What are the dynamics between answer-seeking and sensemaking?

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Sensemaking is widely recognized in PER as an essential learning and reasoning process for physics students to figure out physical phenomena for themselves. There is less emphasis in the literature on how this process develops and the early stages between sensemaking and answer-seeking, which we refer to as emerging sensemaking. We argue that instructors recognizing emerging sensemaking moments are productive for supporting students in sensemaking. Since answer-seeking is relatively common in physics classrooms, it is a promising entry point for students to engage in deeper sensemaking. We use qualitative video data from introductory physics labs for life scientists (IPL^{2}S) to explore the complex reasoning process occurring and discuss emerging sensemaking. We also consider the dynamic relations of answer-seeking processes and provide three examples: TA, graphical, and recall answer-seeking. Through a detailed analysis of these moment-by-moment reasoning processes, we shed light on the complexities of small group dynamics and offer suggestions for future work.

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I. INTRODUCTION AND BACKGROUND

Answer-seeking moves are instances where students exhibit little epistemic agency [1] over the learning process while prioritizing being "correct", regardless of the meaning or mechanistic nature of the information [2]. The epistemic frame of answer-seeking is marked by plug-and-chug behaviors meant to complete the task and move on [3, 4]. Prior work has viewed answer-seeking as an isolated epistemic frame unproductive for student learning. In contrast, sensemaking — when students build or revise an explanation to resolve a gap or inconsistency in understanding [5, 6] — is viewed as highly desirable in various learning environments, including teaching labs [1]. Sensemaking and answer-seeking are often presented as a binary, and less is known about the processes between these endpoints or how answer-seeking moves might contribute to deeper sensemaking.

Research has examined how to support student agency in their learning [1] by applying ideas, intuitions, and experiences [7]; however, the answer-seeking scholarship has not fully explored the associated dynamic relations of reasoning processes. This research aims to unpack and analyze various learning behaviors to understand better the connections and pathways between answer-seeking and sensemaking. We argue that answer-seeking can indicate emerging sensemaking within a "reformed" teaching lab environment. Here, we consider the central question: What are the dynamics between answer-seeking and sensemaking processes within a small group setting?

Our learning environment is a reformed introductory physics laboratory for life science (IPL^{2}S) course [8]. The IPL^{2}S aligns with recent PER results that suggest traditional labs aimed at confirming known physical laws and principles add little value to student learning and can even be counterproductive to student growth and attitudes toward science [9, 10]. The IPL^{2}S course was designed to facilitate sensemaking processes. Lab participants do not seek to verify well-documented results. Instead, they are given autonomy over the investigation, epistemic agency in design, and the chance to build personal knowledge when navigating unknown results.

To gain insight into the wide range of learning processes in an IPL^{2}S course, we have conducted qualitative research to track students' moment-by-moment reasoning, similar to methods used in other studies (e.g., [11, 12]). Physics lab environments that emphasize student agency and authentic engagement with science practices [13] provide a valuable setting to observe a range of reasoning processes, and prior work has shown that sensemaking involves reasoning about procedural and conceptual inconsistencies [6]. For the cases considered here, students are engaged in a spectroscopy investigation. They grapple with conceptual issues around spectroscopy, fluorescence, light scattering, and procedural issues around the optical setup and light collection. Students iteratively refine their understanding through a nonlinear dialogue involving group members, other groups, and instructors [6]. We examine instances of answer-seeking, sensemaking, and in-between behaviors that we label as emerging sensemaking to capture this process.

II. THEORETICAL FRAMEWORK

To explore the variety of answer-seeking processes through sensemaking, observing small group discussions, actions, tone, and word choices is necessary. Thus, we focus on the moment-by-moment timescale to analyze dynamics across multiple interactions to understand students' reasoning. To frame this analysis, we use resource theory to view a person's knowledge as a complex system of organized resources that operate at different levels depending on the context [14, 15]. These small resources comprise more significant concepts and arguments during a moment-by-moment sensemaking [5] or answer-seeking process. Within resource theory, some research has focused on individuals' resources [16]. However, more recently, this perspective has been applied to group learning environments while taking into account how one student's resources impact others understanding [17]. In this lab, students use equipment, discuss conceptual ideas, interact with a teaching assistant (TA), and generate visual representations of spectroscopic data. We expect students to activate various resources related to the lab as they exhibit agency in their construction of new knowledge [1].

The categories described below are used to discern various reasoning behaviors:

General answer-seeking (AS) are moves that are in service of explicitly completing lab goals or peer agendas rather than building an individual understanding of an underlying phenomenon. Examples include attempting to get to the correct answer – or, in the case of a lab environment – complete the investigation as quickly as possible and move on [1, 5, 18, 19]. Notably, general answer-seeking is the umbrella code with several sub-components, and the coding focuses on the students, not the TA.

