Effect of the Level of Inquiry on Student Interactions in Chemistry Laboratories

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Supporting Information

ABSTRACT: The central goal of our exploratory study was to investigate differences in college chemistry students’ interactions during lab experiments with different levels of inquiry. This analysis was approached from three major analytic dimensions: (i) functional analysis; (ii) cognitive processing; and (iii) social processing. According to our results, which were based on the qualitative analysis of direct observations of different groups of students working in general chemistry laboratories, experiments that involved higher levels of inquiry were associated with an increase in the frequency of episodes in which students engaged in proposing ideas versus asking and answering each other’s questions. Higher levels of inquiry also favored episodes in which experimental work was approached in a more exploratory (versus procedural) manner. Increased levels of inquiry were also associated with more frequent episodes of domination in which a few students in a group directed the actions of others. In general, our results elicit trends and highlight issues that can help instructors identify strategies to better support and scaffold productive engagement in the laboratory.

KEYWORDS: First-Year Undergraduate/General, Chemical Education Research, Inquiry-Based/Discovery Learning, Student-Centered Learning

FEATURE: Chemical Education Research

INTRODUCTION

Laboratory work is a core component of high school and college chemistry courses across the world. Unfortunately, research in science education indicates that conventional laboratory activities often fail to engage students in the discussion and analysis of central concepts and ideas, and do not effectively promote the development of inquiry skills.1−3 These types of results have prompted efforts to transform laboratory instruction to provide more opportunities for students to meaningfully participate in scientific practices and discourse.4,5 In the particular case of chemistry, changes to traditional conceptualizations of practical work have been suggested by several authors6−8 and research-based models of reform, such as those that follow the science writing heuristic framework8 or a process-oriented, guided-inquiry learning approach,9 have been developed and enacted in different higher education settings. However, little research has been done that focuses on the analysis of what these new models of instruction afford in terms of college student learning and reflective engagement in experimental work.10−12

In recent years, reform efforts at the general chemistry level at our own university have led to the development of a set of lab experiments that engage students in different levels of inquiry,4 from highly structured lab activities to open-inquiry projects. As part of the evaluation of this reform process, we have explored how engagement in different types of experiments affects students’ interactions while working in small groups. In particular, in this paper we report the results of a qualitative research project designed to investigate differences in students’ interactions while working on experiments involving different levels of inquiry. Applying a well-known analytical framework based on sociocultural discourse analysis,13 we approached our task from three major analytic dimensions:13

1. Functional analysis, used to characterize the communicative strategies employed by the study participants
2. Cognitive processing, used to examine the ways in which students approached the experimental tasks
3. Social processing, used to determine the nature of the social relationships developed through participation in peer groups

The results of our exploratory study provide insights into how to better support and scaffold student work in different laboratory environments.

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INTERACTIONS IN LABORATORY SETTINGS

Experimental work in school science laboratories traditionally involves students working in small groups. Some research studies in this area have explored the effect of individual traits, such as gender, prior knowledge, and personality, on the outcomes of group work. Recent investigations have focused on the role played by social process during collaboration, looking to characterize the interdependence among practices, processes, and conditions leading to co-construction of knowledge in different learning situations. These types of studies pay close attention to the content and function of classroom discourse as elicited through the analysis of student—student and student—teacher interactions.

Analysis of interactions during traditional laboratory work suggests that lab talk is very goal-oriented. On-task conversations and actions are largely focused on managing and completing lab work and tend to be characterized by brief, fragmented utterances. Student talk during experimental activities is mostly centered on procedural issues related to how to carry out specific experimental tasks or how to manage lab equipment. Considerably less time is invested in either analyzing and discussing experimental data or trying to understand concepts and ideas, building connections between theory and practice, or reflecting on science practices.

Krystyniak and Heikkinen compared the verbal interactions involving a single lab team during structured general chemistry labs and extended open-inquiry investigations at the university level. Their results revealed a decrease in student—teacher interactions concerning procedures and data recording and an increase of conversations related to lab safety and data analysis in the context of open inquiry. Participants in this study also talked less about chemistry concepts while engaged in the more open investigations. This outcome was attributed to the high familiarity that the students had with the concepts targeted by the more open-ended experiments. These authors observed that students sought less instructor guidance during the open-inquiry than the noninquiry lab activities. These latter results are consistent with findings from other researchers that indicate that students gain independence from their instructor while involved in open-inquiry investigations. Besides the results of these investigations, little is known about how the level of inquiry affects social processing and cognitive processing in college science laboratories. This knowledge is necessary to identify essential characteristics of experimental tasks that promote the types of interactions known to foster high levels of intellectual engagement and meaningful learning. Thus, we designed the present qualitative study to increase our knowledge in this area.

