

Students collaborating with computer models and physical experiments

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Abstract: This study examines the actions and discourse of students in a chemistry laboratory course as they interact with available social and material resources. In one session, students conduct wet lab experiments; in another, they use molecular modeling software. The analysis demonstrates that the features of the computer-generated representations afford conceptual discussions. The structure of the task and the available material resources in the wet lab more often result in help-seeking behavior.

Keywords: representation, discourse, chemistry

Introduction

Current theories of human knowledge (Greeno, 1998; Brown, Collins, & Duguid, 1989; Resnick, 1988) characterize understanding in terms of people's participation in practices of inquiry and discourse that include interactions with others and with the material and technological resources of their environment. These approaches emphasize the situated processes by which people come to collaboratively construct shared meaning within a particular social, material, and symbolic context. When viewed within a social context, scientific inquiry is seen as an emergent interaction among scientists and between scientists and their materials at hand. Representations are among the material objects that support the discourse and meaning-making of a scientific community of practice.

From the situative perspective, learning is not a one-way transmission and reception of meaning, but a two-way transformative process by which meaning emerges in the space between two interlocutors engaged in joint activity (Pea, 1993). Learning occurs through a series of interleaved assertions, gestures, actions, acknowledgments, requests for clarification, explanations, elaborations, and other linguistic devices for signaling agreement and fixing troubles in shared understanding. Through this discourse, interlocutors may converge on shared meaning that is more than either understood in the beginning (Roschelle, 1992).

Representations can play a key role in negotiating shared understanding in scientific communities (Amman & Knorr-Cetina, 1990; Woolgar, 1990; Goodwin, 1995). For example, in our observations in chemistry laboratories (Kozma, Chin, Russell, & Marx, accepted), we found chemists used diagrams to articulate the structure of compounds they were trying to synthesize and to reason about the processes needed to create these chemicals. They used instrument-generated graphs to confirm or refute the identity and

structure of the resulting product. The confirmation process involved the arduous mapping of the features of the graphs onto the features of diagrams. This interpretive process was aided by discourse between scientists.

But what role do shared representations play in student understanding, particularly in the understanding of science? What do scientific representations add to student discourse over "non-mediated" experiences with the physical phenomena that are the focus of scientific investigations? How do the surface features of mediated and non-mediated experiences shape interactions among students and between students and instructors? How does the structure of the task shape this interaction?

In this study, I look at the potential for computer-based representations of scientific phenomena to support collaborative learning. I compare the activities and discourse between pairs of chemistry laboratory partners as they conduct wet lab experiments and use molecular modeling software. I compare the way computer-generated representations affect student discourse to discourse in the "non-mediated" chemical environment of the wet lab. I look at how different task structures influence this discourse and the resources that are used. Finally, I draw implications for the design of exploratory activities that can support science learning.

Methodology

Subjects

The 8 students that participated in the study were all undergraduates enrolled in an organic chemistry laboratory course at the University of California at Los Angeles. The students volunteered but were monetarily compensated for their participation. Of the 8 students, 7 were females and 1 was a male. The students ranged in age from 18 to 21 years old with 18 being the mode (3 students).

The 8 students formed 4 pairs of lab partners. Two of the pairs were already established as lab partners when they volunteered for the study. These were all females. Two of these students, Anna and Liz (real names are not used), were cousins; the other two, Julie and Tina, had become friends as a result of being lab partners in a previous lab course. Two other young women, Tracy and Andrea, were friends who volunteered for the study so that they could be paired up as partners. The remaining female (Donna) and the sole male (Charles) volunteered independently and they became partners as the result of their participation in the study.

Contexts

Over the 10 weeks of an academic quarter, my research assistant and I observed and videotaped these students during four class periods. This was a "naturalistic study" in which the researchers did not design the activities or interventions that the students used; rather, students engaged in tasks and used resources provided by the instructor as a normal part of the course.

My analysis focuses on the first two of the periods because they offer a unique opportunity to compare and contrast two different sets of activities and resources used in the students' laboratory investigations. The two sessions were both similar and different in their social and material affordances. The sessions were comparable in that the student partners were the same and the sessions were of the same duration. The chemical compound that the students examined was also the same for both sessions. However, the wet lab session differed from the computer session in the tools and representations that the students had at their disposal and in the way the tasks were designed and structured by the instructor.

