LEARNING ASSISTANT- STUDENT INTERACTION IN CALCULUS: A CRITICAL DISCOURSE ANALYSIS

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Learning Assistants (LAs) are undergraduate peer-tutors who, having successfully passed a particular course, return to assist with teaching that course. Through their work across many STEM courses, LAs have been shown to have positive effects on several student outcomes, but little is known about why LAs' presence in classrooms is positively associated with these outcomes. This study provides a novel perspective on this issue by critically analyzing a portion of classroom dialog between an LA and a student in a Calculus I course. The language used by these interlocutors was analyzed with attention to the social and informational aspects of the dialog, examining both the relationship between the student and the LA, and the ways they frame mathematical content. These findings have implications for the future study of LAs' practice and bear relevance to the improvement of LA educational programs.

Keywords: Calculus, Classroom Discourse, Undergraduate Education

Introductory courses in science, technology, engineering, and mathematics (STEM) at the university level in the United States have repeatedly been showed to pose barriers to students' continued participation in these fields (Wu et al., 2018). Subsequently, there have been many calls to reform these courses to increase the number and diversity of technically oriented college graduates who are prepared for careers in STEM fields (Reinholz et al., 2021; Talanquer, 2014). Some of the research-backed approaches to reform involve student-centered instruction emphasizing active learning, group problem-solving, and studio course designs (Freeman et al., 2014; Kim et al., 2013). One way to support facilitation of active-learning approaches has been to incorporate near-peer tutors into course design. Near-peer tutors are undergraduate students who have previously passed the course and who aid in course instruction. They have been implemented across disciplines in various ways, such as peer-supported learning outside or during class instruction (Adreanoff, 2016). While implementation models can vary greatly, they have been consistently shown to support active learning pedagogies and foster student success at the undergraduate level (Williams & Fowler, 2014; Wilson & Varma-Nelson, 2016).

One form of near-peer tutoring, which appears to be particularly effective in fostering aspects of active learning in undergraduate STEM courses is the Learning Assistant (LA) model (Knight et al., 2015). In this model, LAs synchronously aid in course instruction by facilitating small group work. In addition, outside classroom time, LAs are supported through enrollment in a pedagogy course and regular meetings with the instructional staff of the course. In the pedagogy course, LAs are introduced to concepts related to teaching and learning, often with attention to theories of learning and findings from cognitive science, and critically reflect upon their teaching in light of these theoretical concepts. In meetings with their instructional team, LAs review the mathematical content of the course in order to be able to support teaching of that content. This combination of content preparation, synchronous teaching practice, and pedagogical education distinguishes the LA model from other forms of near-peer tutoring (Otero et al., 2010).

Since its inception in 2003 at the University of Colorado - Boulder physics department, the LA model has spread across disciplines, institutions, and countries. Interest in the LA model

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partly stems from a body of literature documenting positive outcomes for students in LA-supported courses, including a range of social, conceptual, and academic benefits (Barrasso & Spilios, 2021). Notably, Herrera et al. (2018) found that, across institutions, students in LA-supported physics courses scored higher on post assessment of conceptual understanding of introductory physics, compared to students in collaborative courses without LAs. This finding is particularly interesting as it suggests that the outcomes seen in LA-supported courses are not the mere consequence of task alterations or group collaboration but can be attributed to LAs.

While positive outcomes of the LA model are well documented, the mechanisms responsible for them are not well understood, and are likely to be multifaceted involving various social, contextual, and contentual factors (Talbot et al., 2016). Still, LA classroom practice is hypothesized to be central to this phenomenon, contributing to these positive outcomes through their deep and frequent interactions with students during class (Hernandez et al., 2021). Studies examining LA-student interactions are mainly focused on LAs' classroom actions (Thompson et al., 2020; Knight et al., 2015), and found that in addition to facilitating tasks, providing feedback, and increasing time spent in group discussions, LAs acted as mentors, offering students advice about the course. Yet, the finer details of LA-student interactions remain unexplored.