In general, the nature of interactions among group members has been shown to strongly influence the quality of collaborative group work. For example, symmetric interactions in which participants contribute equally to the discourse seem to be more productive, as they open spaces for the co-construction of shared understandings. Co-construction of understanding involves contributions from different students that, taken individually, do not represent a complete idea but taken together either complete or continue another student’s idea. Co-construction requires collaborative thinking in which group participants discuss a common problem and actively seek some form of shared understanding that no single participant entirely possessed beforehand. However, co-construction of meaningful understandings requires more than instances of co-regulatory activity; it demands sustained engagement in high-level cognitive processing such as building explanations, developing models, synthesizing ideas, or evaluating arguments, and not simply in sharing information, exchanging ideas, providing definitions, or clarifying procedures.

RESEARCH GOALS

Our investigation was guided by the following research questions:

What interaction patterns characterize students’ work in a general chemistry laboratory?

How does the level of inquiry of lab experiments affect or is reflected in students’ interactions in the laboratory?

The answer to these questions should be of central interest to chemical educators looking to identify critical characteristics of experimental tasks that promote student interactions characterized by high levels of intellectual engagement in the laboratory setting, such as building explanations, developing models, drawing inferences, synthesizing ideas, and evaluating arguments.

METHODOLOGY

Context and Participants

The study was conducted in a research-intensive public university in the southwestern United States. The student body is composed of over 30,000 undergraduate students representing a diverse population (52% female, 48% male; 34% from minority groups, mostly Hispanic). The Department of Chemistry and Biochemistry at this institution offers a two-semester sequence of general chemistry courses for science and engineering majors. Students in these courses attend a 150-min weekly laboratory class in which they work in self-selected groups of three or four people under the supervision of a graduate teaching assistant (TA). On average, 24 students, divided in 6 groups of 4 students, are engaged in experimental work in a given laboratory class, and they attend 14 laboratory sessions in a given academic semester. Most experiments in the general chemistry course involve students in applying diverse analytical techniques (e.g., chromatography, emission and absorption spectroscopy, titration) to study the diverse chemical systems and processes.

Data Collection

The results of this study are based on data collected in laboratory classes taught by the same TA during the first and second semester of the general chemistry course sequence: General Chemistry I (GCI) and General Chemistry II (GCII). This TA was a Ph.D. student in the area of chemical education who had experience teaching general chemistry labs (none of the authors of this paper was involved as instructor of the students in the observed lab sections). These laboratory classes were selected because they were part of a pilot project designed to diversify the level of inquiry of the experiments in which students were to be engaged.

Data were collected using running records, a well-established qualitative research methodology for collecting data in classrooms based on direct observation of teachers and students. A running record is a written narrative noted down by an observer that provides a detailed, continuous description of interactions and behaviors, preserving the natural sequence of events. Observer subjectivity and potential bias is reduced by training the observer, by keeping the notes as complete and descriptive as possible, and by avoiding any
interpretive remarks. Running records may include, for example, descriptions of participants’ actions, materials used, verbatim quotes when possible, and restatements that capture the essence of utterances. Running records do not capture all of the interactions that happen in a given setting, which limits the generalizability of the associated findings. However, they generate a representative sample of sequential events that can be used to elicit general patterns of behavior.21-24

Direct observation of entire experiments by a researcher present in the lab was selected over other research methods (e.g., video or audio recording) given the specific characteristics of experimental work in the observed chemistry laboratories. In this setting, students frequently move around various areas (e.g., lab benches, fume hoods) to complete different activities in a single lab session. Background noise is also constantly generated by over 20 people actively working in a closed space and by fume extractors and air filtration systems. Attempts to generate reliable audio records of students’ conversations in this type of environment during pilot trials were largely unsuccessful. Similar difficulties in using audio and video recording to register student conversations in college lab settings have also been reported by several authors.10,18

To increase the validity and reliability of the running records, pilot data were collected in other laboratories prior to the main study. Both researchers involved in this project simultaneously observed several groups of students working in the lab, took independent field notes using pen and paper during an entire lab session, and then met to review and compare their running records. In general, the field notes were very similar, although on a few occasions certain behaviors were observed by one observer only. The comparison and discussion of pilot field notes led to the definition of a set of guidelines that were used by the first author of this paper when completing the bulk of the observations. These guidelines defined critical observation targets (e.g., who participates in an interaction, who initiates the interaction) and decisions (e.g., to follow the actions of those students judged to be located in the most accessible area of the laboratory when a group splits). During this process, a decision was made to restrict observations to on-task behaviors involving interactions between two or more people. This decision was guided both by the research goals and by the need to facilitate thorough note taking during those times in which students were engaged in experimental activity.

