Student in-the-moment learning in LA-facilitated interactions in undergraduate chemistry and physics courses

Jessica M. Karch, Ira Caspari-Gnann
Department of Chemistry, Tufts University, Medford, MA

Abstract

To develop global scientific literacy, equitable pedagogical practices and a theoretically grounded understanding of in-the-moment learning are critical. One promising practice is the learning assistant (LA) model. Implementing LAs in large-enrollment lecture courses has had a positive impact on various measurable student outcomes, particularly for marginalized students, including improved course grades, decreased Drop/Fail/Withdraw rates, and conceptual knowledge acquisition. However, little is known about the nature of in-the-moment learning that leads to these outcomes. We sought to answer the research question: How does student in-the-moment learning progress in interactions facilitated by an LA? Videos of small-group interactions with LAs (n=19) were recorded in remote introductory physics and chemistry courses at two institutions. To analyze in-the-moment learning, we used practical epistemology analysis, which operationalizes learning as noticing and filling gaps, i.e., things that need to be made intelligible, with relations, i.e., pieces of knowledge or actions that are immediately intelligible. We found three patterns that trace the different ways LAs do or do not pick up on student ideas when opening gaps in order to to (1) advance students forward in the activity, (2) deepen conceptual understanding, and (3) facilitate mutual understanding. Implications for theory and practice will be discussed.

Problem

Developing scientific literacy for all, and broadening the definition of "scientific literacy" beyond fluency in the Western canon, are key objectives to developing a more equitable and just scientific community. In the classroom, this can be fostered by developing and implementing pedagogical strategies that center diverse voices and support historically marginalized students by building opportunities for in-the-moment learning. This is particularly important in introductory STEM courses, which have historically contributed to the marginalization of groups of students in science, based on factors such as race and socioeconomic status (Chang et al., 2008; Gasiewski et al., 2012). One approach that addresses this inequity and promotes student-centered instruction is the learning assistant model (Van Dusen & Nissen, 2020). Learning assistants (LAs) are advanced undergraduate students who assist in large-enrollment lecture courses by circling around the room to answer questions and facilitate small group discussions (Otero et al., 2010). The LA model has yielded positive effects on measurable cognitive and affective student outcomes in a variety of STEM disciplines (e.g., Alzen et al., 2018; Barrasso & Spilios, 2021; Kiste et al., 2017; Talbot et al., 2015), including evidence that it particularly supports historically marginalized students (Sellami et al., 2017; Van Dusen & Nissen, 2020).

To understand why the presence of LAs leads to positive outcomes, both the nature of the interaction between LAs and students and the impact on student learning need to be examined. On the one hand, studies have focused on characterizing the nature of LAs' actions and purposes during interactions with students, e.g., by developing an action taxonomy (Thompson et al., 2020). On the other hand, several studies have tried to parse the exact impact on student learning outcomes, such as improved conceptual understanding in courses implementing the LA model (e.g., Alzen et al., 2018; Herrera et al., 2018). While Knight and collaborators (2015) found that the nature of LA utterances influences student discourse, such as the types of questions that prompt reasoning, not much is known about *how* student learning occurs *during* interactions with LAs. To understand how LAs may support developing scientific literacy for all students that goes beyond fluency in the Western canon, it is important to have a theoretically grounded understanding of how student learning progresses during these interactions, e.g., how and whether students' disciplinary ideas are picked up on, developed, and advanced. Thus, this study seeks to answer the question: *How does in-the-moment learning progress during group activities facilitated by a learning assistant*?

Theoretical Framing

Our study of students' in-the-moment learning is guided by sociocultural theory, in particular, we employ practical epistemology analysis (PEA). Developed from Wittgenstein's work on language games and from sociocultural traditions (Vygotsky, 1978; Wittgenstein, 1967, 1969), PEA conceptualizes learning as how "meaning changes during discourse" (Wickman & Östman, 2002, p.601) through how students make ideas and actions continuous during an activity (Hamza & Wickman, 2013). This learning can be observed through four concepts: gap, relation, encounter, and standing fast (Wickman, 2004; Wickman & Östman, 2002). A *gap* is a need to make something intelligible in order to progress during an activity. A gap does not imply a cognitive gap in knowledge, but rather a socially situated and contextually dependent need for sense making, which can be expressed directly through asking questions, or indirectly through being filled. To fill these gaps, students build *relations* between pieces of knowledge or actions whose meanings are implicitly assumed to be understood by the actors in the interaction and which can then be used during the activity. These relations *stand fast*, which means they are immediately intelligible in that particular moment and do not require further explanation. Gaps are noticed (expressed directly or indirectly) and filled with relations during *encounters*, or interactions between multiple individuals or between an individual and a material or epistemic artifact, such as a problem. Through these four concepts, in-the-moment learning can be operationalized as "a process where gaps are filled by construing new differences and similarities to what is immediately intelligible" (Wickman & Östman, 2002, p. 603).

