not direct the students towards one answer or one correct way of solving the problem, but instead centered two different answers and how they compared to one another.

In a very similar example, a group of physics students determined the direction of the acceleration vector of a ball speeding up in circular motion. They were given five answer choices (Fig. 9), and the student Piper described the group's answer as follows: "*We were talking about just how the acceleration values would always point radially inwards, and so that, the acceleration for this ball should have the arrow pointing towards the center and starting out where the ball is [number 1].*" Like LA Aadegil, who used moderately authoritative advancing in response to his students coming to an agreement on one answer, LA Catherine recognized that the students agreed to an answer quickly and wanted to challenge the students' answer—specifically mentioning in her interview that she wanted them to consider more perspectives than the one they agreed to. Thus, she responded with: "*That makes a lot of sense. What would you think [say] to somebody who said number 3? [the vector tangent to the circle (*Fig. 9*)]*".

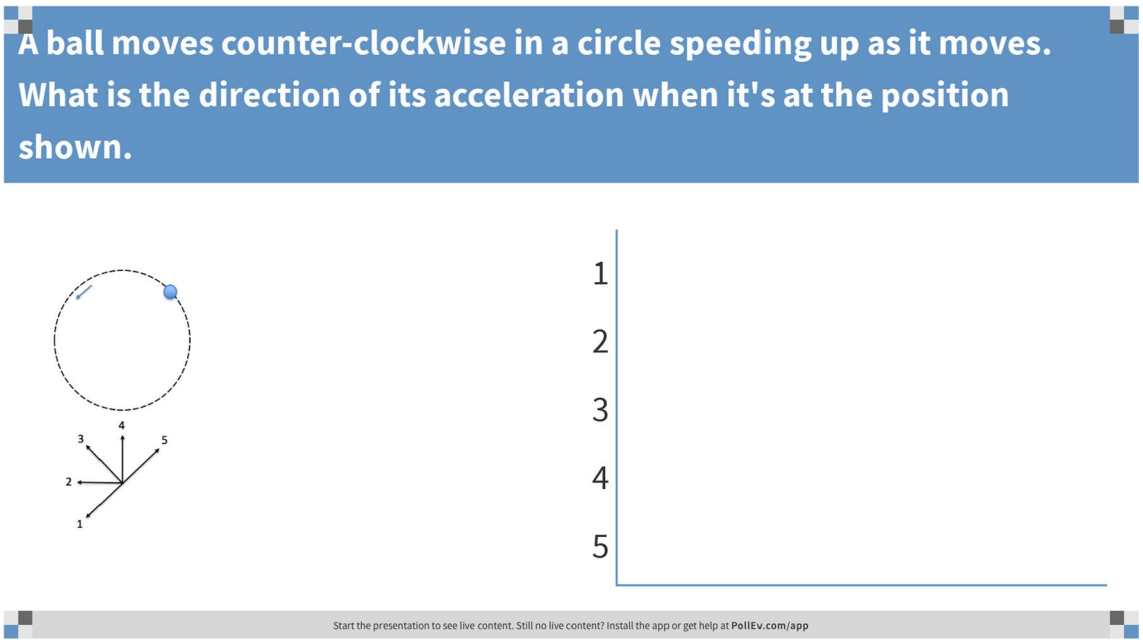

Fig. 9 The problem LA Catherine and students worked on. It is focused on determining the acceleration vector of an object moving in a circular path

Catherine advanced the conversation by including multiple ideas that may further develop student thinking. Unlike LA Aadegil, who asked questions from his perspective to make the discussion more challenging, LA Catherine challenged the students by asking them to consider the point of view of somebody who selected a different answer choice and respond to that person. Like LA Rain's utterance, this question did not hint towards the correct answer but instead encouraged the consideration of a more diverse set of ideas. In fact, the LA admitted in her interview that she did not think about the question enough to determine a correct answer.

Very dialogic advancing

Even more dialogic advancing actions opened the conversation to include multiple perspectives introduced by the students rather than the LA. Often, these actions involved LAs asking students to elaborate or justify their own answers such that they independently develop a more advanced argument for their answers. LAs also encouraged students to continue thinking using their own perspectives, as shown in the following examples. In a chemistry lecture, a group of students discussed with their LA the entropy of a reaction. The students brought up arguments that centered different factors related to entropy:

> *Zoe: For the entropy change of the products versus the reactants, I looked at the phases, and noticed that it's going from a liquid to gas, so that means that the, there's a rise in entropy on the formation of the products. So that gives rise to a positive change in entropy.*
> *[...]*
>
> *Zara: I tried to think about configurations, but I didn't get there quite…*

Noticing that Zara did not get a chance to finish their thought, the LA asked whether the student wanted to discuss configurations, to which they replied that they were confused:

> *LA Cosog: Do you want to try to dive into configurations a bit now, or if anyone would like to dive into configurations?*
>
> *Zara: I'm still kind of confused on configurations, so I'd like to not, actually.*
>
> *Zoe: We think it's like basically like, I think it's basically like, I mean, I don't know if I'm 100 percent right, cause I definitely am struggling with that too. That's one of the harder ones for me, is like the arrangement of like the subatomic molecules and particles, I think, or like, yeah.*

After the two students, Zara and Zoe, explained their confusion to the LA, the LA asked a third student in the group, Milo, if she had any thoughts. The student replied:

Milo: Yeah, I'm also confused about the configuration thing. So, I guess looking at this obviously the reactants have more, like a more complex molecule than the products. And so given that, there's more likely more configurations in the reactants than in the products.