Wet Lab: In the wet lab, students had reagents, beakers, electric heaters, filters, and vacuum pumps. They also had a set of directions that guided their laboratory work in a step-by-step fashion. The task, in brief, was to synthesize dibenzalacetone in a two-step process. The students then measured the melting point of this product. The particular temperature at which the compound melts is taken as evidence that the students indeed synthesized the intended product.

The student pairs were designated as "lab partners" in the wet lab but they were directed to each do their own experiment, side-by-side. In actuality, students were more or less involved in joint activities with their designated partner and this was reflected in the patterns we saw in the analysis. At one end of the continuum, the male and female lab partners, Charles and Donna, often spent more time interacting with other students than with each other during this session although they did not interact much with others at all. On the other end, Julie and Tina (the females who became friends as partners in another lab course) decided to do the experiment together, despite the directions, and used as an excuse the fact that an essential piece of equipment in Julie's set up was not working. However, these students wrote up separate lab reports.

Computer Lab: In the computer lab, each pair of students had a computer workstation and molecule modeling software application called *Spartan*. The students activities were guided by a set of directions and questions. The students were directed to construct a molecular model of dibenzalacetone (the product that they had synthesized in the previous session), compare the isomers of this compound, examine and measure the bond angles and lengths of these structures using tools in the software, and optimize their energies, again using a computational function of the software. Figure 1 is a display of this compound. The intent of this activity was to have students determine which of the isomers they had synthesized in the previous wet lab session.

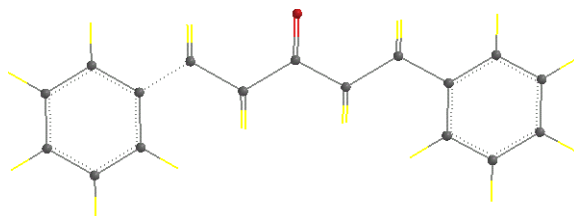


Figure 1. A molecular model of dibenzalacetone.

Each pair of students worked together in the computer lab at a single workstation and was explicitly directed to take turns using the software. They were also directed to compose answers to the questions and enter these in the Web-based question/answer sheet. Each pair of students turned in one set of answers. In the following analysis we look at how the differences between the available resources and the task structure affected student discourse and understanding.

Procedures

While observing these sessions, we maintained field notes in which we recorded incidents of lab partners interacting with each other, with other students, with the instructor, and with the physical resources in their environment. These field notes were parsed into incidents and coded. The beginning of an incident was marked when a statement, action, or interaction was initiated by a student or TA and marked as concluded when the set of interactions related to the initiating event were discontinued. These incidents were then coded by the type of participants involved (student, partner, other students, TA) and by the kind of physical and verbal activity (e.g., set up equipment, negotiate a shared goal, discuss a chemistry concept, ask for help) in which these participants were engaged.

We analyzed these codes for patterns of activities that might distinguish between wet lab and computer lab sessions. We then transcribed selected segments that illustrated these patterns and conducted a more fine-grained analysis of student discourse and activities to determine the features of tasks, tools, and representations that support these patterns.

Analysis

The two sets of sessions that are the focus of this study lasted an average of 2 hours and 37 minutes. The wet lab sessions averaged 2 hours and 30 minutes, while the computer lab sessions averaged 2 hours and 43 minutes. During this time, 612 incidents were recorded and subsequently coded; 294 incidents, or 1.96 per minute, for the wet lab and 318 incidents, or 1.95 per minute, for the computer lab. Although there were small differences in average lengths of the two types of sessions, the number of incidents per minute that occurred were the same. There were, however, large differences between the wet lab and the computer lab in the types of incidents that we observed.

Less collaboration and more help-seeking in the wet lab. The type of incident that occurred most often in the wet lab was help-seeking. Out of 294 incidents recorded in the wet lab, 139 (47.3%) were coded as students seeking help, either from other students or from the instructor. Many of these incidents (61 of the 139) involved students seeking help with equipment set up or experimental procedures from their partner (23 incidents), their TA (22 incidents), or students other than their partner (16 incidents). Another 48 involved students seeking help with the analysis of results. Most often, this consisted of the student periodically asking the TA if their results were sufficient for the task (i.e., if they were done yet).

An incident typical of others in the wet lab occurred between Anna and Liz as they conducted their separate experiments:

A: (1) Are you supposed to get every drop out of this thing-bottle?

L: Yeah, because I think we're doing a yield.

A: What?

L: A yie . . . percent yield analysis after.

A: It's impossible to get every last drop.

1. Both students are individually scraping flasks to collect precipitate. Anna comes over to Liz.

An interaction that typified others between students and their TA was this one when Anna approaches the TA to ask about one of the procedures.