Design of Study

During Fall 2020 and Spring 2021, data were collected from eight remotely taught large lecture introductory physics and general chemistry courses that implemented the learning assistant model. Data were collected from two different institutions in the northeastern United States: a primarily white private R1 university (four physics and one general chemistry course) and a highly diverse public university (three general chemistry courses). The 19 LAs who participated in the study each recorded their interactions with groups of students as they worked on solving disciplinary problems during three interactive lectures in Zoom breakout rooms. Collecting interaction data from a variety of contexts (multiple disciplines, and multiple topics and problem contexts within each discipline) allowed us to both examine the socioculturally mediated nature of in-the-moment learning as well as construct more generalizable patterns that emerged in diverse settings. These interactions were transcribed, and salient pieces of information about tone, gestures, and what the students interacted with on the screen were integrated into the transcript.

Analysis and Findings

To answer the research question of how in-the-moment learning progresses during LA-facilitated interactions, the transcripts were analyzed to identify how groups approached the task in terms of what gaps they noticed and what relations they used to fill the gaps. To assure reliability in the coding, all interactions were analyzed by two coders, who discussed their coding until they reached 100% consensus. To analyze the data, we identified (1) *what* was the gap that was noticed, e.g., what was the "question in the air" that the individual or group were trying to make sense of, (2) *how* was the gap filled, e.g., what were the relations that were being used to answer the question, and (3) *who* noticed and filled the gaps, e.g., the LA or the students, and which students. We also attended to the pieces of knowledge students used to build relations. Here, we understand a piece of knowledge as an idea or action which, when brought into dialogue with another piece of knowledge, is used to build a relation, i.e., a connection between two pieces of knowledge.

To understand how student learning progressed, we focused on the relationships between the pieces of knowledge that were used to fill previous gaps and those brought into question in order to notice a current gap. That is, we focused on how students' needs to make something intelligible and the nature of what they needed to make intelligible in order to progress in the activity connected to the reasoning they had already been engaged in. In particular, we examined whether pieces of knowledge used to open gaps were first introduced (e.g., spoken) during that gap or whether they had been previously used by a student. We found three patterns (see Figure 1). First, gaps were oriented around a need to make a newly introduced piece of knowledge intelligible. Second, gaps were opened to build relations between a newly introduced and already present piece of knowledge, or new relations between two already present pieces of knowledge. Third, gaps were opened to bring an existing relation, or something that stood fast into question. Each of these patterns could be initiated by either the LA or the student, however, for the purpose of this paper, we focus on LA-initiated patterns. Below we provide representative examples of each pattern.

Pattern 1. In the first pattern, gaps are opened based on new pieces of information that the LA introduces to the meaning-making space. That is, the LA introduces a need for the students to progress forward in the activity by making a newly introduced idea intelligible. For example, a group of chemistry students working with LA John were tasked with figuring out the most acidic proton on two organic molecules, a property that is dependent on electronegativity and other chemical concepts. The students approached the problem by thinking about electronegativity, while LA John brought in a new piece of information *(knowledge pieces used to build relations are italicized)*:

Grace: It looks like the *one [molecule] on the right* has *more electronegative atoms surrounding it,* because it has the *fluorine to the left*, whereas the *one [molecule] on the left is mostly surrounded by CH'*s.

Caleb: So probably the *H on the OH group moved furthest to the left* [leftmost OH group in the molecule on the right], cause it's *closest to the fluorines*.

[conversation about electronegativity continues for a moment]

LA John: Are there any *resonance structures*?

Here, students Grace and Caleb related the electronegativity of atoms in the molecule with the atoms' proximity to different H's (protons) they considered as candidates of being most acidic. After the conversation about electronegativity continued for a moment, LA John noticed a gap that introduced a new piece of knowledge, i.e., resonance structures (highlighted in orange to contrast with previously introduced pieces of knowledge in purple). In opening this gap, he created a need to make sense of a new idea that refers to a chemical concept different from that of electronegativity. The students then followed John's cue and shifted away from what they had been thinking about, i.e., electronegativity, towards what John had introduced, i.e., resonance. In Pattern 1, a need is introduced to make sense of a new piece of information in order to progress forward in the activity. Although this may move the activity forward, it also may interrupt the continuity of the students' learning, as new relations do not need to be connected to the pieces and relations used to fill earlier gaps.