Noticing this student's confidence about the complexity being related to the configuration, the LA asked: "*I'm curious. What's necessarily making you say that one of them's definitively more complex? [...] Like what are you basing that off of?*" These utterances were advancing moves because the LA wanted the students to further elaborate on the initial ideas they brought up. These utterances were also dialogic because they involved the students bringing in multiple different ideas and answers, making the conversation multivocal. However, unlike the utterances made by LA Rain and LA Catherine who introduced outside perspectives to the conversation, LA Cosog's utterances focus completely on the student group in front of him. Specifically, he encouraged Milo to use her ideas to help alleviate the confusions of Zara and Zoe.

In an example from a physics lecture, a group of students discussed how the electric potential energy and charge of a capacitor changes when its plates are separated. One student, Cheki, voiced a confusion about the purpose of a battery, something that was brought up in the group multiple times:

Cheki: This one confused me, cause this one's going back to the battery's still connected for the whole time. But there could be other one, I don't, yeah, it was disconnected on the other one. And the fact that each question specifies whether or not the battery's still connected leads me to believe that that definitely changes something. For this, I believe I said that charge stayed the same, and then electric potential would increase, and I think the electric potential would increase for the same reason that we were thinking about for the one I put before this. But then I didn't see why charged would change. But also for like the voltage of the capacitor, if it's still connected to the battery, I don't see why that would change. So maybe they do both stay the same and I agree with [inaudible]. That's why I was confused. Is it still being connected to the battery aspect of it?

In her interview, the LA described noticing that this idea was brought up but never addressed by the whole group. Thus, the LA tried to flesh out the ideas the students had about this confusion:

LA Rose: Yeah. So what is your, do you have an idea of what the battery might be, like, contributing, or are you just not sure? When you were thinking through this, did you have kind of an intuition? Or anyone can answer that.

Here, LA Rose recognized that Cheki was thinking about the conceptual aspects of the problem—what a battery does and how that will affect the capacitor—which gave her the opportunity to discuss the students' intuitions about the problem. In discussing these ideas, she advanced the conversation by encouraging students to use their intuitions to address the confusion. This utterance was dialogic because LA Rose gave space for students to continue conversation and solve problems together using their own ideas, giving room for multiple points of view. This example is similar to the first very dialogic example in that both LA utterances foregrounded student ideas in a broad and open way; the example contrasts with the authoritative examples of LA Keap and LA Aadegil, where correct or more complex ideas came from the LA in the form of closed questions that centered particular ideas. What differentiates the interaction of LA Rose from the moderately dialogic utterances of LA Rain and LA Catherine is that LA Rose advanced the conversation using the ideas of the students in the participating group instead of ideas of students outside the group. Thus, like LA Cosog's interaction, LA Rose's interaction is the most dialogic on the spectrum with regard to the power the participating students' perspectives have in the discourse.

Eliciting spectrum

Very authoritative eliciting

The eliciting moves that the LAs used can also be categorized using the authoritative-to-dialogic spectrum described for advancing moves. Like the very authoritative advancing moves, the very authoritative eliciting moves centered the canonically correct perspective in the conversation. LAs used these types of moves when they would ask students questions with the intention of assessing their correctness. Very authoritative eliciting moves differed from very authoritative advancing moves because the latter focused more on pushing student thinking forward to a correct answer while the former focused more on evaluating correct student thinking. In the following example, a chemistry LA joined a group of students as they discussed the increasing boiling points of isobutane, methoxyethane, and acetone. The students started out the discussion by relating polarity to the boiling point:

River: But then as you go the right [from isobutane over methoxyethane to acetone], like they're polar, so it's going to be more, it's going to be more difficult for you to separate the atoms, so you're going to need more energy, plus the higher boiling point.

The LA recognized the validity of their ideas, but also noticed that the students did not specifically bring up the different types of intermolecular forces. Believing the

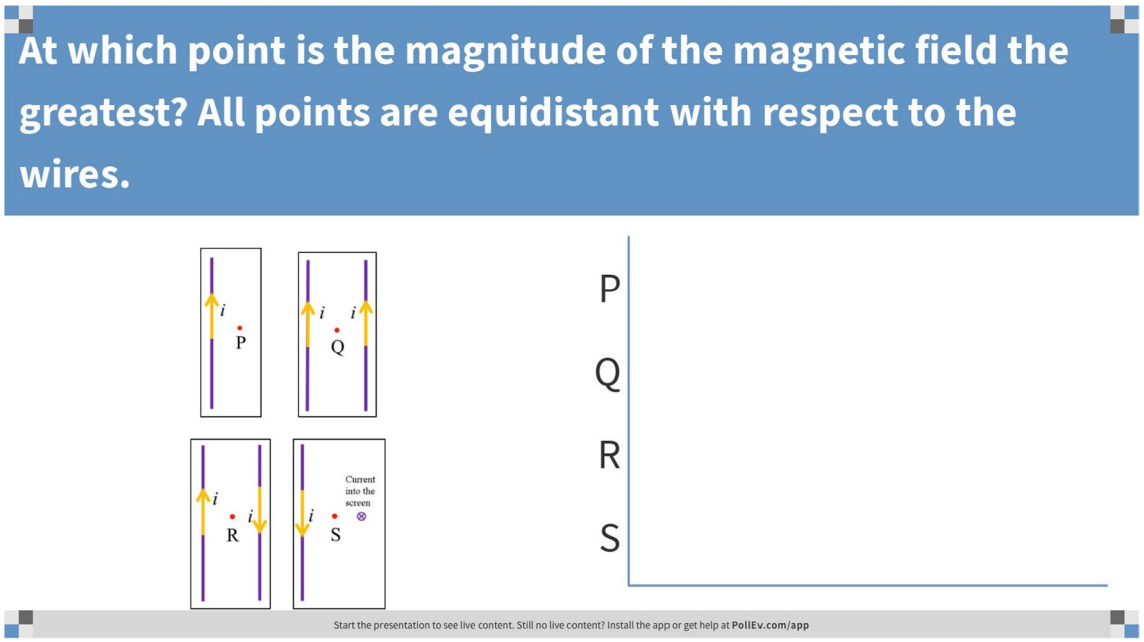

Fig. 10 The problem LA Rose and students worked on. It is focused on determining the magnitude of the magnetic fields generated by current carrying wires

