Fostering Representational Competence through Argumentation with Multi-Representational Displays

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Abstract: The present study examines how students collaboratively reason about scientific phenomena by coordinating multiple representations presented in a single display in the Connected Chemistry modeling environment. A case study of two secondary students working together to solve a chemical equilibrium problem illustrates how students privilege one representation, yet problem solve by collaboratively integrating information from multiple representations. Working with the environment, individual students make a rapid initial judgment about which displayed representation is most useful for a particular task and ignore information presented in other representations unless their peers prompt them to use that information. Analyzed individually, each student would appear to lack representational competence, yet together the dyad demonstrates sophisticated coordination of representations. Using these observations, the study posits that an individual student's difficulties with coordinating representations can be mitigated by embedding multi-representational displays in collaborative activities that foster argumentation about representations.

Introduction

In many science domains, particularly chemistry, teaching and learning makes extensive use of external representations. In the classroom, students must often interpret and manipulate multiple representations of a single phenomenon to apprehend elementary concepts. For example, any given chemical reaction can be represented with an energy coordinate diagram, a molecular orbital diagram or a reaction mechanism that together describe the reaction. Historically, chemists have developed many representations to embed vast amounts of information in small diagrams and to make problem solving more efficient (Hoffmann & Laszlo, 1991). Indeed, the most successful problem solving strategies used by expert chemists employ simultaneous, coordinated use of several representations. Although unproblematic for experts, the wide variety of external representations and their coordinated use has been a reported learning barrier for chemistry students for decades (Johnstone, 1993). To address students' learning difficulties with multiple representations in chemistry, new computer-based curricula attempt to enhance students' interpretation of chemical representations through simultaneous displays of multiple representations (Kozma, Russell, Jones, Marx, & Davis, 1996; Stieff & Wilensky, 2003; Wu, Krajcik, & Soloway, 2001). Although each learning environment is unique, all share a common goal of making explicit the information embedded in multiple representations concurrently with a visual display of submicroscopic views of molecular interactions. Thus, each provides "multiple, linked representations" to help students coordinate among representations (Kozma, et al., 1996, p. 41).

Although such environments are based on the assumption that the simultaneous display of representations fosters learning, students have reported the same difficulties understanding and interpreting representations in these environments that they report when using canonical static representations. For example, in a study of the 4M:Chem learning environment Kozma and Russell (1997) reported that experts were able to use the displays intuitively and efficiently, but students were unable to choose among or coordinate the given representations to problem solve. Similarly, Wu et al. (2001) reported that students using the eChem modeling environment were given to comparing the surface features of displayed representations instead of comparing the embedded conceptual information. Thus, in the early stages of chemistry learning, students appear to lack content knowledge that allows them to make inferences from the wide array of chemical representations available. Clearly, the capabilities of novel technologies to display coordinated multiple representations is impressive, yet the historical barriers to working with multiple representations persist in this medium.

A close examination of student behavior when working with multiple representations offers some insight into the persistence of learning barriers in novel curricular environments. In a study of physics students, diSessa et al. (1991) posited that students maintain many ideas about the role of representations in science learning, which they termed "meta-representational competence". Namely, learning is heavily influenced by a student's "expertise in inventing, evaluating and refining a variety of representational forms" (diSessa et al, 1991, p. 86). Although this expertise is of course influenced by domain content knowledge, diSessa and colleagues have suggested that meta-representational competence is to some degree domain independent. Thus, students may be more or less given to making correct inferences with given representations or generating their own useful representations for problem solving. As such, simultaneous displays of multiple representations may present challenges for students less competent in evaluating and manipulating scientific representations.

Despite the reported challenges regarding (meta)-representational competence, recent work has revealed that students are quite capable of coordinating across multiple representations in computer displays to problem solving effectively. Using eye tracking techniques and verbal protocols of chemistry student problem solving with multi-representational displays, Stieff, Hegarty, and Deslongchamps (2011) illustrated that even with minimal content knowledge chemistry students are able to select the most effective representation to problem solve. Equally important, their results revealed that in cases where students do not verbally refer to using multiple representations, their eye movement behavior suggests they attend to information presented in multiple representations. The extent to which the students in their study made use of information in multiple representations remains unclear, however, as 80% of the participants relied primarily on the information presented in only one representation to justify their claims about chemical phenomena.