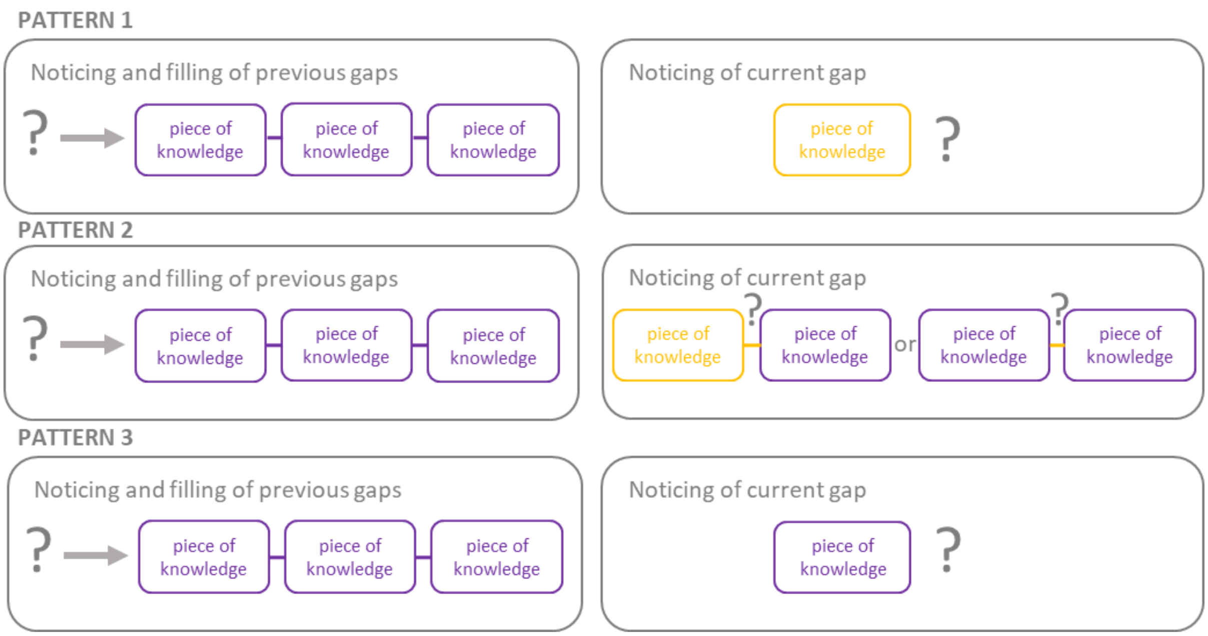

Figure 1. *Representations of the three patterns. Pieces of knowledge (represented by yellow and purple boxes) come into question when gaps are noticed (represented by question marks). The left side of the figure shows the noticing and filling of previous gaps during a group's problem solving, while the right shows the noticing of a current gap that follows one of the three patterns. Yellow represents newly introduced pieces of knowledge and/or relations, and purple represents already present pieces of knowledge and/or relations.*

Pattern 2. In the second pattern, gaps are opened when a piece of knowledge that had previously been standing fast (as evidenced by its use to build relations) is leveraged as the starting point for a new gap. That is, the LA introduces a need to progress forward in the activity through (1) relating an idea the LA brings in with a piece that was already present, e.g., that had previously been used to make a relation, or (2) relating two already present ideas that had previously been unconnected. For example, a group of chemistry students were working with LA Ruthie to visualize what happens when two molecules react to form a product. After an extended discussion to understand how the atoms on the reactant molecule mapped to the atoms on the product molecule, the students tried to figure out how the reaction occurred, e.g., how those atoms came to be in those places on the product. They eventually started trying to make sense of the ways in which the molecules physically interacted with each other, and how that could explain the ways bonds broke and formed:

Alexis: Yeah, because a *collision* would lead to a *higher kinetic energy*.
LA Ruthie: But do you— This was early on in the lectures, I think. But you remember also what's important about the *collisions* for them to be *effective*?

Here, LA Ruthie picked up on one of the pieces used by student Alexis, collision, and juxtaposed it to a new one, effective, to open a gap: What's important about the collisions for them to be effective? In opening this gap, he invited the students to think more deeply about the mechanistic role collisions play in facilitating whether a reaction occurs, and in particular that it is not just important that two molecules collide, but rather that the molecules are oriented in a certain way when they do. In Pattern 2, a need is introduced to make a relation between a piece the students had already been using and a piece introduced by the LA. This influences how the activity progresses forward, as the learning is made continuous through the explicit connection and problematization of students' earlier ideas.