This study provides a new perspective on LA-student engagement by beginning to analyze the language LAs use in the classroom, through the lens of Critical Discourse Analysis (CDA). CDA pays particular attention to the ways in which language relates identity, information, and action within specific contexts (Gee, 2014a); thus, it captures both the social and contentual features of an LA's classroom language. Attending to these two features is critical for understanding LAs' classroom role, since LAs are both temporally closer to the learning process and relationally closer to students. This study offers a fine-grained analysis of the language used by one LA with a student in a university Calculus I course. Specifically, we ask:

5. What social identities and relationships are enacted and sustained by the LA and student through their language?
6. How do the LA and student use language to foreground and background particular mathematical content and concepts?

Theoretical Perspectives & Literature Review

This focus on classroom language when exploring LA practice is motivated by Vygotsky's sociocultural perspective which conceptualizes learning as a social process mediated by individual's interaction with people and tools in social contexts. Learning occurs when an individual interacts with a "more knowledgeable other" (MKO), such as a teacher or a peer, around tasks and concepts that an individual may not be able to do on their own but is able to achieve with MKO's help. The language used by MKO to facilitate the learning process plays an essential role in an individual's learning, since "just as a mold gives shape to a substance, words can shape an activity into a structure" (Vygotsky, 1978, p.28).

In classrooms, LAs act as MKOs supporting student learning, and have a unique relationship with the students and the course's content. LAs are closer to students than course instructors and/or graduate teaching assistants (GTA). LAs share a peer status with the students in the course by virtue of being undergraduate students at the same institution and commonly participating in the student culture and subcultures of the institution. With respect to content, LAs have some mathematical authority since they have passed the course but are still relatively close to the experiences of first-time learners. As such LAs are less likely to suffer from the

expert blind spot and may attend to issued missed by other instructors. These relationships between LAs, students, and content create a unique power dynamic within the classroom; LAs are not so powerful as to be intimidating, but not so powerless as to be unreliable sources of aid (Robertson et al., 2014; Hernandez et al., 2021).

To capture the nuances of this power dynamic through scrutiny of the linguistic choices made by LAs and students participating in classroom dialogue, we utilized Gee's (2014a) Critical Discourse Analysis (CDA) framework. Gee views language as a tirade of "ways of saying (informing), doing (action), and being (identity)" (Gee, 2014a, p.8) integrated with each other through grammar. CDA is a form of discourse analysis, which ties deep functional linguistics analysis with critical social concepts such as power and identity (Lin, 2014).

The use of CDA is gaining traction in mathematics education. Recent studies used CDA to explore teachers' discourse around race and gender (McNeill et al., 2022) and teachers' linguistic moves which invite or discourage students to participate in classroom discourse (Wagner & Herbel-Eisenmann, 2008). With respect to studying near-peer tutoring, DiMaio (2020) used CDA to understand how near-peer tutors in university writing centers utilize politeness to navigate between their collaborative roles as peers and authoritative roles as teachers.

Considering the social functions of language and LA's unique social positioning in the classroom as near-peer tutors, CDA provides a useful lens for scrutinizing the language of LA-students interactions. Thus, CDA provides our study with a means to understand the relational dynamics between LAs and students in undergraduate mathematics classrooms.

Methods

Setting

This study is a part of a larger project aiming to improve teaching and learning in introductory STEM courses at a large public university in the northeast of the United States. One aspect of this initiative was introducing an LA program to the mathematics department to support Calculus I instruction. The LA program followed research-based best practices, with novice LAs enrolled in a pedagogy course (along with near-peer tutors of other STEM courses) in which they learned about general principles of teaching and learning. The LAs also attended a weekly meeting with a course instructor to discuss upcoming content.

The Calculus I course followed a lecture-recitation model, with students attending a large lecture (~ 160 students) led by faculty members three days a week and a smaller recitation (~ 20 students) led by GTAs and LAs twice a week. In these recitations, students worked in small groups on activities or problem sets (common for all recitations) related to the content of the lecture. Another aspect of the larger project was introducing six specially designed conceptually oriented activities for students to engage with during recitation sessions. The GTAs launched the activities, facilitated student group work, directed whole class discussions, and proctored quizzes. The LAs' primary role was to support students while they worked in small groups. Thus, the LAs had a less authoritative role than the GTAs, as they were not responsible for grading students, coordinating course logistics, or delivering content. Still, LAs had ample opportunities to form relationships with students and the GTA, since each LA was assigned to particular recitation sections for whole semester.