students might not have realized the complexity of the problem, she said:

> *LA Fisha: Yeah. That's a great thought. So you see that the correlation, the relation between the boiling points and the intermolecular forces. So yeah. The higher the boiling point it is, then you need to overcome— Like the intermolecular forces are strongest, and you have to overcome that. Yeah, that's a great start. So before we proceed, can someone tell me the two types of intermolecular forces that we've just learned?*

By asking about the concepts the students had just gone over in lecture, LA Fisha hoped to make sure the students knew the foundational information they needed to discuss the question in more depth. She further demonstrated this with her follow-up question: "*When we talk about dispersion forces, what did we specifically like consider when we are comparing the strength of dispersion forces?*" LA Fisha's initial moves were very authoritative because they directly related to the content needed to correctly answer the question. Further, they were eliciting because they assessed the students' knowledge.

While LA Fisha assessed student knowledge at the relative beginning of a problem-solving process so that the students could build further on what was explained in lecture, other LAs, like LA Rose, chose to do so after students settled on an answer. In this example, LA Rose joined a group discussing a problem that involved the right-hand rule (Fig. 10). The students in the group had quickly settled on an answer:

> *Abby: I personally said that R, I think, would have the highest value. So I can like just go through the way that I thought about it, even though like massive disclaimer. I definitely am not sure in any way, shape, or form. But I thought that if we use like the right-hand thumb rule, then the magnetic field would get added up at R, and that would be equal to twice the magnetic fields at P and Q after like I did that. And then I thought the magnetic field at Q would actually equal to zero. So basically when I like tried plugging in all of that as well, that was kind of what I got. But again, I don't know if it's right. So I would love to hear other, what other people got for that.*
>
> *Joelle: I also got R for basically the exact same reasoning. And I just basically used the same methods, the right-hand rule. I got the Q, the fields would cancel out, so like you said, and that P would be half of that of R.*
>
> *Lin: Yeah, me too.*
>
> *Cree: Me too. Same thing.*

Knowing that students in general got confused due to the many different types of right-hand rules, the LA asked:

> *LA Rose: Yeah, so I know that like, at least just like as a class in general, there was kind of a lot of confusion about the right-hand rule initially, like because there are quite a few variations, and kind of knowing when to use them. Did you find that you like struggled with this question because of that, or did this kind of help clear things up? Like did you all use the one where like you put your thumb in terms of the current, and your hand wraps around?*

The LA felt this question was important to ask even though the students already came to an answer so quickly because she wanted to make sure all the students were on the same page. The utterance was very authoritative because it evaluated whether the students were using the correct right-hand rule. It was also eliciting because the students had already come to an answer, so the LA was finding out about their process rather than pushing them forward.

Moderately authoritative eliciting

Much like moderately authoritative advancing moves, moderately authoritative eliciting moves center the LA's perspective. Often, this was presented as the LA choosing a certain line of thinking being discussed by a student and highlighting it for the rest of the group. Often, the LAs would ask if other students would agree to this highlighted line of reasoning, or they would ask students specific questions that expose their thinking. For example, LA Daisy was working with a group of chemistry students as they discussed the "rate vs. concentration of O_2" graph of the reaction "$O_2 \rightarrow 2\ O$." One student, Dante, seemed to have a confident grasp on the material:

> *Dante: I think it's unimolecular, cause you have one thing at play. Not to be confused with bimolecular or termolecular reaction, as we all know now. So these things buzzing around, it would kind of be the same as the example we just got, right? [. . .] it's just going to be a linear equation, because the O_2 isn't being squared or anything. It's just a standalone variable in the first order.*
>
> *Eric: Yeah. [Ariel starts to speak but gets cut off]*

Having worked with this group before, LA Daisy knew that Dante tended to speak the most, and she believed that the rest of the group tended to just agree with what he said. She thought that they might not be as confident in their answers as he was. To give the other students more room to speak, she asked: "*Will that be in the positive direction, do you think, Arie1, or do you think it'll go in the negative direction?*".

This utterance was still authoritative because it minimized the space of what could be said in the conversation. This was because the LA herself highlighted one student perspective (Dante's) as correct. However, the utterance is only moderately authoritative because LA Daisy involved another student who had not had the chance to contribute her ideas and did not intend assessing whether the student knew whether the slope would be positive or negative. Instead, she was more concerned about giving more students the chance to speak, and specifically in this case a student who was cut off earlier. Similarly, the utterance was eliciting because the LA was more focused on hearing from more students than advancing the ideas they had.