Pattern 3. In the third pattern, pieces that previously stood fast are brought into question. That is, the LA introduces a need to question that which had been previously considered immediately intelligible. For example, physics students Aswini, Lisa, and Cassandra were working with LA Asahi to try to figure out the direction of a current in a solenoid. To do so, they needed to use the right hand rule, a common epistemic tool in physics to relate the direction of multiple vectors in three dimensions. The encounter began with one student, Aswini, using the right hand rule to explain the direction of the magnetic force. Aswini built relations about the direction of the force based on the right hand rule, which for her stood fast. However, LA Asahi called this piece into question:

Aswini: Okay. I was thinking it's going to *repel*, just because in the problem that we had in the P-set, when the *kern* and the *two wires* were *going in the same direction*, the wires were *attracting*. And in this case, the *kern* is *going in opposite directions*. So I was like, okay, it's going to *repel* in this case, *cause of the direction of the force with our thumb*. What do you guys think?

Cassandra: [LA Asahi starts speaking at the same time] Yeah, I agree. You can go, Asahi.

LA Asahi: All right, so I'm just trying to clarify for—Did you use the *first right-hand rule* for it, where the *thumb is the force*, Aswini?

To student Aswini, the right hand rule was so implicitly understood that she did not name it, but rather signaled its use through her hand gestures and her description of the direction of the force being shown by "our thumb." However, LA Asahi introduced a new gap: Did you use the first right-hand rule for it, where the thumb is the force, Aswini? Through introducing this gap, he called the piece right-hand rule into question by drawing attention to the fact that there are multiple right hand rules that could potentially be appropriate for the task at hand, but which would yield different solutions to the problem. The students started to negotiate which right hand rule was appropriate to use in this situation, and this active negotiation led them to uncover other inconsistencies within the group's reasoning. Eventually Aswini and Cassandra came to realize that not only had they been using the wrong right hand rule, they had been using it in different ways. By interrogating what they had assumed to be understood (the right-hand rule), they came to a deeper understanding both of each other's reasoning as well as of the underpinning concepts. In Pattern 3, a need is introduced that destabilizes what is assumed intelligible. This influences how the learning in the activity progresses, as meanings are continuously transformed, challenged, and deepened.

Discussion and Conclusions

In this paper, we demonstrate how PEA can be used to operationalize student in-the-moment learning, and in particular how it can be used to trace the development of ideas in LA-facilitated interactions. The three patterns described above provide insight into how student learning progresses during LA-facilitated interactions. We show that student learning progresses through how gaps are noticed and filled, how pieces of knowledge can be used across different gaps, and how these pieces can come into question through the noticing of new gaps; that is, we can trace how learning is made continuous or discontinuous (Hamza & Wickman, 2013). In presenting these findings, we focused primarily on how the LA enacted each of these patterns, and how they built on and called student ideas into question. This allows us to start to bridge the gap in the literature around how an LA can influence the way student learning progresses depending on how they make use of and respond to pieces of knowledge students bring to the conversation. In Pattern 1, the LA introduces a need to make sense of a new idea to advance students forward in the problem solving. John introduced the idea of "resonance structure," perhaps because to him, thinking about resonance structures can be an entry point to figuring out the acidity of a proton in a molecule. In Pattern 2, the LA builds on the students' previous pieces to advance their conceptual understanding of the topic. Ruthie related Alexis's piece "collision" to a new piece "effective" to move the group toward a deeper understanding of a particular chemical concept ("collision effectiveness"). In Pattern 3, the LA calls a previously unspoken assumption into question. Aswini's reasoning was underpinned by the use of the right hand rule. By problematizing and drawing attention to the multiple versions of the right hand rule, Asahi initiated a discussion that led to the students negotiating meaning, unearthing inconsistencies, and coming to collective understanding of the problem at hand. Each of these LA-mediated outcomes, i.e., advancing in the problem, deepening conceptual understanding, and facilitating collective understanding, illustrate potential mechanisms by which an LA can facilitate students' in-the-moment learning. Furthermore, while PEA had been previously employed in other contexts to uncover mechanisms of how students learn (e.g., Hamza & Wickman, 2013; Manneh et al., 2018; Wickman, 2004), this approach is new to study the context of LAs, and provides a lens to understand how LAs may contribute to improved student outcomes (e.g., Alzen et al., 2018; Herrera et al., 2018).