Restrictions imposed by personnel resources and the research methodology limited the observations to one single group per lab session. Thus, in order to increase the diversity of the observed lab groups, the work of different groups was followed at different moments during an academic semester. Overall, a total of five randomly selected groups of students were observed: three of them working on GCI laboratories and two of them engaged in GCII labs. Signed consent forms approved by our Institutional Review Board were collected from all of the participants. Analysis of general achievement data indicated that the 20 students involved in these groups had an average grade point average (GPA) of 2.40 out of 4.00, slightly lower than the average GPA for all of the students in the general chemistry course (2.60/4.00). The difference in the distribution of grades was not statistically significant. Detailed information about the composition of the observed student groups and the experiments in which they were engaged are presented in Table 1.

### Level of Inquiry

To characterize the level of inquiry that each lab experiment represented, a rubric was built based on similar rubrics used by other authors to describe the inquiry continuum,25,26 but taking into consideration the specific nature of the observed lab activities (see Table S1 in the Supporting Information). This rubric was used to evaluate the level of inquiry of each of the observed lab experiments. The evaluation was based on direct observations of student work in the lab, as well as on the analysis of what students were asked to do during each experiment as described in the students’ lab manual and in the written notes that TAs were required to use to guide lab activities. The resulting categories for each experiment are indicated in the rightmost column in Table 1. As shown in this table, study participants were engaged in experiments corresponding to four different levels: verification (level 1); structured (level 2); guided (level 3); and open (level 4). Given that the number of experiments corresponding to level 4 was rather small (one per semester), opportunities to observe groups working in those types of labs were limited.

### Data Analysis

The collected running records were descriptive accounts of the sequence of events in a group’s lab work. For example, consider this description of the interaction between students L1, A1, B1, and N1:

L1 leaves the bench and tries to find mortar and sand. She can’t. So she asks TA, and TA shows her where they are. A1 gets the solvents and she is mixing them (10 mL/
Table 2. Interaction Analysis Examples for the Group Engaged in the Experiment about Identification of Plastics

<table>
<thead>
<tr>
<th>Examples of Events As Captured in the Running Records</th>
<th>Functional Analysis</th>
<th>Cognitive Processing</th>
<th>Social Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1 and L1 go to B1 and ask ‘What do we do next?’ B1: ‘We need to weigh all the plastics and get the cylinder’</td>
<td>Interrogative/Responsive</td>
<td>Procedural</td>
<td>Confusion/Tutoring</td>
</tr>
<tr>
<td>B1 and N1 finish fast. N1 suggests to the whole group that they split up again to do more measurements.</td>
<td>Compositional</td>
<td>Procedural</td>
<td>Domination</td>
</tr>
<tr>
<td>L1 and A1 both do the measurement, compare their numbers, and find differences that they cannot explain. A1: ‘I will do it again’ L1: ‘Yeah’</td>
<td>Evaluative</td>
<td>Exploratory</td>
<td>Collaborative</td>
</tr>
<tr>
<td>B1 asks N1 ‘Can you go and measure the mass for these unknowns?’ (The unknowns L1 and A1 took; L1 and A1 did not know what to do with them, so they did not really measure anything.)</td>
<td>Directive</td>
<td>Procedural</td>
<td>Domination</td>
</tr>
</tbody>
</table>

10 mL acetone/hexane. L1 puts the solvent in the mortar. B1 and A1 are watching. N1 is taking notes. The extraction is not very good. They stop and take notes. B1: ‘We can add more 50/50 mixture of solvents.’ B1 faces to L1: ‘Can you pour more into the beaker?’ TA comes over....