In a similar example, LA Dan was working with a group of physics students to discuss different scenarios of two carts colliding. In general, the LA noticed that the group was rather unresponsive, with one student mainly talking with him. Thus, when the most dominant student summarized his ideas, LA Dan asked the group: "*Were you guys thinking something similar?*" In a more indirect way compared to LA Daisy, LA Dan tried to involve more students by getting them to build off of the more vocal student. This was moderately authoritative because the LA highlighted one perspective—the dominant student's idea in the conversation. The utterance differs from the very authoritative utterances of LA Rose or LA Fisha because it did not highlight the canonically correct concepts needed to answer the problem. And much like the other eliciting moves, this utterance had a purpose of uncovering student thinking.

Moderately dialogic eliciting

Both moderately dialogic advancing and eliciting focus on an intermixing of perspectives in the conversation. While moderately dialogic advancing involved the intermixing of outside perspectives with the perspectives of the students in the group, moderately dialogic eliciting involved the mixing of multiple perspectives within the group itself, mainly due to the "uncovering" nature of eliciting moves limiting the number of perspectives that can enter the conversation to perspectives that students in the group bring forward. In general, these moderately dialogic eliciting moves focused on the group itself and whether they had room for their ideas rather than the ideas they had. For example, most often, the LAs would ask students if they had other ideas to contribute besides the ones already discussed. To exemplify, LA Salvador was working with a group of chemistry students as they identified several molecules as polar or nonpolar. The students started out by identifying acetone as polar due to its oxygen being electronegative and the dipole moment pointing towards the oxygen. The LA validated their reasoning before asking: "*Does anybody think anything else in terms of how they would explain it? You did a fabulous job, but I just*

want to see how other people would interpret it." The LA wanted to encourage everyone to share their ideas, which made the move eliciting. Unlike the authoritative eliciting examples, LA Salvador does not limit the scope of the students' answers to the canonically correct perspective or to the ideas of one person in the discussion. Instead, he opens the floor for more ideas and interpretations, making the utterance moderately dialogic.

In a very similar example, LA Este and a group of physics students discussed a question about light refraction in a water droplet. When the group was asked whether the light would be fully or partially refracted, one student responded:

> *Jupiter: I guess I would say like does it partially, if it partially refracts, does it depend on like how it hits the water droplet? Cause when I thought about it, I just thought it would like totally refract, but I didn't know.*

Seeing that other students agreed with Jupiter's statement that light orientation would affect the refraction, the LA said: "*That makes sense. Any other—Yeah, I see Julius nodding as well in agreement. Any other thoughts?*" By acknowledging Jupiter's contributions and vocalizing Julius's nodding, the LA aimed to make the students more comfortable in the conversation. She hoped this would help center the students more, especially since the group was rather quiet. Like LA Salvador's utterance, LA Este's utterance elicited other student ideas from the group directly by asking for more thoughts and indirectly by creating a supportive environment that encouraged participation. Also like LA Salvador's utterance, this utterance was moderately dialogic because it encouraged the students to bring other perspectives into the conversation than the one already vocalized.

Very dialogic eliciting

Very dialogic eliciting is much like very dialogic advancing in that both center the perspectives of the students in the group only. While moderately dialogic eliciting moves also center the students in the group, the two differ because very dialogic eliciting focuses completely on the lines of reasoning brought in by the students. LAs would often rebroadcast student ideas and ask students to clarify the reasoning they had mentioned. On the other hand, when LAs used moderately dialogic eliciting moves, they would ask for more ideas, making the focus of the conversation more on the group itself than the ideas they shared. In the following example, LA John discussed with a group of chemistry students the same "$O_2 \rightarrow 2\ O$" reaction as LA Daisy did. After establishing that the "rate vs. concentration of O_2" graph was a positive linear function, the students started discussing how a graph of "concentration of O_2 vs. time" would appear. One student explained their ideas:

> *Anby: The rate increases as the concentration of O_2 increases. So, but if it's just, if we're just saying, like at a certain rate. Like say that the rate is fixed. Like if we're working with just like one specific rate, then like how is the concentration going to change over time, if that makes sense? Like I'm trying to—That's not a good way of explaining it. Like there are two separate like—Yeah, that's not a good way, yeah, not a good way of me explaining it, but—*

Noticing that the student was having difficulty, LA John tried to rephrase what Anby was saying so they could confirm or deny the accuracy of his rephrasing and expand on what they meant: "*If I'm hearing you right, are you saying like we're taking a specific point on the first graph?*" This utterance was eliciting because the LA was trying to understand what Anby was saying. Further, it was very dialogic because it highlighted how the student was talking about the problem in the moment. Unlike LA Salvador and LA Este's moderately dialogic eliciting moves, which encouraged other students to contribute their ideas, this move centered the students' ideas rather than made room for more ideas. And unlike LA Daisy and LA Dan's moderately authoritative moves, which highlighted student ideas as well, this move gave space for the student to clarify their ideas rather than move along the problem with the same line of reasoning.

LA Raul used a similar utterance when discussing the following prompt with a group of physics students: "I lift a 5 kg [block] from the floor to a height of 1 m, carry it 4 m, then set it back down on the floor. What is the total work I did on the block?" Raul had revealed in his interview that he did not know how to solve the problem, so he decided to try to solve the problem alongside the students. At one point, one student who had originally thought the answer was 200 Joules said the following:

> *Tenzin: Now that I'm thinking about it, I also think that it's zero. I guess using the same concept of like things canceling each other out. So essentially like when you pick it up, that pickup, like that force that you use to pick it up is being cancelled. Like it's a negative force on the other side when you like bring it back down, whichever way you're looking at it. And so that becomes potentially zero net like work done on the vertical direction. But on the horizontal direction, when you move it from one place to the other, like when you like start moving it and then when you go to the end, when you slow down to stop it from its like continuous, or whatever motion that it's going through, like that addition of force, and*

then as you like slow down, that like subtraction of force, I guess like essentially, the positive and negative like cancel out.