Graphical answer-seeking (Graphical AS) are instances when students focus on their graphical representations to quickly draw conclusions of visually apparent characteristics with little or no discussion. Examples include noticing trend lines, numbers on the axis, or vibrant colors. In the lab setting, students may even spend substantial amounts of time potentially rearranging information in ways that do not meaningfully contribute to their understanding.

TA answer-seeking (TA AS) are instances where students prioritize the TA instruction, comments, and recommendations over following individual or group agency. For example, this is often seen in a more traditional lab mindset [10], where students focus on figuring out what the TA indicates or how to answer the TA questions rather than a strong focus on understanding the phenomenon or new knowledge.

Recall answer-seeking (Recall AS) are instances when students recall or reproduce an answer or formal facts in service of correcting the gap in their understanding. Examples include explicit terminology to reference the physical phenomenon or the investigation for answer-seeking purposes rather than relying on prior knowledge to construct new understanding. Recall answer-seeking can be seen as *cutting and pasting* [20] facts, rather than noticing gaps or inconsistencies in understanding [5, 6].

These three specific types of answer-seeking behaviors emerged from our data inspection and formed the basic codes for our qualitative analysis. We also encountered conceptual and procedural sensemaking as described previously [6]; however, sensemaking is used in our data without further subcodes. Key to this work, we also recognize cases in between answer-seeking and sensemaking, which we call emerging sensemaking **(Emerging SM)**. In particular, emerging sensemaking are instances when student reasoning shifts toward genuine sensemaking or may revert to some form of answer-seeking. Examples include noticing an inconsistency, observing something interesting in the data without exploring the physical phenomenon, or driving for resolution. During emerging sensemaking, we see students making meaningful connections as described in the sensemaking literature [5] but relying on other group members to figure out the phenomenon.

III. CONTEXT & METHODS

Our data come from four undergraduate students during a Spectroscopy & Fluorescence lab in the second-semester IPL^{2}S course at a large research university [8]. Many students in this course are life/health science majors and are juniors or seniors. Both semesters of this course were completely overhauled in 2017-18 according to stakeholder recommendations [21, 22] and the NEXUS/Physics curriculum [23], which emphasize open-ended lab experiments [6]; the IPL^{2}S courses have evolved further since the initial reforms. The second-semester IPL^{2}S course is broken into four primary investigations — hemodynamics, electrophoresis, spectroscopy & fluorescence, and circuits & axon transmission — each spanning three weeks. In groups of three to four, students collaborate to develop research plans, collect and analyze data, synthesize their data in peer argumentation sessions, and prepare a final lab report.

During data collection, video cameras and backup audio recorders were placed at each group's workstations, and computer screen recordings were gathered. Wide-angle camera lenses on shelves above group stations captured the entire group's head and body positions around the computers [6]. Group station recordings are helpful to see the precise moments when the TA interacts with the group to distinguish between sensemaking and TA answer-seeking. We use the screen capture software recordings as an extension to observing group behaviors so we can see how they work with or manipulate their data and representations.

Three of the authors of this paper were present during data collection to take ethnographic field notes and observe overall interactions [24]. Based on an initial review of the field notes, including a preliminary scan of all four participating groups, we focused on one particular group because their interactions revealed a rich variety of reasoning behaviors weighted somewhat toward the answer-seeking end of the spectrum. We inspected the videos of the IPL^{2}S data, made transcripts, and began preliminary coding in *ATLAS.ti* [25].

Our team met regularly to discuss the data, re-watch the recordings, and discuss the literature. Together, we iterated the code book and engaged in collaborative viewing sessions to achieve consensus [15, 26]. Identifying the dynamics between answer-seeking and sensemaking required us to examine multiple participants' interactions over time to see the layers emerge. During this process, we coded the entire transcript using the previously mentioned codes for answer-seeking and sensemaking. While reviewing audiovisual recordings and transcripts from the group, we noted instances where individual members took limited ownership of their learning. The group's interactions presented as efforts to produce canonically correct answers [1], taking up low epistemic agency, and not identifying what may have gone wrong or be incorrect in order to understand and resolve the issue [27, 28]. However, pathways are emerging between answer-seeking and sensemaking. The selected final cases provide examples of the dynamic relations of answer-seeking and sensemaking for the observed group [29].

IV. ANALYSIS OF TWO CASE STUDIES

Here, we present two cases: one illustrating distinctive answer-seeking behaviors and the other demonstrating emerging sensemaking. Group members previously collected data through a fiber-optic cable and spectrometer to measure how light interacts with chlorophyll and distilled water. During the cases we include, the students are learning to decipher their data by examining spectroscopic phenomena through the various transformations that may have occurred. The students discuss the implications of their data with the TA (Leo) through their visual representations (see Fig. 1). Students are gaining experience comparing plots and recognizing how light interacts with different substances, such as chlorophyll and distilled water.