While work such as this demonstrates that students are capable of coordinating across representations in multi-representational displays, it fails to account for students' use of multiple representations in collaborative settings. Outside of chemistry, researchers have shown that multi- representational environments can be highly effective in supporting collaborative learning among students (Stahl, Koschmann, & Suthers, 2006; White & Pea, in press). In particular, such work has shown that designed environments that allow students to construct individual representations for collaborative use or designs that assign individual representations to group members and require group coordination often result in highly effective learning and problem solving. Together, these studies suggest that the challenges using multi-representational displays in the chemistry classroom can be overcome with carefully designed learning environments.

In this spirit, the present study analyzes representational competence displayed by a dyad using a multi-representational display in the chemistry classroom. Using a case study approach, I attempt to merge prior work in chemistry that centers on individual's working with multiple representations with work from other disciplines that focuses on the coordination of personal representations across groups. Specifically, I aim to explore how inquiry-based activities can encourage students to coordinate among representations using one shared multi-representational display. The results illustrate how individual students make a rapid initial judgment about which representation is most useful for making scientific claims and ignore information presented in other representations unless prompted by peers to use that information. Using these observations, the study posits that an individual student's difficulties with coordinating representations can be mitigated by embedding multi-representational displays in learning environments that include collaborative activities that foster argumentation.

Present Study

To examine representational competence with multi-representational displays, the present study analyzed six pairs of students completing one activity using the Connected Chemistry learning environment (Stieff, 2005). The activity discussed below included simulations programmed in the Netlogo modeling language (Wilensky, 1999). Using the simulation in the classroom, the dyads completed guided inquiry activities in which they observed molecular interactions to learn how macro-level concepts and relationships emerge from submicroscopic interactions. Here, I present observations from one dyad learning about chemical equilibrium.

Context & Participants

The case study presented here was constructed from field observations of one implementation of a Connected Chemistry Unit in Shadylane High School. Shadylane High is located in a middle-class urban community serving a primarily Asian and Latino student body and was ranked in the 7th decile statewide at the time of the study. Mr. Drake, who had worked in a chemistry-related industry for 20 years prior to teaching, had taught chemistry for 13 years at the time of this study. He noted that he rarely used educational technology resources in his classroom. Mr. Drake described the students in the case study, Jan and Sheila, as two "top achieving" and "highly motivated" students. Individual interviews with Jan and Sheila after the classroom observations reported here indicated that both students self-identified as college-bound and highly interested in science. Although neither student reported using computer activities frequently in the classroom, each had previously participated in a Connected Chemistry implementation several months prior to the present study. Thus, they stated they were familiar with the environment, and each had the sense that the computers were inherently helpful for learning chemistry. As Sheila said, the simulations "let you see what is going on".

During the three-day observation of Jan and Sheila working together on one laptop, the class completed a series of worksheets included in the Chemical Equilibrium Unit. The worksheets required the students to observe simulations of four different chemical reactions and answer questions about different aspects of each reaction. A primary learning objective of the unit aimed to support students' ability to distinguish *reversible* reactions from *irreversible* reactions. Briefly, *reversible* reactions are reactions that involve the simultaneous conversion of reactants into products and products back into reactants; *irreversible* reactions are reactions in which the reactants convert into products, but products do not convert back into reactants. To that end, each worksheet asked the students to observe both macroscopic plots and submicroscopic molecular interactions and make claims about which two reactions are reversible and justify their claim with evidence from the display.

The Chemical Equilibrium Simulation

Like all Connected Chemistry simulations, the Chemical Equilibrium simulation (see Figure 1) is a multi-representational display that includes three distinct representations that students are asked to coordinate. First, the simulation contains a *graphics window* that displays a simulation of submicroscopic chemical interactions using space-filling chemical representations. Second, the simulation includes a *plotting window* that displays macro-level variables, such as concentration, using a graphical representation. Third, the simulation contains symbolic representations of the chemical reactions displayed in the graphics window.