The LA thought that this reasoning was logical, and followed up with:

LA Raul: Okay. So you're saying like the putting it up and down cancels out, and then when you're going across, the fact that you have to stop at the end cancels out with the force across?

After the LA followed along with the student's argument, he rephrased what he heard the student say. This was especially important to him because the student had changed answers. Much like LA John, LA Raul tried to clarify what the student was thinking, which was a very dialogic eliciting move. Both LA John and LA Raul represent the most dialogic moves on the eliciting spectrum because they centered student thinking without involving outside concepts or ideas.

Summary of the authoritative-to-dialogic spectrum through the lens of power

The perspectives the LAs centered on the authoritative-to-dialogic spectrum are based on varying power differentials between LAs as facilitators and students. The very authoritative perspective created the highest power differential between the LA as the facilitator of the discussion and the students because the perspective that drives the conversation comes from an institutional position of more power, i.e., the LA position, and it comes from a position of power in the STEM field, i.e., canonical correctness. The moderately authoritative perspective created a lower power differential between the LA as the facilitator of the discussion and the students because the perspective that drives the conversation comes from an institutional position of more power, i.e., the LA position, but does not come from a position of power in the STEM field, i.e., canonical correctness. The moderately dialogic perspective created a lower power differential between the LA and the students than the moderately authoritative perspective because the perspectives introduced into the conversation are not the ones of the subject with institutional power, i.e., the LA, even though the LA has authority in deciding to bring in additional perspectives. The very dialogic perspective created the lowest power differential between the LA as the facilitator of the discussion and the students because it gives the most power to the students themselves.

Limitations

While the holistic approach of narratives had the advantage of better aligning with sociocultural theories by capturing LA moves as they relate to purposes rather than capturing every utterance with the assumption that each utterance is intentional (Leont'ev & Cole, 2009), it led to authoritative eliciting moves being very rare in comparison to how often they occurred in Dini et al.'s (2020) study. This was because advancing actions sometimes consisted of smaller eliciting moves and advancing moves with a greater purpose of advancing. For example, the LA for whom we represented a narrative in Fig. 3 said the following during her interaction with the student group:

LA Azari: Make a graph. Yeah. But through that, she [the professor] just wants to make sure you have an understanding of how the molecules collide, and endothermic, exothermic, intermediates, bimolecular, unimolecular. Just like, these are terms that you're eventually going to learn, but this exercise is aimed at making sure you like just talk about, how does it get to that chart? You know. So in like this slide, what do you guys, like what's happening here? Just like talk about it. What's going on? Are the bonds breaking? Is there a bond being made? Is it endothermic, exothermic?

While the questions the LA asked at the end of this utterance were authoritative eliciting individually, in the context of the entire utterance and in the context of the LA's purpose and facilitation pattern during this interaction with this group of students, there was stronger evidence supporting coding of these lines as authoritative advancing because they aimed to give clues and guidance to the students to help them solve the problem.

Furthermore, employing narrative inquiry comes with the typical limitations of the methodology. Since narrative inquiry neglects objective reality, it is inevitable that the narratives are subjective (Moen, 2006). In line with recommendations for narrative inquiry (Moen, 2006), we took several measures to ensure the quality of our study given this limitation: we made sure during interviews and data analysis that we carefully listened to LAs and understood their perspective. We also triangulated recordings of LA–student interactions with LA interviews to capture what we observed in the interactions alongside how the LAs perceived it. Along the entire research process, we were aware of our subjectivity and involved multiple researchers with different positionalities, i.e., the first and the second author had both been students in LA-supported classes, the second author had been an LA in her past, and the third and corresponding author are both instructors teaching with LAs. The extensive data analysis process (Fig. 2) ensured we were intentional about our interpretations along the way and was accompanied by multiple levels of consensus-seeking checks.

Our way of organizing the authoritative-to-dialogic spectrum from most power differential between LA and

student perspective to least power differential between LA and student perspective is not the only way one can think about an authoritative-to-dialogic spectrum using the perspectives centered in the conversation. For example, consider how we positioned moderately dialogic and very dialogic on the spectrum. We saw LA moves based on the perspective of the students in a group alone as more dialogic than LA moves that include the perspective of outside sources because they center the perspective of the participating students to a greater extent, and thus the LA does not direct authoritatively in any way. However, if one focuses less on the power differential between LA and students derived from Freire (1968/2000) and more on the number of perspectives included (Mortimer & Scott, 2003), one may interpret the act of including outside perspectives as more dialogic, as it can lead to the inclusion of more voices and ideas, i.e., become more multivocal. Nevertheless, we decided to emphasize power dynamics between LAs and students in placing moderately and very dialogic facilitation on the spectrum because the act of asking for perspectives outside of the current train of thought of the student group can not only limit the dialogue to what the LA introduces but can also create an unequal dialogue between the LA and the students. Given the dominance of authoritativeness imposed by instructors on students (e.g., Alkhouri et al., 2021; Chin, 2006; Coffey et al., 2011; Kranzfelder et al., 2020; Lederman et al., 2013; Patchen & Smithenry, 2013; Rosebery et al., 2016; Roth, 2009; Russ et al., 2009; van Es & Sherin, 2002), we thought the power differential between LA and students was more important to emphasize than the number of student views included in the conversation.