Participants

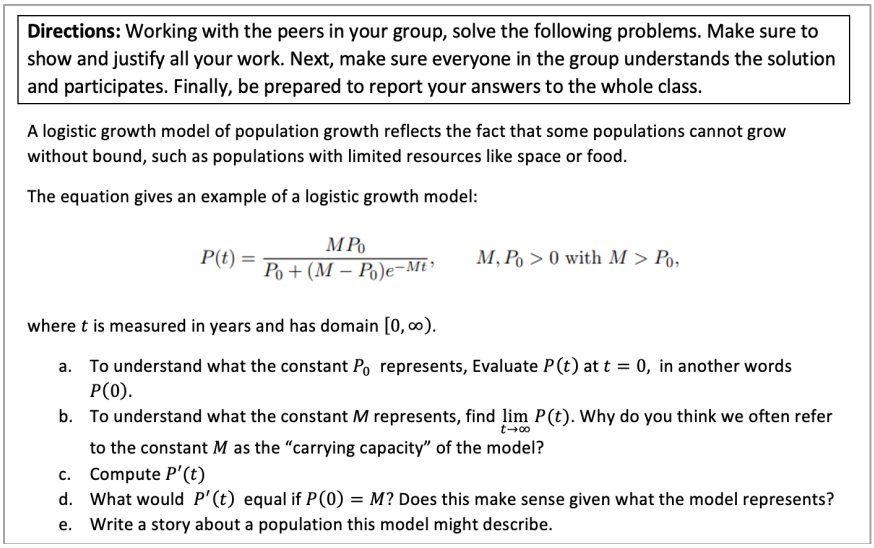
This inquiry was conducted in Fall 2022; it focuses on a single LA's interaction with a small group of students in a Calculus I recitation section. The LA, Nia, identifies as a woman of color from southeast Asia; she is a biology major sophomore in her first semester as an LA. She took Calculus I in the previous semester and was recruited based on strong recommendations from her

calculus GTA and professor. The GTA that Nia worked with was a last-year mathematics Ph.D. with the six years of experience in a variety of courses in the mathematics department.

For data collection, we randomly selected one group from the recitation, who remained consistent throughout the semester. The group consisted of four freshmen STEM majors: three female and one male, all identified as white. The students seemed to communicate and collaborate well on activities. There was a tendency for the three female students to work together, while the male student worked independently. He appeared to prefer working at his own pace, often raising his hand for help from the GTA or LA, while the female students tended to consult one another. Despite the split along gendered lines, this dynamic did not appear tense, with the none of the group members dominating discussion.

Data Collection

The group was recorded six times during the semester when the conceptually oriented activities were implemented. The recordings were done with a tabletop 360 video camera, which can simultaneously capture interactions among multiple interlocutors even in noisy classroom environments (Buchbinder et al., 2021). This paper is focused on the fine-grained analysis of one recitation session, that occurred around the middle of the semester. The class setting was typical, with students working on a worksheet in their small groups for most of the class, followed by a short class discussion of the answers. The activity worksheet on the topic of logarithmic differentiation (Figure 1) was designed by the project's research team.



Directions: Working with the peers in your group, solve the following problems. Make sure to show and justify all your work. Next, make sure everyone in the group understands the solution and participates. Finally, be prepared to report your answers to the whole class.

A logistic growth model of population growth reflects the fact that some populations cannot grow without bound, such as populations with limited resources like space or food.

The equation gives an example of a logistic growth model:

$$P(t) = \frac{MP_0}{P_0 + (M - P_0)e^{-Mt}}, \qquad M, P_0 > 0 \text{ with } M > P_0,$$

where t is measured in years and has domain $[0, \infty)$.

a. To understand what the constant P_0 represents, Evaluate $P(t)$ at $t = 0$, in another words $P(0)$.
b. To understand what the constant M represents, find $\lim_{t \to \infty} P(t)$. Why do you think we often refer to the constant M as the "carrying capacity" of the model?
c. Compute $P'(t)$
d. What would $P'(t)$ equal if $P(0) = M$? Does this make sense given what the model represents?
e. Write a story about a population this model might describe.