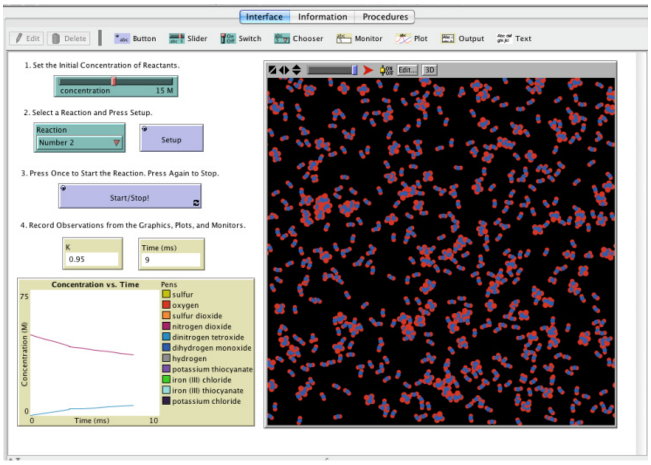

Figure 1. The Chemical Equilibrium #1 simulation includes a large graphics window that illustrates dynamic molecule interactions and a plotting window that illustrates macroscopic changes in concentration resultant from behavior in the graphics window. Symbolic representations are present in the legend and on the worksheets.

Coordinating Representations through Argumentation

Here, I discuss how one dyad decided which reactions were reversible while working on the Connected Chemistry Chemical Equilibrium Unit during the first day of the 3-day unit. The exchanges between Jan and Sheila reveal that each student privileges the information embedded in a unique representation on the display, but together they coordinate across representations by arguing about the information in each representation. I propose that the constraints of the activity to provide multiple pieces of evidence from the simulation to support a claim fostered disagreement between Jan and Sheila about which representation has the "best" evidence. In turn, this disagreement leads Jan and Sheila to coordinate their representations to justify their answers.

Sheila and Jan begin the first activity immediately after watching the 'Reaction 1' demonstration from Mr. Drake. Previously, Mr. Drake had described Sheila and Jan as two of his most motivated students, which was evident in their initial approach to the activity. The girls slowly read over the instructions independently and then together begin to manipulate the simulation for 'Reaction 2'. They note the activity asks them to record observations both from the plotting window as well as the graphics window to decide which two of the four reactions are reversible. From their first interaction with the simulation, Sheila appears to struggle interpreting the interface and the relationship between the graphics window, reporting monitors and the plot. In contrast, Jan rapidly reads information off the display. With Jan's support, Sheila learns to locate important information in the display, and in turn, teaches Jan how to find hidden information by interacting with the display (1).

Sheila: (*Reading from the worksheet.*) Reactants, what do we got? What is this? (*Sheila points to the graphics window.*) (...) I can't even tell what this is. I think it's oxygen?
Jan: I think it's N-O-2. (*Jan looks to where Sheila is pointing, and then looks at the molecular representation key on the worksheet. She leans forward and looks closely at the screen*). Yes, it's N-O-2.
Sheila: Are you sure?
Jan: Yes.
Sheila: OK, so nitrogen is/
Jan: That's the reactant that we started with.
Sheila: I guess so. So, what do we have (..) just N-O-2?
Jan: I guess.
Sheila: Wait, should we start it? So, we start it and then this/ (*She points to the graphics window.*)
Jan: (*Jan reaches over and starts the simulation. The simulation proceeds illustrating the reversible conversion of* NO_2 *to* N_2O_4.)