These notes often included verbatim quotes of brief utterances or restatements of students’ words as captured in the flow of a conversation. All of the running records were analyzed and coded using a qualitative approach based on a well-known framework for sociocultural discourse analysis. In particular, actions and utterances captured in transcripts or field notes were carefully analyzed to infer the character and purpose of interactions (functional analysis in terms of language functions), the different ways in which the tasks were processed (cognitive processing), and the nature of the relationships developed via social activity (social processing).

The analytical process started by dividing the running records for a given lab session into a sequence of “episodes” with boundaries determined by perceived changes in the nature of the interactions as indicated by changes in the topic of conversation or in the nature of the experimental activity. This segmentation process resulted in an average of 24 distinct episodes of on-task activity per running record across all types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs; the mean values (M) for number of episodes for different types of labs were very similar: M(L1) = 25; M(L2) = 23; M(L3) = 27; M(L4) = 22. The nature of each episode was then characterized by very similar: M(L1) = 25; M(L2) = 23; M(L3) = 27; M(L4) = 22. The nature of each episode was then characterized by...

Data analysis was completed in various steps. A coding system was proposed and discussed by the two researchers involved in the study based on the selected framework for discourse analysis and independent informal coding of several running records. This coding system was then applied by the first author of this paper to the formal analysis of one record. During this task, coding segments were defined at the episodic level. Both the proposed segmentation of the field notes and the specific codes assigned to each episode were then independently reviewed by the second researcher, who either agreed with the assignments or proposed alternative segmentations or codes. Comparison and discussion of ideas helped refine the coding system and the identification of boundaries between episodes. Once agreement was reached, the process was repeated with more field notes until total disagreements were less than 10% of the total episodes and codes. The authors then repeated the process until achieving over 90% agreement in 20% of the collected field notes. The resulting coding system was then applied by the first author to analyze the totality of the data. As part of the global analysis of the data, descriptive statistics were employed to compare the frequency of different types of coded interactions. These quantitative results were used to highlight and visually represent trends in the data that may be indicative of general patterns of behavior in the observed labs.

MAJOR FINDINGS

In this section, we describe students’ interactions in the general chemistry labs, as elicited from our running records. As part of this analysis, we also describe general trends in the effect of the level of inquiry on different aspects of students’ interactions. We restrict our description to changes in the three language functions, the three cognitive processing modes, and the three social processing modes that were most commonly observed in the different types of labs. The effect of the level of inquiry on other less frequent language function and social processing modes can be directly derived from the analysis of the numerical data presented in Table S2 in the Supporting Information. Given that many of these other categories did not turn up to a great extent in our data, identification of potential trends should be done with caution.

Functional Analysis (Language Functions)

Although the extent to which our study participants engaged in interactions coded as corresponding to different language functions varied between types of experiments, the language...
functions most commonly elicited across different running records corresponded to interrogative/responsive (27.5% of all of the coded episodes across all types of experiments), compositional (19.3%), and directive (16.0%). These results imply that a significant proportion of the interactions captured by our observations were related to students asking questions or responding to questions from peers (interrogative/responsive), proposing ideas (compositional), and directing each other’s actions (directive). Concrete examples of the types of interactions associated with these different language functions (and other discourse modes) are presented in Table 2.

Comparison of running records for lab experiments with different levels of inquiry revealed changes in the frequencies of common language functions. In particular, increasing levels of inquiry were associated with lower proportions of episodes involving interrogative/responsive interactions and higher proportions of episodes in the compositional and directive categories. This trend is illustrated in Figure 1 in which we present the percentages of coded episodes in each of these three major language functions in relation to the level of inquiry of the observed lab experiments. These results suggest that experiments with a higher level of inquiry seemed to prompt students to propose more ideas, reducing the amount of peer questioning related to the tasks at hand.

Given that we did not have the opportunity to observe several groups working on the same experiment, the described changes in the purpose of students’ interactions with level of inquiry may have been influenced by the specific characteristics of the observed lab groups (e.g., knowledge and motivation of their group members). However, comparison of running records for lab groups working on different experiments with the same level of inquiry did not elicit major differences in the frequency of various language functions. This result suggests that the trends depicted in Figure 1 were more likely influenced by the level of inquiry of the lab activities than by individual group characteristics. Similar results were obtained when comparing cognitive and social processing in groups working on experiments with the same level of inquiry.