A: You know what these--when you add the 5 milliliters of water, are you supposed to stir the product and then the pH, or--'cause . . .

TA: You can do that if you want.

A: 'Cause it . . .

TA: Don't stir it too much, but just mix it up a little bit.

A: 'Cause it's getting darker.

TA: The product?

A: Yeah, the pH is—the color is getting, like . . .

TA: Okay, that's 'cause you probably didn't stir it well enough at first. It's not gonna get darker.

A: Oh.

TA: Just make sure it—check your water; make sure you didn't contaminate the water.

A: Okay.

TA: Go get some fresh water.

A: Okay.

TA: Okay?

A: Thanks.

Another 18.7% of the incidents in the wet lab (55 of 294) were initiated by instructors who provided assistance to students. Again, the assistance most often related to procedure (22 incidents) or analysis of results (20 incidents). Typical is this exchange between the TA and Liz as he observes her procedure. Liz is operating the suction pump and the TA walks up and looks into her filter at the filtrate:

TA: Good. Okay, it's starting to (1) . . . No, no, keep it on. It'll take a minute. Then, the second time, that would be when you turn it off and you put the water in right? Take your glass stirring rod and dip it into the water and then test it on the pH paper. (2)

L: Okay.

1. *L starts to turn off the pump.*
2. *The TA takes the glass rod and demonstrates how to use it with the pH paper.*

Far fewer incidents in the wet lab involved joint actions between lab partners. Incidents that were coded as joint actions or collaborations included discussions or joint decisions about goals or plans for the session, coordinated action that implemented a plan or the specified procedures for the session, substantive discussions about the chemistry concepts that were related to the investigation, and stated inferences that built on students' collaborative activities. Incidents that were not coded as collaborative were ones where students made an individual statement, TAs initiated the interaction, or students sought help from the TA or other students. Only 20.7% of the incidents in the wet lab (61 of 294) were some kind of collaborative or joint action.

Interestingly, Julie and Tina—the students who decided to do their experiment together—accounted for a majority of the joint actions in the wet lab session. Approximately 51% or 31 of the 61 total collaborative incidents were exhibited by these two students. That is, Julie and Tina engaged in more joint actions during their wet lab session than all the other students combined. Anna and Liz (the two cousins) displayed 15 joint actions. Tracy and Andrea engaged in 10 such incidents. Charles and Donna (the two students who were assigned to work together) displayed only 5 collaborative incidents.

The most frequent form of joint action exhibited during the wet lab session related to making inferences or judgments that built on collaborative work. Of the 61 incidents of joint action that occurred during the wet lab, 27 (or 44.3%) involved stating a hypothesis; making an observation, claim, or conclusion; or providing a warrant or justification for an inference. Another 18 (or 29.5%) of the incidents related to joint actions by which students set up their equipment, implemented laboratory procedures, and recorded their results.

Unsurprisingly, Julie's and Tina's actions disproportionately influenced these results. These two young women accounted for 13 of the 27 collaborative inferences, 7 of 9 discussions of substantive chemistry, and 4 of 7 joint decisions. The following incident is typical of Julie's and Tina's collaboration as they discuss the product of their shared experiment:

T: This (1) was our last one, huh?

J: That was the last one, but that one (2) looks better than that one (3).

T: I know. 'Cause I think some parts get it, some parts don't.

J: I think it's one more. Yeah, you're right.

T: You know? Like, that's why I try to put it on all of 'em (4), but I don't know.

J: I think this should be the last one because it shouldn't . . even if it does change like this, this is still . . .

T: That's enough. I think that's, yeah, okay.

J: 'Cause the package says "Blue is basic and pink is acidic." So this is still considered to be neutral.

1. *The girls have arrayed the pH strips for all of their measurements in a column from first to last. T points to the latest pH strip.*
2. *J points to the next to the last strip.*
3. *Then J points to the last one.*
4. *T motions her hand in circles above the precipitate being filtered to represent the water bottle she used to wash the crystals.*

Here the two lab partners are examining the differences in color between pH papers to jointly decide if they have washed the crystals sufficiently. Based on the color differences, they infer that the precipitate is neutral and they can stop washing it. This protocol contrasts sharply with the one above where Anna did not make her own decision about whether or not she had washed her precipitate enough. Rather, she relied on the TA and defers to his judgment, even though he did not look at her experiment.