Figure 1: Logarithmic Differentiation Activity

This paper presents the fine-grained analysis of a three-minute video of the fifty-minute class session. The clip was selected because it was Nia's only sustained interaction with this group in the lesson. The interaction occurred toward the end of the class session. While Nia initially approached the whole group, she decided to work one-on-one with the male student - Ken. Nia and Ken's discussion focused on part (c) of the activity which calls for using logarithmic differentiation to find the derivative of the given logistic growth model. Nia and Ken's conversation about this problem was analyzed using CDA.

Analytic Framework

According to Gee (2014a) CDA "is a reflexive, reciprocal process in which we shuttle back and forth between structure (form, design) of a piece of language and the situated meanings it is attempting to build about the world, identities, and relationships in a specific context" (p.148). It involves continued engagement with the data and the surrounding context (Mullet, 2018), with the research questions operationalized through examination of personal pronouns and specialist and vernacular term use. The process began with the first author creating an extended transcript of the selected video clip which included clarifications of referents ('this", "here", "what we did before"), gestures (pointing, writing instructions) and emotions (joking, frowning) extracted from the context of the 360-degree video. Constructing such transcript is a theoretically driven process informed by research goals (Ochs, 1979). In our case, the decision to shape the transcript around text accuracy, referents of speech, and clarity of social meaning reflect this study's focus on mathematical content, social relationships, and personal identities.

The transcript was then segmented into units of analysis: idea units and stanzas. Idea units (Gee, 2014a; Gee, 2014b) are complete or partial clauses identified by short breaks in speech. These breaks typically go unrecognized by the listener, but they are key indicators of when new information is introduced by the speaker. Analyzing the discourse at this fine-grained level is important for detecting small changes in what the interlocutors talk about and how. The idea units were then grouped into stanzas. A stanza is a sequence of idea units related to one specific topic, event or character (Gee, 2014b). This larger unit of analysis allows tracking the overall movement of the dialogue, identifying the major events and shifts in conversation. The 77 idea units identified in the transcript, were organized into eight stanzas averaging 14.25 idea units each (ranging in length from four to 18 idea units).

The segmented transcript was analyzed in two ways. To address the first question about the identities and relationships enacted and sustained throughout the dialog, the personal pronouns used by the speakers were examined. Personal pronouns are an important articulation of individuals' representation, giving insight into how the speakers socially position themselves and each other in the classroom (Wagner, 2007). The language around these pronouns, especially the actions of these subjects, provides additional detail regarding the nature of their social positioning. To address the second research question about mathematical content and concepts, the analysis focused on mathematical terms used by the speakers, operationalized through Gee's (2014a) notion of specialist and vernacular language. Specialist terms are more formal words often used by an expert in some area, while vernacular terms are ones used by a novice or layman. The words around these terms were also analyzed to illuminate their function in the dialog. It is important to note that the two lines of analysis - the personal pronouns and specialist and vernacular terms – are complementary, since the types of terms one uses reflect their social positioning and, reflexively, one's social positioning affects their authority surrounding terminology use. Thus, both analyses were used to answer the two research questions.

Results

Identities and Relationship

Throughout the interaction, Ken's identity was as an active author of mathematics, as evidenced by Ken and Nia's personal pronoun use (Table 1). Nia consistently used the personal pronoun "you", positioning Ken as the central agent in the mathematical process. This positioning was simultaneously enforced by Ken, who primarily uses the personal pronoun "I", indicating that the mathematics belongs to him, and he is the one responsible for doing mathematics. Nia's language further reinforces Ken's identity as an active author in several

ways. She repeatedly created space for Ken to carry out mathematics and communicate his ideas via explicit direction (e.g., “Do it. Tell me what it is.”) and asking questions (e.g., "How would you…"), thus placing the responsibility for doing the mathematical work upon Ken. Nia also identified the products of Ken’s work as his own (e.g., “You have…”, “You did…”) rather than independently existing or communally owned entities (e.g., “It is…", "We have…”).