Basing our characterization of LA facilitation practices on the FAEM (that was developed in the context of K-12 science teaching) constrained what we captured about LA practices to the facilitation of student learning through discourse. This means we did not capture effects of LAs such as role modeling, building community outside of class, and changing classroom practices through their role as instructional partners of faculty (Hite et al., 2021; Jardine, 2020; Winterton et al., 2020). Situating our work in the formative assessment system described by Jardine (2019), we only captured what the LAs noticed about students and how they acted upon that noticing in their interaction with the students and did not include mechanisms such as LAs reporting back to the faculty they work with. While this limits the scope of our work, characterizing LA actions through the lens of authoritativeness and dialogicity enables us to capture how LAs enact their role as near-peers in their facilitation of student disciplinary thinking. For example, LAs who used moderately authoritative advancing moves often gave advice on how to tackle a conceptual challenge based on what had helped them when they were a student in the class.

In our holistic description of LA facilitation practices, we included certain factors such as purpose, noticing, and interpreting, while other factors that influence facilitation were not examined because this study focused on the microcosms of LA–student interactions in order to characterize the nature of LA facilitation as it relates to LA purposes. There are other factors that also influence what LAs do during their facilitation such as rules of the classroom, goals of the professor, training of LAs, context of the classroom environment (remote or in-person), etc. For example, two of the professors in our study had vastly different expectations for their LAs and students. LAs in one of these classrooms enacted actions more often on the authoritative side of the spectrum while LAs in the other classroom enacted actions more often on the dialogic side of the spectrum. Based on our analysis presented here, the purposes we describe explain the actions the LAs took, but in order to explain differences across classrooms, we need to explain what is informing the different purposes in the first place. This will be the focus of our future work within the larger project.

Discussion

The development of an authoritative-to-dialogic spectrum adds to the existing FAEM as well as the existing conceptualization of authoritativeness and dialogicity (Dini et al., 2020; Freire, 1968/2000; Mortimer & Scott, 2003). As mentioned previously, our work is not the first to identify the existence of a spectrum of moves between authoritative and dialogic. While previous studies either used the second dimension of the communicative approach (Mortimer & Scott, 2003) to further shed light on differences in authoritative and dialogic facilitation (Lee & Kim, 2016; Tee et al., 2022) or justified the existence of a middle-ground without further characterizing it (Van Booven, 2015), our work is the first to use a theoretical approach with respect to the degree of authoritativeness and dialogicity in defining the spectrum. Our work not only outlines specific degrees of authoritative and dialogic discourse alone as one communicative dimension, but also draws on the justice-oriented definition of dialogue from Freire (1968/2000). Compared to mixing the dialogic-authoritative dimension with the degree of interactivity (Tee et al., 2022), the affordance of our more nuanced focus on the dialogic-authoritative dimension is that it foregrounds the substance of views brought in, where they are coming from, and how they influence power differentials between views.

Given our study context, our elaboration on the spectrum of authoritative-to-dialogic facilitation practices is directly applicable to LA practices. Thinking about the transferability of moves on the authoritative-to-dialogic

spectrum to other instructors, such as TAs, professors, or K-12 teachers, literature evidence that LAs use more reformed teaching practices than other instructors (Gray et al., 2016; Luckie et al., 2020; Ruder & Stanford, 2020) indicates that it might be more difficult for other instructors to fully use the dialogic side of the spectrum. Additionally, the role of an LA is different than that of any other instructor as they are aids to students, supporting their learning instead of focusing also on planning lessons and evaluating students (Barrasso & Spilios, 2021), which makes the power differential between other instructors and students likely larger than that between LAs and students (Winterton et al., 2020). This might complicate the transferriblity of LA facilitation practices to other instructors. However, there are also some arguments for why learning from the dialogic-to-authoritative spectrum seen in our LA-focused study might be particularly beneficial for other instructors who interact with students in group discussions as the LAs do. For example, it might be easier to employ moderately authoritative or moderately dialogic moves than directly switching from authoritative expectations implemented in traditional classrooms to very dialogic moves. In the context of our larger research project, we have also collected video data from whole class discussions led by the professors of the classes and we see evidence of actions employed by the professors along the whole spectrum. Future research is needed to investigate whether and how professors, TAs, and K-12 teachers employ the perspectives of the authoritative-to-dialogic spectrum found in this LA-focused study.

Returning to the LA literature, most work has focused on student outcomes in LA-facilitated classrooms (Alzen et al., 2018a, 2018b; Herrera et al., 2018; Miller et al., 2013; Sellami et al., 2017; Talbot et al., 2015; Van Dusen & Nissen, 2020; Van Dusen et al., 2015, 2016) and some work also proposed mechanisms through which LAs can support students, such as social support as well as cognitive and affective roles of LAs (Hernandez et al., 2021; Kornreich-Leshem et al., 2022). While other studies explain some of these benefits through what LAs do beyond their facilitation of student class discussions, such as through serving as role models for students or faculty consultants (Jardine, 2020; Winterton et al., 2020), our research adds to this work by demonstrating how LAs provide some of these benefits directly through their facilitation. The authoritative-to-dialogic spectrum of eliciting and advancing actions we describe moves knowledge in the field about what LAs do specifically from a detailed focus on the variety of moves (Knight et al., 2015; Thompson, 2019; Thompson et al., 2020) to a more in-depth investigation of broader categories of actions by contextualizing what drives these actions, focusing on the perspectives LAs lean on to achieve certain purposes. Our future work within the larger research project will expand connections between LA facilitation and the nature of student responses (Knight et al., 2015) towards the specific mechanism of how the different eliciting and advancing moves LAs employ affect student learning.