Collaboration and conceptual discourse in the computer lab. In contrast to the wet lab, collaboration in the computer lab was far greater in amount and in proportion to the overall number of incidents coded during this session. While 20.7% of the incidents in the wet lab (61 of 294) were coded as some kind of collaborative or joint action, 50.9% of the incidents in the computer lab were coded as joint actions—162 of 318.

The most common collaborative activity was the discussion of substantive chemistry, with 57.4% of the joint actions (93 of 162) being of this sort. This compared to only 9 (or 14.6%) of the joint actions in the wet lab that involved the discussion of substantive chemistry. Of the 93 incidents in which students discussed chemistry in the computer lab, 47 involved the discussion of chemical concepts, such as "dipole moment" or "torsional strain." Another 29 involved the discussion of molecular structure, such as the appropriate arrangement or bonding of atoms in a molecule. And 17 involved analysis of the results of students' molecular modeling, such as the correctness of measurements of bond lengths or angles.

The following computer lab discussion about electronegative forces is between Anna and Liz, a pair of students who did not discuss substantive chemistry at all during the wet lab session. They have followed directions in their guide and used the molecular modeling software to build a molecule of acetic acid, the first step in their process. The guide states: "Briefly describe the shape of your molecule." Anna and Liz are discussing their answer and Liz is typing it into the guide that appears in a browser:

L: What's the bonding on SP2 (1)? This can't be right. SP is—SP is—SP is 180.

A: Yes. Okay

L: So SP2 is 120 and SP3 is 109? Yeah.

A: Yeah.

A: Oh that's fine. Change that to 109 (2). I think it would be . . . I'll just say one more thing and that's like, ah, about the lone pairs on the oxygen, single bonded oxygen. . . The lone pairs on the oxygen—on the single bond, single bond, single bond oxygen, um, what do you call that? Um.

L: What do you want to say?

A: You know it pulls (3). What do you call that? There is a term for it, when you have lone pairs and things, um, what she talked about in lecture, basically. The, um . . .

L: They're attracted to it?

A: Electronegative.

L: Oh dipole?

A: Dipole. She calls it dipole moment (4). High-dipole moment, maybe.

L: But so does the oxygen itself.

A: Yeah, but, look, if—if the double—if the lone pairs were not there (5), then the oxygen, um, the hydrogen would be like differently.

1. *Liz points to the answer she just typed in.*
2. *Anna points to the answer.*
3. *Anna makes to fists and pulls them apart to represent the forces she is trying to describe.*
4. *Liz starts typing.*
5. *Anna points to portion of the molecule on the screen with a pen and draws a line in the air to stand for the angle that the bond would be if the lone pairs were not there.*

In this case, Anna and Liz moved from a description of the bonding angles to a discussion of the causes these angles and the concepts of electro-negativity and dipole moments.

While conceptual discussion was greater in the computer lab, there were fewer incidents of help seeking. In the wet lab, 47.3% of the incidents were coded as students seeking help; in the computer lab, only 16.7% of the incidents were coded as help seeking. Far fewer of these were instances where students sought the instructor's help even though they were working with sophisticated equipment. Students asked the instructors for help only 5 times during the computer lab session, while they asked the instructor for help 50 times in the wet lab. More importantly, the kind of help students sought from the TA and each other was more often related to chemistry concepts. Students asked others for help on understanding chemistry concepts 15 times during the computer lab and only 2 times during the wet lab.

While students sought TA help less often, instructors volunteered their help more often in the computer lab. Instructors approached students with help and comments 81 times during the computer session and 55 times during the wet lab session. In fact, 19.8% of the TA's interactions with the students in the computer lab were unsolicited offers of help while only 1.8% of the TA interaction in the wet lab involved offering any help. Again, it is important to note that the kind of discourse between TAs and students was different between wet lab a computer lab sessions. TAs discussed chemistry concepts 18 times during the computer lab and only 1 time during the wet lab.

An interaction between students and an instructor typical of others was this one where the Julie and Tina asked the TA to help them as they started the task of designing an enzyme that would isolate their compound.

TA: The way enzymes work is that you have a shape that it fits into.

J: Yeah.

T: Right.

TA: The enzyme is, basically, the pocket you're making.

J: Yeah.

TA: The substrate goes in the enzyme.

T: Uh-huh.

TA: Because you're making something that has its own shape, but, besides just fitting, it also needs to have some sort of a , say, hydrogen bonding.

T: Right.

TA: Okay?

J: So would it be right if, at the tips of our pocket, we put, like, um, a benzene right?

TA: You could.

T: 'Cause that's hydrophobic.