Table 1: LA and Student Personal Pronoun Use

Personal Pronoun	Nia *Number of Occurrences*	Ken *Number of Occurrences*
I	1	7
Me	1	0
Us	4	0
We	3	1
You	14	0

Nia’s primarily identity in the interaction is that of mathematically authoritative MKO. This is evident in Nia’s responses to Ken’s work, which were often short, direct evaluations such as “correct” or “no”. Nia’s role as a MKO is illustrated in Table 2, as she demonstrates that she understands what Ken knows and what he is confused about. Nia provided Ken with a similar but more familiar to him example to work through. This bridging between what Ken knows and what he can do with assistance is precisely the role of an MKO (Vygotsky, 1978). Nia takes up her role as an MKO by taking an authoritative stance with respect to the mathematics involved in the conversation. This is seen in her evaluation of Ken’s work (Line 8) and in directing him to carry out mathematical processes (Line 6). This type of interaction, when Ken brings up his confusion and Nia responds with a similar example for Ken to work through, happened three times through this short videoclip, solidifying Nia’s role as an authoritative MKO.

Table 2: Excerpt of LA-Student Dialog

Line	Speaker	Text
1	Ken	But still it's like it's two parts here. [*Ken referring to* $ln\ (P_0 + (M - P_0)e^{-Mt})$ *when taking the derivative in part (c) of the worksheet*]
2	Nia	Yeah…OK so let's do…how would you differentiate the natural log of $x^2 + 3$?
3	Ken	Where?
4	Nia	This one, $x^2 + 3$. [*Nia has written an example* $ln\ (x^2 + 3)$ *on a blank sheet of paper*]
5	Ken	This on bottom and derivative up top.
6	Nia	Do it. Tell me what it is.
7	Ken	$2x$ and one over $x^2 + 3$
8	Nia	Correct. Now you want to do the same thing with that. It’s literally the exact same thing. You have a constant, you have a coefficient multiplied by your function.

These identities of Ken as an active author of mathematics and of Nia as an authoritative MKO, someone who evaluates and guides what Ken is doing, illuminate the hierarchical element

in their relationship. Nia presents herself as the mathematical authority, which is acknowledged by Ken. This is evident in the excerpt in Table 2 when, in response to Ken's concern, Nia introduced a related example for Ken to work through and was responsible for judging the validity of his work. Ken willingly follows Nia's example and directions, whether or not he understands their relevance, trusting Nia to provide information that is productive to his learning. Nia's authority with respect to mathematics is also evident in the number and the variety of specialist terms she used, especially compared to those used by Ken (Table 3). Moreover, when Ken used specialist terms, these terms were typically introduced by Nia first (e.g., Nia: "so you have to derive both sides of the equation" Ken: "Derive them, right... Yeah, yeah").

Despite a notable hierarchy in Nia and Ken's interactions, there are aspects of their relationship that are notably "peer". This is evident in Nia's initial approach to the group asking, "How are you guys doing?". This informal and broad question mirrors the everyday language of college students addressing one another. Ken picks up this informality, responding with a joke about being stuck on a problem: "I just think I'm such a genius. But..." (pause). The peer nature of this relationship is also seen through Nia's ability to understand the vernacular terms Ken uses (Table 3). Returning to the excerpt in Table 2, note that Nia has no trouble understanding that when Ken says, "two parts," he refers to the two expressions which are added together within the natural log. This is not a trivial translation, as there were several other ways in which Ken could have been separating this expression into "two parts." Nia's ability to understand Ken's language reflects her keen understanding of student difficulties when taking the derivative of natural logs. There is a strong sense of Nia's mathematical authority within this interaction, but we also see her and Ken engage as peers in their mathematical and non-mathematical talk.