One potential application of our research is in LA training. As part of the LA model, LAs are required to take a pedagogy course to improve their facilitation practices (Otero et al., 2010). Since it has been found that LAs' pedagogical knowledge about formative assessment grows less in the pedagogy course than other areas (Top et al., 2018), the application of our research findings in the pedagogy course can contribute to filling a gap in productive learning opportunities for LAs. In spring 2022, the authoritative-to-dialogic spectrum was integrated in the LA pedagogy course at our own institution. After an introduction to the spectrum, LAs engaged in mock discussions with three LAs as students and one as an LA about open-ended STEM problems while the other LAs observed the group. Afterwards, they had a discussion of what moves they saw the LA making and where they would categorize it on the authoritative-to-dialogic spectrum. This lesson was one of the highlights of the semester as informal observations demonstrated how throughout the entire semester LAs connected other topics such as student resources (Campbell et al., 2016) or status during group interactions (Horn, 2012) back to authoritative and dialogic facilitation. The LAs reported to the pedagogy instructor (corresponding author) that they found it specifically helpful to see the different options on the spectrum and felt that they could directly draw on the examples from the research for their practice leading to a diversification of their practices. These informal observations and reports need to be systematically studied in future research.

For LA and possibly other instructor training, the spectrum can be valuable in helping facilitators navigate the tension between authoritative and dialogic actions. For example, if a facilitator wants students to rely and expand upon their own point of view, and yet their ideas do not seem productive towards canonical science development that the facilitator is also hoping for, then this facilitator might experience a tension. Very authoritative facilitation does not seem entirely appropriate for this facilitator as it would lead away from student thinking and towards thinking in the canonically correct way. Very dialogic facilitation also does not seem entirely appropriate because it would not lead to canonical science. Moderately authoritative or moderately dialogic facilitation could be helpful to resolve this tension because students might feel more empowered to rely on their own perspective by engaging in dialogue with an instructor or outside perspective that does not claim to be canonically correct.

Through this dialogue students can expand their point of view and progress toward canonical correctness may be made. It is important to note that the use of the entire spectrum including very authoritative moves is beneficial for student learning. For instance, it was important for LA Keap to use very authoritative advancing moves to correct the use of chemistry symbolism as this aligned with her purpose under the time constraint. If LA Keap had goals that required a more dialogic facilitation in addition to correcting the use of symbolism, she could have also combined this with other parts of the spectrum, such as by inquiring what the students intended to communicate with their use of symbolism or what reasoning may be behind different uses of the symbolism. The various purposes, affordances, and constraints in different classroom environments require all parts of the spectrum to be in use, making it a valuable training tool.

The authoritative-to-dialogic spectrum may ease the difficult transition towards more dialogic practices in classrooms (Coffey et al., 2011; Russ et al., 2009), which is important in the development of an equitable classroom that supports students as autonomous builders of sense and knowledge (Cherbow & McNeill, 2022; Kaya & Ahi, 2022; Kim, 2021; Oh et al., 2022; Soysal, 2021; Soysal & Yilmaz-Tuzun, 2021). As stated previously, authoritative facilitation practices are over-represented in classrooms despite a call for more student-centered classroom discourse (Coffey et al., 2011; Russ et al., 2009). While directly transitioning from very authoritative practices to very dialogic practices may be difficult, utilizing intermediate categories may allow instructors to gently incorporate different strategies in the classroom that aim at equity of individuality by lifting marginalized voices up. For instance, moderately dialogic eliciting may be used to incorporate marginalized voices in group work. Moderately dialogic advancing might have utility in raising ideas not vocalized in the conversation that others might have been thinking about. It may also highlight the power of other ways of knowing that are often marginalized in science classrooms or encourage students to actively engage with other ideas compared to their own. And of course, very dialogic advancing and eliciting centers student ideas and experiences and may encourage them to take ownership over their ideas.

It is important to acknowledge that a more dialogic move is not always more equitable than a more authoritative move. For instance, an LA can use their authority, or a more authoritative move, to direct students away from what they have been discussing to invite other perspectives and open up room for marginalized voices. Still, it is easy to see how an authoritative voice can also easily limit marginalized voices and open space for dominant ones. This often came up in the data when LAs would ask to hear other thoughts because the thoughts presented were wrong or the LA did not understand the thoughts presented. As such, a transition towards including and balancing dialogic practices alongside authoritative ones in classroom discourse is especially important to value and develop student thinking.

Conclusion

The authoritative-to-dialogic spectrum of LA facilitation practices adds to theory around authoritative and dialogic practices as it reconsiders what perspectives can drive LA enactment of facilitation other than the perspective of canonically correct science (very authoritative) and the perspective of the students involved in the discussion (very dialogic). If an LA employs their perspective without the claim of being correct (moderately authoritative), it allows the LA to give advice without employing the power of disciplinary correctness. If an LA brings outside perspectives into the conversation (moderately dialogic), these can exist alongside the student perspectives and expand or challenge the student perspectives. The authoritative-to-dialogic spectrum can be used by researchers to characterize the middle-ground between maximal authoritativeness and dialogicity based on the underlying theory of authoritativeness and dialogicity. It can be used by LAs and possibly by other instructors to grapple with the tension between authoritativeness and dialogicity and to transition from one to the other. The deep connection of purposes to the characterization of actions presented here allows for an intentional use of different practices along the spectrum. The spectrum can provide an avenue away from the dominance of very authoritative facilitation towards a greater variety of practices that give students more voice and power when discussing disciplinary problems and developing their own thinking. This can contribute to equity of individuality by lifting marginalized voices up.