Contributions to Science Teaching and Learning and to NARST

Our work refines the way practical epistemology can be used as we not only focus on what and how students learn but also, in line with sociocultural theory, whose ideas are carried forward and how that affects students' learning. Returning to the theme of the NARST conference, this work makes two contributions to science teaching and learning and to NARST. First, our work may be useful to inform training LAs, and possibly other science teachers, to be more intentional about the gaps they open when facilitating small-group learning, and in particular to be intentional about focusing on and attending to students' disciplinary thinking. In our findings, Patterns 2 and 3 build on the disciplinary ideas students bring to support the progression of their learning; however, Pattern 1 does not build on student ideas, and instead centers the LA's own understanding. These patterns can be used to train LAs and teachers to strategize about how they can center student thinking rather than their own through their discourse and their questioning patterns. Second, our work may inform how to broaden the idea of scientific literacy and to connect it to in-the-moment learning. Through our use of PEA, we trace how ideas develop in interactions and how they contribute to how students' meanings undergo transformation. By diversifying the types of relations that are used in these in-the-moment encounters, and by broadening the types of needs that are centered to progress forward in an activity beyond those dictated by Western ways of knowing, we can create opportunities in the moment to not only support the development of scientific literacy, but also to create a broader picture of what scientific literacy is and how it can come to be.

Acknowledgements

This material is based upon work supported by the National Science Foundation under Grant No. DUE-2000603. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References Cited

Alzen, J. L., Langdon, L. S., & Otero, V. K. (2018). A logistic regression investigation of the relationship between the Learning Assistant model and failure rates in introductory STEM courses. *International Journal of STEM Education*, *5*, 1-12.

Barrasso, A. P., & Spilios, K. E. (2021). A scoping review of literature assessing the impact of the learning assistant model. *International Journal of STEM Education*, *8*, 1-18.

Chang, M. J., Cerna, O., Han, J., & Saenz, V. (2008). The Contradictory Roles of Institutional Status in Retaining Underrepresented Minorities in Biomedical and Behavioral Science Majors. *Review of Higher Education*, *31*(4), 433–464.

Gasiewski, J. A., Eagan, M. K., Garcia, G. A., Hurtado, S., & Chang, M. J. (2012). From Gatekeeping to Engagement: A Multicontextual, Mixed Method Study of Student Academic Engagement in Introductory STEM Courses. *Research in Higher Education*, *53*(2), 229–261.

Hamza, K. M., & Wickman, P.-O. (2013). Supporting students' progression in science: Continuity between the particular, the contingent, and the general. *Science Education*, *97*(1), 113–138.

Herrera, X., Nissen, J. M., & Van Dusen, B. (2018, December 31). *Student Outcomes Across Collaborative-Learning Environments*. 2018 Physics Education Research Conference Proceedings. https://www.compadre.org/per/items/detail.cfm?ID=14796

Kiste, A. L., Scott, G. E., Bukenberger, J., Markmann, M., & Moore, J. (2017). An examination of student outcomes in studio chemistry. *Chem. Educ. Res. Pract.*, *18*(1), 233–249.

Knight, J. K., Wise, S. B., Rentsch, J., & Furtak, E. M. (2015). Cues Matter: Learning Assistants Influence Introductory Biology Student Interactions during Clicker-Question Discussions. *CBE Life Sciences Education*, *14*(4), 1–14.

Manneh, I. A., Rundgren, C.-J., Hamza, K. M., & Eriksson, L. (2018). Tutor-student interaction in undergraduate chemistry: A case of learning to make relevant distinctions of molecular structures for determining oxidation states of atoms. *International Journal of Science Education*, *40*(16), 2023–2043.

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

Sellami, N., Shaked, S., Laski, F. A., Eagan, K. M., & Sanders, E. R. (2017). Implementation of a Learning Assistant Program Improves Student Performance on Higher-Order Assessments. *CBE Life Sciences Education*, *16*(4), 1–10.

Talbot, R. M., Hartley, L. M., Marzetta, K., & Wee, B. S. (2015). Transforming Undergraduate Science Education With Learning Assistants: Student Satisfaction in Large-Enrollment Courses. *Journal of College Science Teaching*, *44*(5), 24–30.

Thompson, A. N., Talbot, R. M., Doughty, L., Huvard, H., Le, P., Hartley, L., & Boyer, J. (2020). Development and application of the Action Taxonomy for Learning Assistants (ATLAs). *International Journal of STEM Education*, *7*(1), 1–14.

Van Dusen, B., & Nissen, J. (2020). Associations between learning assistants, passing introductory physics, and equity: A quantitative critical race theory investigation. *Physical Review Physics Education Research*, *16*(1), 1–15.

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

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

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

Wittgenstein, L. (1967). *Philosophical investigations* (3rd ed.). Blackwell.

Wittgenstein, L. (1969). *On certainty*. Blackwell.