Table 3: LA and Student Vocabulary through the Dialog

	Specialist Terms	Vernacular Terms
Nia	Coefficient, constant, derive, differentiate, equation, function, minus, multiplied, natural log, numerator, product rule	Something over something else
Ken	Coefficient, constant, derive, derivative, function, product rule	On bottom, up top, two parts, over

Mathematical Content

Nia and Ken primarily frame mathematical content through a binary classification of right or wrong. At the beginning of the interaction, Ken talked about his work as "completely like wrong." In response, Nia began to go through the answers on his worksheet, pointing out "that is correct, that is correct, that is correct," before arriving at the question Ken thought was wrong. Then, Nia began reviewing what Ken has done on the question so far, focusing on the "right steps" that he has completed. Both Nia and Ken used language to classify Ken's productions as correct or incorrect. This theme is continually enacted in the interaction, with Nia frequently phrasing her feedback to Ken as "correct" or "no", and Ken focused on obtaining "the right answer." "Right and wrong" were foregrounded by both Nia and Ken as the primary features of concern within the process of doing mathematics rather than specific content or affective qualities of the work, such as effort.

In addition, throughout this interaction, Nia centered mathematics as a rule-based process. This is evident through Nia's phrasing of mathematics in terms of verbs rather than nouns,

saying things like “you have to derive” instead of “you have to take the derivative”. Using verbs instead of nouns to frame specialist mathematical terms suggests that these are not static concepts but active processes that must be carried out by an agent.

Nia further framed these processes as sets of rules which can be applied across various contexts. At one point in the interaction, Nia referred to Ken’s previous work saying, "but you remember how we've had issues with this before." By this, she identified a previously seen analogous structure to invoke processes related to solving the problem at hand. This is also seen in the excerpt in Table 2, Line 8, when Nia explained that the same rules maybe be used to solve the worksheet problem and the example she provided. The stance that Nia conveys toward mathematics as a rule-based process, is consistent with her positioning herself as an authoritative MKO in the interaction, meaning that she has the status to say what mathematics is and how it is done. However, it is unclear whether Ken embraces Nia’s stance toward mathematics, since during their interaction, he primarily asked questions rather than explaining his work to Nia.

Discussion

The micro-level analysis of LA-student interactions offers important insights into the nature of LAs’ classroom practices. Through her language use, Nia enacts and sustains her identity as an authoritative MKO while simultaneously identifying Ken as an active author of mathematics. These identities are also sustained through Ken’s language. These identities imply a clear hierarchal relationship, with Nia positioned as the primary mathematical authority, but this relationship also has peer elements. Nia and Ken also use language to foreground mathematics as essentially right or wrong, with Nia further framing mathematics as a rule-based process.

While this analysis is focused on a single LA and student across just a three-minute episode, our results point to several educational implications. First, Nia is a clear example of how LAs can act as MKOs in the classroom. Nia was able to able to capitalize on her knowledge and recent experience as a learner in Calculus I course to quickly assess Ken’s knowledge, identify the origin of his difficulty, and provide appropriate examples to help him identify the analogy and make progress on his work. Though brief, this interaction exemplifies how LAs can effectively facilitate student engagement in class. Further, the results of this study can be useful for educators of LAs, who can use these results to facilitate discussions in LAs pedagogy courses around the issues of identity, power dynamics, and perspectives on mathematics as a discipline.

This study provides a fresh perspective on the classroom practices of LAs. Previous inquiries into LA practice have provided evidence that LAs can facilitate student engagement within the classroom through actions such as asking questions and providing feedback to students (Thompson et al., 2020; Knight et al., 2015). This study looks beyond categorization of LAs’ actions, explicating the nature of the relationships that these actions generate. Detailing the types of LAs’ relationships with students and how they frame course content, in the way utilized in the current study, is a vital step toward understanding the mechanisms behind the positive effects of LAs on student outcomes reported in the literature (Barrasso & Spilios, 2021). In addition, our study illustrates the utility of CDA for analyzing LA classroom practice, and the power of this analytic approach to elicit a wealth of information about the social and contentual dynamics between the student and the LA. Through our ongoing inquiry into small group discourse using CDA, we hope to provide further insights into LAs’ classroom roles and the ways in which they impact student learning process in Calculus classrooms.

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