The first case we discuss highlights the different types of answer-seeking. During this time, all four group members are present and listening. The conversation, however, is primarily between Leo and the student Rex, with Kai occasionally interjecting brief affirmations like "k" and "ok". We observe that Rex is not sensemaking; instead, Rex is relying on Leo to indicate what to do and what to look at. Rex is also answer-seeking by asking how to interpret the graph and attempting to copy and paste ideas by mentioning UV light from unknown sources. Codes to categorize the interactions in the dialog follow the transcript.

TA: What you can do is compare across peaks within the same spectrum. (Kai: k) So, like specifically talking

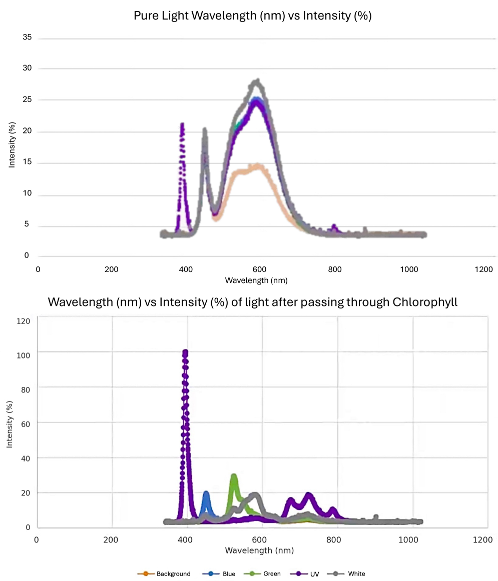

FIG. 1. Relevant plots were discussed by the group during the two cases. The upper plot shows unfiltered light, while the lower plot shows light passing through chlorophyll. Characteristics of light can be inferred by comparing both plots and observing the relative heights of the peaks.

about the UV, you could compare like the primary UV peak to the secondary peak, like the next largest. (Kai: ok) And then see how that intensity changes between different spectra.

Rex: Say the first one goes from say 22 to 25. [Graphical AS]

Rex: Is that what you're saying? [TA AS]

Rex: The first UV peak, purple one? [Graphical AS]

TA: Although, So for your question, I think really what you should be thinking about is a.

Rex: Something it's got to do with UV light, because UV light is what kills stuff and if were talking about, right. [Recall AS]

Rex: Is that the right track? Like water decreases. [TA AS]

TA: So, that's an, that's an interesting track. That's not what I was thinking of, (Rex: alright) but that's an interesting track to think about. What all I was going to say was, you should you should look and see how similar the spectra are between the, between the pure spectrum, between the pure light and then after it passes through chlorophyll versus after it passes through water.

We see three specific ways Rex is answer-seeking in response to what the TA discusses. Rex prioritizes the TA instruction and recommendations rather than working to revise individual understanding to resolve a gap or inconsistency. **The second case** occurs moments later as the group continues discussing the peaks in their plots. At this point, three of the four students (Cal, Kai, Rex) in the group engage in different varieties of answer-seeking along with moments of emerging sensemaking. Meanwhile, the fourth student, Ash, remains quiet. We picked case two because each student within the group is doing different things while discussing ideas with the TA on and off.

Cal: The purple is the UV light right? (Kai: yeah) So you have this, you have the primary peak at 22 and then this secondary peak at 25. Or, I'm sorry, the primary peak at, like 400 or like 390. [TA AS]

Cal: And then like, this one. But then that same peak isn't there in the, is that through chlorophyll? [Emerging SM]

Rex: Is the one on the right (see upper Fig. 1) through water or just pure light being shined? [Graphical AS]

Kai: It's just the regular light.

Rex: All right, so we need to get the one with the water on.

Kai: Its right here.

Cal: So both, so in both water and in the chlorophyll, this 600 nanometer wavelength disappears. Like it, like it goes. It's completely gone. [Emerging SM]

Rex: That's true. I see what you're saying.

Cal: And that kind of makes sense for, for chlorophyll, where that's more or less the green wavelength right between 500 and 600 nanometers. So for chlorophyll to absorb, the green part of UV light, that kind of makes sense but then water absorbs kind of the same, wavelength. [SM]

Kai: Yeah, what I thought he was saying is, that he's like look here and be like. The intensity of the first UV peak is 22 the second one is 25 so that's a 3% change and then do the same over here and be like, instead, this one had a, you'd say this is the second peak, had a, what, 70% change. [TA AS]

Kai: I don't, –(Cal: yeah)– I don't get how, you're not, you can't compare them to each other, is I think where my confusion lies. [Emerging SM]

Cal: You can compare the ratios of them to each other. [TA AS]

Kai: Yeah, well yeah, I guess. I don't know. [AS]