**Cognitive Processing**

The analysis of our running records indicated that procedural thinking played a central role in most of the observed interactions in the lab. Overall, 54.7% of all of the coded episodes were associated with instances in which students were focused on handling, organizing, or executing experimental tasks (see Table 2, and Table S2 in the Supporting Information, for specific examples). Only 33.9% of the coded episodes were related to exploratory activities, which included suggesting and exploring experimental alternatives; a small percentage of the observed interactions (11.4%) involved interpretative work (i.e., generating explanations or building arguments). However, as shown in Figure 2, the level of inquiry of the experiments seemed to affect the extent to which procedural versus exploratory modes of cognitive processing dominated the nature of the observed interactions. In general, our results indicate that higher levels of inquiry favored exploratory reasoning over procedural thinking, but did not seem to have a major impact on the interpretative component.

According to our results, there was a decrease in exploratory instances of cognitive processing in moving from level 3 (guided) to level 4 (open) in the inquiry scale (Figure 2). This result may be related to sample size issues, given the limited number of observed lab experiments (only two) corresponding to the highest level of inquiry. However, the increase in the procedural mode for inquiry level 4 labs may be linked to intrinsic demands of the open-inquiry experiments that required students to come up with their own procedures to solve their proposed research questions. Our qualitative analysis of running records for the more open inquiry labs indicated that students spent considerable time organizing their work and looking for resources required to complete the various experimental tasks. On the other hand, all of the experiments identified as belonging to inquiry level 3 consistently involved a higher percentage of exploratory episodes than other types of labs. In these guided-inquiry labs, students frequently received general guidance (e.g., suggestion of feasible experimental techniques, reduced list of available equipment and materials) in performing experimental procedures, which may have created more opportunities for exploratory cognitive processing.
Social Processing

The analysis of the running records from the perspective of social processing elicited three major modes of social processing observed across all types of experiments: domination (28.6%); tutoring (23.7%); and confusion (22.4%). Domination refers to instances in which a student in the group controlled decisions or actions of the group or some of the group members. Although the term “domination” may have negative connotations in common language, we used it in this study to simply characterize episodes in which group actions were directed by a single individual. These episodes may have included instances of positive or negative leadership. Tutoring corresponds to episodes in which one student provided support to others by answering questions or guiding their work. Lastly, confusion identifies instances when one or more group members do not know very well how to proceed or fail to communicate clearly with others. These three modes of social processing were frequently interrelated; for example, episodes of confusion often involved instances of tutoring and a given episode could have been characterized using both of these codes.

The frequency of different modes of social processing also seemed to be affected by the level of inquiry, as shown in Figure 3. In particular, the frequency of observed episodes of domination consistently increased with increasing levels of inquiry, while instances of tutoring and confusion became more infrequent. Our qualitative analysis of running records for different types of experiments indicated that some students were likely to adopt the role of leaders or facilitators of group work when facing nonroutine tasks that required them to come up with their own ideas or make their own decisions. In these situations, it was common to observe one or two members of a group taking on or asserting a facilitation or leadership role. This may explain why instances of domination of lab activity were more frequently observed in experiments with a higher level of inquiry. Episodes of collaboration in which group members equally participated in decision making or meaning making were infrequent (an average of 9% of all coded episodes) and remained at a similarly low level across different types of experiments (see Table S2 in the Supporting Information).

Our analysis of social interactions and activity in lab groups also allowed us to identify four major roles typically adopted by different members of a group:

1. Facilitator—Facilitated or led group work by answering questions, providing explanations, making decisions, and assigning tasks
2. Active Participant—Actively participated in different group activities, knowing what to do and providing support to others but without making major decisions or assigning tasks to others
3. Passive Participant—Worked mainly as task assistant for the Facilitator in a group
4. Nonparticipant—Failed to participate or was marginally involved in lab activities

All five groups of students that were observed as part of our study included some members who tended to act either as facilitators or active participants, and others who assumed the roles of either passive participants or nonparticipants.

As part of our analysis, students’ roles were tracked through the different running records. Our results indicated that students were likely to preserve their roles within and across different experiments, but role changes occurred from time to time. When a role change was observed, it was frequently associated with one of the following situations:

The nature of the experimental task changed and particular students seemed to have more knowledge or familiarity with the experimental procedures. These more knowledgeable or more skilled students frequently adopted the roles of facilitator or active participant. Students encountered a problem or were confused about how to proceed. In these cases, these students often adopted a more passive role while others directed group activities.

The demands of laboratory work increased. In these situations, passive or nonparticipating work increased. In these situations, passive or nonparticipating students in the observed lab groups often took on a more active role.