Sheila: What HAPPENED? Something happened!
Jan: (*Speaking quickly*.) It made N-2-O-4.
Sheila: Ohhh! OK!
Jan: (*Jan records values onto her worksheet*.) So K is .958.
Sheila: Huh?
Jan: K is .958.
Sheila: Wait. Where are you getting that? That's time? Can we change that?
Jan: I don't know why it's like that (*She points to the monitor displaying the value of K*). I think it's/
Sheila: That's uh (…) OK. I am going to start it over again.
Jan: Let it go to 5 seconds.
Sheila: Ok, is this what we start out with?
Jan: Yeah, I think it's just...
Sheila: At this time (*5 seconds*), K is .95? (*She points to the K monitor. The simulation runs past the 5-second mark, and Jan reaches forward to stop it at 9 seconds*.)
Both: AWW!
Sheila: I think it skipped.
Jan: Can you just type in 5?
Sheila: No, we have to get the concentration back from time zero. Ummm (...)
Jan: Do we have the concentrations for those? (…) I think you have to start it to see it?
Sheila: So the concentration is .95 of this? (*She points to the K monitor*).
Jan: No that is K, which is/
Sheila: Huh? What's K? I think K is the concentration of this (*She points to the graphics window*).
Jan: No, K isn't concentration (…) It's like the point of equilibrium (…) It's like the constant of equilibrium. It/
Sheila: (*While Jan is explaining K, Sheila moves the pointer. When she moves the pointer over the plotting window, concentration values for each substance are displayed.*) No, wait, look you can just go here. (*She moves to a point on the plot were time is 5 seconds, and the value 38.3 appears, as in Figure 2a.*) Time at 5 is 38.3. (*They both write down 38.3 as the concentration of* NO_2*.*) That's about as close as it gets.

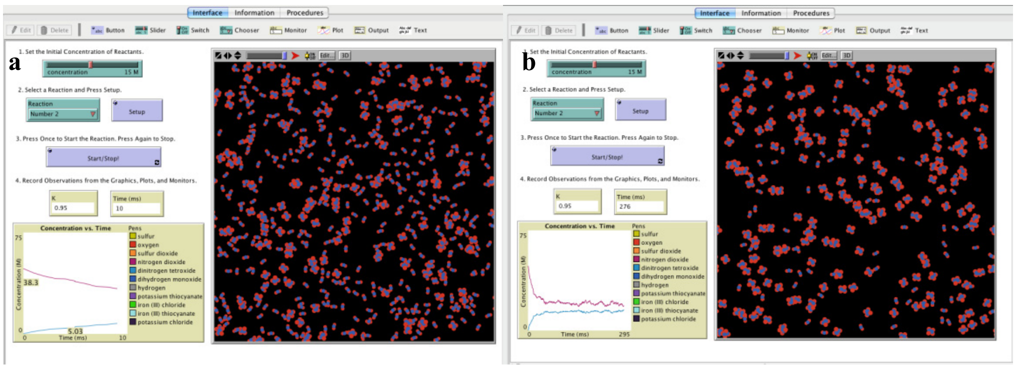

Figure 2. Screenshots of Reaction 1 at t = 9ms (a) and t = 275ms (b) When the Reaction Reaches Equilibrium.

In the above transcript, Sheila displays some confusion over where to locate important information in the interface. For example, Sheila appears unclear about what substance is represented by the graphics window and the meaning of 'K'. As she looks over the display, she mistakenly claims that the molecules in the graphics window are oxygen and that the value of K corresponds to the concentration of substances in the graphics window. In contrast, Jan immediately uses the key provided on the activity worksheet to state the molecular representation is NO_2 and the value of K is not concentration, but the equilibrium constant. In fact, the only information Jan cannot immediately locate in the display is the concentration. Gradually, Sheila comes to agree with Jan's explanation of the display and each representation, and she begins to investigate the interface on her own by moving the pointer over various windows. From her simple interaction, Jan discovers that she can locate the concentration of substances in the graphics window by placing the pointer over the relevant plot (Figure 2a). In this way, Sheila similarly supports Jan by helping her locate information necessary to complete the activity.

This simple four-minute interchange between Jan and Sheila suggests that their cooperative exchange allows them to come to understand each representation and feature of the display together. Although Sheila struggles at first to interpret the graphics display and monitors, she does not exclusively rely on Jan to interpret the simulation for her. Rather, with a small amount of guidance from Jan, she quickly apprehends the meaning of various elements in the display and in turn discovers a feature of the interface that allows her to locate information that Jan was seeking. As the girls proceed to complete the task, however, it becomes apparent that each makes a rapid initial decision about which representation, the macroscopic plot or the submicroscopic graphics, is most useful for determining if the reaction is reversible. Despite agreement between the girls on classifying the reaction as reversible, they at first ignore the evidence offered by the other.