TA: Can you put non-polar groups together—is that what you're thinking?

T: Yeah.

TA: Uh-huh. That would be fine.

Whereas discussions between students and instructors in the wet lab focused on procedures, the discussion here of how to build a enzyme becomes deeply conceptual. This interaction contrasts significantly with that between Anna and the TA, cited earlier. In Anna's case, the instructor directed the entire exchange. Here the discussion starts with the instructor describing the function of an enzyme but the conversation shifts to one of the students who begins to describe how she would build her molecule.

Discussion

The design of the tasks and the use of representations are confounded in this natural experiment. Students had access to modeling software in the computer lab and the task was structured as a joint activity. In the wet lab, students had no computer and they were not assigned a joint activity. But even with confounded experiments, it is still possible to attribute some causality when process is examined and not just the outcomes of an experiment (Kozma, 1994).

Our analysis of the student interactions makes it clear that the amount and nature of collaboration between partners had less to do with the availability of computer software and more to do with the way the instructor designed and structured the task. In the wet lab, students were at adjacent lab stations, they had the same directions, equipment, and compounds, and they were working at the same time. But simultaneous, parallel activity and identical materials were not sufficient conditions to engage students in collaboration. When these materials and activities were structured around a joint task or shared product, collaboration was more likely to occur. Julie and Tina spontaneously engaged in a joint task in the wet lab because one set of equipment failed (and quite likely because of personal preferences) and their collaboration was relatively high. Otherwise, the incidence of collaboration in the wet lab was very low.

Furthermore, the interactions among students and between students and TAs had a unique character in the wet lab, they were most often help-seeking interactions. For the most part, students in the wet lab interacted with each other and with the TA only when they encountered problems or impasses. In the computer lab, help seeking occurred less often because the coordination of action required of joint tasks allowed students to coordinate their understanding before impasses occurred. That is, mechanisms for repairing understanding are embedded in the natural interactions that occur during collaboration (Clark, 1997). Consequently, misunderstandings were addressed early on before they become problems or impasses. These early repairs are not available when people are working individually, even when they are working on the same task in parallel. These results argue for the use of joint tasks and products when student collaboration is desired.

While a low incidence of collaboration and a high incidence of help-seeking can be attributed to the way the instructor structured the task in the wet lab, the high incidence of conceptual talk can be attributed to differences in the material and symbolic resources available to the students in the two situations. This finding is more central to our theoretical discussion. The symbolic resources available in the computer lab afforded discussions about chemical concepts, while those in the wet lab did not.

Students in the wet lab had access to equipment and physical processes needed to synthesize their desired compound. They also used and acted upon various chemical compounds while running their reactions. What type of discourse did these resources afford? The use of equipment most often prompted comments about its operation, rather than about the underlying chemical processes or changes that resulted from its use. Even the chemical compounds themselves did not evoke discussions of their chemical nature. More often, the use of actual chemicals resulted in questions about their physical status (e.g., where the crystals dry enough?) rather than their underlying structure.

The high incidence of conceptual talk in the computer lab can be attributed to the shared use of the molecular modeling software and the representations that it provided, rather than the shared task, per se. Even when collaboration occurred in the wet lab (i.e., Julie and Tina), the incidents of conceptual discussion of chemistry concepts was much lower than in the computer lab because the symbolic resources were not structured to support this type of discussion.

In an earlier study (Kozma, Chin, Russell, and Marx, accepted) we demonstrated how the symbolic features of structural diagrams supported the understanding and conceptual talk of professional chemists. In this study, we see that the features of these representations support the conceptual talk of students. Specific features in the diagrams generated by the molecular modeling software (such as balls and lines) corresponded to particular structural elements within the molecule (such as atoms and bonds). Furthermore, students were able to computationally operate on these representations: minimize their energy, rotate substructures, and measure the distances between atoms and the angles within structures. These features and capabilities supported student discussion of corresponding chemical concepts such as the arrangement, shape and structure of a compound. In addition, these representations supported the discussion of more abstract but related

concepts, such as dipole moment and torsional strain. Not only did these representations support the conceptual talk among students, they increased the conceptual talk between students and TAs. Discussions with TAs moved from a focus on help-seeking related to procedure in the wet lab to concepts such as molecular shape, hydrogen bonding, and non-polar groups in the computer lab. These findings give evidence that computerized simulations provide students with symbolic and procedural capabilities that support conceptual discussion and the social construction of understanding.

Acknowledgments

The author gratefully acknowledges support from the National Science Foundation and the Office of Naval Research.

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