CONCLUSIONS AND IMPLICATIONS

The aim of our exploratory study was to investigate differences in college chemistry students’ interactions during lab experiments with different levels of inquiry. Although we recognize the limitations of our study, which is based on the use of running records to capture student interactions in a small number of lab groups, we believe that our findings reveal trends and highlight issues that can both guide future systematic observations of lab activity and help us identify strategies to better support and scaffold productive engagement in the laboratory.

Our results revealed positive shifts in the nature of students’ interactions during lab work with increasing levels of inquiry. For example, we observed an increase in the relative frequency of episodes in which students engaged in proposing ideas versus asking and answering each other’s questions about the tasks at hand. Higher levels of inquiry, particularly level 3 (guided inquiry), also favored episodes in which experimental work was approached in a more exploratory (versus procedural) manner. This latter outcome suggests that a basic degree of structure and guidance may be needed to facilitate the emergence of more independent exploratory reasoning in college science laboratories at the introductory levels. In general, guided inquiry seemed to promote the most desirable types of student interactions, yet more research is needed to...
clearly identify what aspects of these types of tasks result in the more productive behaviors.

Although the results of our study highlight important cognitive benefits of engaging college general chemistry students in more open investigations, they also reveal major challenges in the successful implementation of experiments with high levels of inquiry. While these types of lab activities seemed to increase the frequency with which students engaged in proposing and exploring ideas, as well as in making decisions, they did not necessarily result in more interpretative and collaborative ways of thinking. Several research studies on the implementation of inquiry activities have highlighted the challenges associated with using practical work to promote meaningful collaborations and high levels of cognitive processing.28,29 According to existing research, the routine nature of traditional laboratory work at different educational levels shapes how most students frame and approach practical activity.28 In particular, students seem to conceive practical work as implementing well-defined procedures to collect data that will confirm a scientific principle. It is likely that this type of epistemological frame29 may also constrain students’ reasoning and actions in general chemistry labs. Research indicates that how lab activities are structured influence what prior knowledge students find relevant to their own learning in such environments.30

Analyses of learning environments that have successfully created opportunities for students to engage in interpretative reasoning suggest that recurrent opportunities for small group and whole class discussion, reflection, and self-assessment are critical to foster such types of reasoning.27,28 Conversations during these group activities should be carefully scaffolded using questions or specific tasks that push students to self-assess their knowledge, skills, decisions and actions, critically think about their data, and begin building arguments based on evidence. Related research in university chemistry labs indicate that lab environments that constantly challenge students to think through experimental problems and figure out solutions promote metacognition and problem-solving skills.12

In terms of social processing in lab groups, our results elicited a significant shift with inquiry level. While experiments classified as level 1 and level 2 were characterized by the abundance of tutoring events, experimental activity in levels 3 and 4 labs were characterized by instances of domination in which one or two students in a group made most decisions and directed the actions of others. Episodes of collaborative work in which a group of students co-constructed understanding were seldom observed, regardless of the level of inquiry in the experiments. These results suggest that group work in college labs needs to be explicitly taught and carefully monitored to ensure productive collaborations. Research in collaborative learning indicates that domination of group work by some individuals may be avoided by organizing activities to ensure interdependence, co-regulation, and individual accountability. This could be done by assigning rotating managerial (e.g., facilitator, monitor, manager) and cognitive (e.g., clarifier, questioner, explainer) roles.14

Our overall results suggest that changing the level of inquiry of laboratory experiments may be a necessary but not sufficient condition for creating a learning environment in which students collaboratively engage in high levels of cognitive processing. Collaborative group work in college laboratories needs to be carefully scaffolded to guide student reasoning in more productive ways. This scaffolding may require that TAs become better at consistently pressing students to intellectually engage with their investigations. In this regard, training TAs to use discourse tools such as those generated by Windschitl and colleagues31 may be highly beneficial. These tools are designed to engage students in three types of discourse activities while working in inquiry-based tasks: eliciting hypothesis and ideas, making sense of material activity, and generating evidence-based explanations.32 These types of resources could help TAs initiate and sustain group conversations that focus on interpretative reasoning rather than on procedural matters. Additionally, TAs may need to be trained to better support collaborative work by positively reinforcing productive group behaviors, promoting individual accountability, and fostering shared leadership and consensus decision making.

ASSOCIATED CONTENT

Supporting Information
Rubric used to characterize levels of inquiry; data table on functions and modes of observed collaborative groups. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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