Future work may focus on comparing LAs' actions during group interactions with their professors' actions during whole-class discussions to see whether observing a model of facilitation practices influences how LAs tend to interact with students. Future work within the larger research project will analyze the relationships between LAs' purposes, LAs' actions, and the effect of their actions on student learning. On a grander scale, our future research within the larger project will obtain insights from the other factors outside of LA purposes and LA noticing and interpreting (such as social norms, classroom rules, student/professor interactions, etc.) that influence LAs' purposes, LAs' actions, and the effect of their actions.

Appendix

See Table 6.

Table 6 Coding scheme with narrative examples and quotes

Codes	Subcodes	Definition and generic examples	Specific example narrative portion and example interaction quotes (if applicable)
Eliciting	Authoritative	Finding out about student thinking in a restricted way that centers one perspective as an authority e.g., probing for specific facts/skills, checking understanding, asking for definitions, asking for answer alignment	The LA checks over the students work step-by-step to confirm whether she is correct or not *Interaction transcript excerpt:* *LA: Is that the first order? [...] So your R squared value is exactly one? [...] Let's see. Could I just check how you got this. So that's [the natural log] of that. All right*
	Dialogic	Finding out about student thinking in an open way that acknowledges multiple perspectives as equal e.g., rephrasing/rebroadcasting ideas, asking for more ideas	The LA asks open questions that directly acknowledge and reflect what the vocal students mention and indirectly encourage non-vocal students to speak up *Interaction transcript excerpt:* *LA: Yeah, that makes sense to me. So just to echo what you were saying, it's like you think that the potential energy is going to increase, and one of the reasons why is because if you have like opposite charges, then pulling the[m] further away would increase the potential energy. [Pause] Okay, I'm seeing nods. Great. Have you all gotten to the other questions as well? What are some thoughts on that one, those ones? And someone else can answer*
Advancing	Authoritative	Furthering student thinking in a restricted way that centers one perspective as an authority e.g., correcting students, giving answers, guiding with restrictive questions, giving specific advice	The LA tells a student important information and confirms right/wrong answers, answering any questions along the way *Interaction transcript excerpt:* *Student: Oh wait. Is the H, the CH_2 in the middle, all three of them like dipole–dipole?* *LA: Well remember, dipole–dipole isn't the result of like a single bond. It's the whole molecule all together. Plus I think CH doesn't actually form a polar bond, right, with a similar electronegativity*
	Dialogic	Furthering student thinking in an open way that acknowledges multiple perspectives as equal e.g., asking for reasoning or elaboration, encouraging multiple students to compare their ideas	The LA directly follows up with a student's reasoning by asking him to elaborate on the forces he's identifying in the problem *Interaction transcript excerpt:* *LA: Bob [student], do you see the tension force as being supplied like by the person?* *[...]* *LA: I guess I am curious about like what forces you're identifying as working, sort of like at work in this problem*
Noticing and interpreting	Authoritative	Judging students, often comparing them to the canonical perspective or assuming their content strengths or deficiencies e.g., noticing a gap in knowledge, noticing a correct answer, assuming a student does not know what is going on	He notices that this student's work is correct, and she has a perfect R^2 value

Table 6 (continued)

Codes	Subcodes	Definition and generic examples	Specific example narrative portion and example interaction quotes (if applicable)
	Dialogic	Observing students, often paying attention to their reasoning, paying attention to their behavior, and focusing on their assets e.g., noticing who is dominating the conversation and who is left out, picking up on how students feel, following the sensibility of a student's reasoning	As the LA actively listens to the students' conversation, she notices that students have different arguments for entropy and still come to a consensus, but that they disagree on enthalpy
Overall purpose/ in-the-moment purpose	Attending to students' learning process	Helping students in the whole class (overall purpose)/ in the current group (in-the-moment purpose) with a process or skill directly related to class content e.g., aiming at how to answer stepwise, use of scientific vocabulary, including all students, a specific approach or method	The LA thinks there may be too many ideas in the conversation, which can be overwhelming, so she wants to center one idea at a time for the students to think about
	Developing students' content understanding	Promoting in-depth content understanding and connections among multiple concepts for all students in the class (overall purpose)/ in the current group (in-the-moment purpose) e.g., aiming at justified content, recognizing misconceptions, synthesis of ideas	The LA wants to establish a stronger foundation of knowledge before addressing the question conceptually
	Nurturing students' positive qualities and attitudes	Encouraging certain personality traits or characteristics not related to class content for students in the whole class (overall purpose)/ in the current group (in-the-moment purpose) e.g., aiming at students' confidence, self-reliance	The LA values reassuring the students and giving them confidence since he believes that people second guess themselves a lot, so having someone to tell them that they are on the right track makes the students feel good about themselves

Abbreviations

LA	Learning assistant
TA	Teaching assistant
FAEM	Formative assessment enactment model
FA	Formative assessment
STEM	Science, technology, engineering, and mathematics

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Author contributions
ICG conceived and designed the study. CMLC, NMM, and ICG all contributed to data collection. All authors engaged in data analysis. CMLC, VD, and ICG interpreted the findings. CMLC and ICG wrote the original draft of this manuscript and VD and NMM reviewed and edited. NMM, VD, and ICG revised the manuscript throughout the journal's revision process. All authors read and approved the final manuscript.

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Availability of data and materials
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Declarations

Competing interests
The authors declare they have no competing interests.

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