Sheila: So, what is that (*She points to the graphics window*.)? N-O-2 is combining to form....
Jan: N-2-O-4 (*She points to the trace of N_2O_4 displayed on the plot.*)
Sheila: Was that in the first one though? Hmm (...) We don't really know/ So/ Do we have any of the reactants in there? (*She points to the graphics screen*.) Yeah, there's still reactants, N-O-2.
Jan: Well I think/ I don't/ we should let it run longer/ I want to see if (...) um (...) (*The girls are silent for ~10 seconds as they watch the simulation run.*) Is it reversible?
Sheila: No/ look/ Yeah, it's REVERSIBLE/ 'cause look here (*She points to the graphics window*.) there's still N-O-2.
Jan: I know, but look they are getting smaller though (*She points to the plot of NO_2, which is gradually decreasing*.). I don't think it's reversible (...) (*After a few seconds, the simulation reaches a steady state and the plots of NO_2 and N_2O_4 stop changing*.) Oh wait/ Yeah, it's reversible. (*She points to the constant concentrations plots*.)
Sheila: (*Writing on her worksheet.*) Ok, so reversible. So, it's reversible and these little dudes are/ (*She points to the graphics window. Sheila notes the motion of the molecules on her observation and Jan records a sketch of the plot of her worksheet*.)

As Sheila and Jan record their observations of 'Reaction 2', it becomes evidence that each relies primarily on one representation to support the claim that the simulated reaction is reversible. Reasoning primarily from the submicroscopic representations in the graphics window, Sheila argues that because she can see that NO_2 still exists in the graphics window, the reaction is reversible. Indeed, her reasoning is sound as all of the NO_2 would convert into N_2O_4 were the reaction irreversible. At first, Jan disagrees with Sheila and argues that the reaction may be irreversible because the concentration of NO_2 is decreasing over time. She ignores Sheila's appeal to the submicroscopic representation and insists they allow the reaction to run longer. Sheila urges Jan to "look here" at the graphics window to justify her claim that the reaction is reversible. Despite her appeal, Jan remains focused on the changing plot, and only agrees that the reaction is reversible when the concentrations become stable at equilibrium and the amount of NO_2 stops decreasing. Ignoring Jan's appeal to the plots, Sheila records her observations of the submicroscopic window by noting the behavior of the "little dudes", while Jan draws a sketch of the final plot shown in Figure 2b.

Now confident in their approach to the activity, the pair setup 'Reaction 3' (Figure 3a). In contrast to reaction two, 'Reaction 3' is an irreversible reaction that illustrates the condensation of gaseous oxygen and hydrogen to form liquid water. From their experience with 'Reaction 2', they are able to quickly locate the information in the display requested on the worksheet and rapidly fill in values. When deciding if the reaction is reversible, the girls disagree using information from different representations. As Jan and Sheila attempt to reconcile their disagreement over whether the reaction is reversible, they again show a bias toward using only one representation in the display. Moreover, each challenges the other's interpretation of her chosen representation to establish an additional warrant for their different claims.

Jan: So, it's forming water/ basically forming water. (*She points to the plot of water concentration.*) So it must be irreversible if it's becoming constant (*She traces the constant value of water concentration on the plot with her finger.*)
Sheila: No, that's forming water. (*She points to the graphics window*.)
Jan: I know, but must be irreversible if it's staying constant. (*She points to the plot again*.)
Sheila: So then, what now do we put for the submicroscopic observations? Oh, it's REVERSIBLE.
Jan: (*She points to the plots of H_2 and O_2 which are decreasing logarithmically*.) Why do these keep going down, when this one (*She points to the plot of water.)* is constant?
Sheila: I don't know (…) Let's keep going. (*They watch as the simulation continues to run*.)
Jan: OH, it's becoming more and more water, it's becoming denser? (*She points to the bottom of the graphics screen where the water molecules have condensed.*
Sheila: Oh yeah. Well, look at that...
Jan: So, it's not/ it must be irreversible.