Cal: So if I, so if I take, if I take this, if I take this wavelengths peak and ratio it to, say, like, the 600 wavelength peak. And compare the ratio of that to the ratio of this, then that can start to say something meaningful about the property that that, that thing has versus –(Kai: yeah)– just like –(TA: ok so, I'm) [Emerging SM]

Cal: Can you help us guide our thoughts? (TA: yes) Cause I feel like I'm rambling and –starting to go into nowhere. [AS and TA AS]

TA: –No you actually, you, no there was good stuff, um. Because there is a time limit to how long we can be here. I am going to ask a question, that hopefully will put you on a good track, which is, when the light passed through water, was there, very much absorption of any of the lights? Or do their spectrum look the same as when you, as just like the pure spectrum? And then you should think about that same question for chlorophyll.

When analyzing these two example cases, we can identify instances when students are not taking ownership of their learning. The case two transcript showcases the balance between sensemaking and merely following TA instructions. Without looking at the granular context of this interaction, it would be easier to assign a straightforward binary between sensemaking and answer-seeking. When we read the dialog in the context of the first example, where the TA directs the students toward a formal objective, we can see the layers between TA answer-seeking and emerging sensemaking begin to occur.

If we read just the comments from Cal, we see how quickly they turn from answer-seeking to emerging sensemaking to sensemaking. The conversation later ends with Cal demonstrating emerging sensemaking type comments, but this time, Cal shifts towards answer-seeking by asking for help. Thus, we argue that emerging sensemaking moments are key for instructors to recognize whether to facilitate directing students towards ownership of their learning [1] or providing encouragement.

The data also shows that Kai is primarily TA answer-seeking as most of their dialogue involves explaining confusion in the context of what Leo previously indicates. Kai does, however, engage in moments of emerging sensemaking when Kai begins to recognize where their confusion lies. Kai does not, however, vocally work to resolve their confusion and how it relates to what Cal is working to understand in data. Meanwhile, Rex remains primarily in the answer-seeking mode.

Across both cases, we get a sense of the types of answer-seeking and the mix of emerging sensemaking cases beyond a simple binary of one or the other. We see how both emerging sensemaking and answer-seeking are happening simultaneously. The transcript ends with the TA recognizing a time constraint with what the group still needs to accomplish before the end of the lab, and Leo ultimately pushes them towards finishing the investigation.

V. DISCUSSION AND LIMITATIONS

In the existing PER literature, sensemaking has been widely valued in labs [6], while answer-seeking has generally been viewed as less helpful. There has been a tendency to view answer-seeking and sensemaking as a dichotomy, often focusing on whole groups without considering variability within the group. By recognizing that answer-seeking includes several subcategories, we conceptualize the dynamics leading toward emerging sensemaking and seek productive ways to support students in sensemaking. Analyzing one group of students, we see the precise moments where individuals follow their unique reasoning trajectories, shifting between answer-seeking and sensemaking behaviors rather than consistently engaging in one or the other. The cases provided show how students navigate emerging sensemaking during small group discussions, adding to the literature that recognizes the complexity of group dynamics in a physics learning environment [11, 30]. There are moments when one individual might engage in more answer-seeking of one type while other students simultaneously participate in different activities, including sensemaking. Examining multiple talk turns across various group member interactions is necessary to capture the dynamic process.

The authors note that following every idea that surfaces due to parallel discussions in a loud lab environment is not possible. There are moments where conversation is lost when students interact with peers in another group or stand in locations beyond the range of audio recorders. Additionally, while the instructor encouraged students to use classroom computers, there were instances where individual group members enacted data analysis on their personal devices. Using numerous, partially redundant recording devices alleviated these limitations, allowing us to piece some meaningful interactions together. Another limitation stems from our institution's data collection procedures, as we could not collect more nuanced demographics. Future work would benefit from carefully evaluating group dynamics with consideration of demographics, including identities, backgrounds, and gender that may impact sensemaking and answer-seeking.

Our results, however, are essential for building a nuanced model of the complex relationship and progression between answer-seeking, sensemaking, and student reasoning. Rather than focusing on answer-seeking as an undesirable behavior, there is an opportunity to explore how answer-seeking can be a valuable part of the process leading toward sensemaking. Given that answer-seeking is ubiquitous in labs and other learning environments, our findings suggest that instructors can look at the nuances of answer-seeking by recognizing and acknowledging student confusion and use it as an opportunity to guide students towards sensemaking. This work raises further questions about how the refined details of TA comments influence when students engage in different types of answer-seeking and sensemaking, knowing the impact a TA can have on student learning. This research may especially help support TAs, who play vital roles in the physics learning experiences of numerous undergraduates. Future work would benefit from focusing on how to encourage students that are answer-seeking toward emerging sensemaking in order to refine TA training along with other instructor supports.

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