Sheila: No, it is reversible. Look! (*She waves her pen above toward the top of the graphics window were two H_2 and two O_2 molecules can still be seen as in Figure 3b.*)

Jan: But the/

Sheila: They are constant down there (*She points to the plots of H_2 and O_2, which are approaching 0 on the plot, and then she points again to molecules of hydrogen and oxygen that can be seen in the graphics window.*)

Jan: Probably not after a long time/ that (*She points to the two hydrogen and two oxygen molecules in the graphics window.*) is just because of evaporation.

Sheila: Oooooohhhh (….) Wait/ is^ it reversible?>

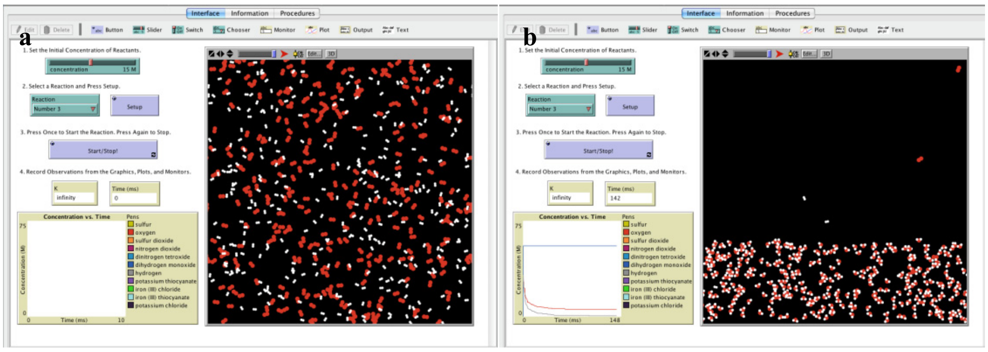

Figure 3. Screenshots of Reaction 3 at t = 9ms (a) and t = 142ms (b) When the Reaction Is Near Completion.

The above transcript illustrates how Jan again focuses on the constant concentration in the plot that suggests the reaction is irreversible; Sheila again focuses on the presence of starting reactants in the graphics window to justify her claim that the reaction is reversible. Interestingly, neither Jan nor Sheila appear confident and express confusion over what they are seeing. Namely, Jan cannot reconcile her observation that the concentration of the product (i.e., water) appears constant while the concentration of the reactants (i.e., hydrogen and oxygen) continues to decrease. Similarly, Sheila seems uncertain as to whether the reaction truly is reversible given only a few molecules of reactants can be seen and more reactants do not seem to be forming as in 'Reaction 2'. The girls' confusion is warranted: the reaction is irreversible, but they have stopped the simulation before it has run to completion. Thus, a few molecules of hydrogen and oxygen have yet to randomly collide to form water molecules and the graphics window shows them condensing into and evaporating out of the liquid water. Complicating the issue is that the concentration of liquid water is indeed constant and remains unchanging despite the formation of more water molecules as the reaction proceeds. Thus, the plot accurately shows the product concentration remains constant while the reactant concentration continually decreases.

Interestingly, the girls attempt to reinterpret each others chosen representation: Jan argues that Sheila's remaining reactants are due to "evaporation" and the reaction is therefore irreversible as reactants are not forming; Sheila points out that the hydrogen and oxygen concentrations have become "constant down there" and the reaction is therefore reversible because the concentration would otherwise decrease. As the pair continues to disagree over whether the reaction is irreversible, they call another student, Maria, over to settle the dispute. As the reaction continues, Sheila and Jan appear to 'trade' representations to garner additional evidence.

Jan: (*Calling over to Maria who is working with another student.*) Did you say reversible or irreversible because it's evaporating and then it goes back?

Maria: No, because it would have/ cause it would have broken apart again. (*She comes over to look at the screen.*)

Jan: But if you wait long enough this is what happens to it/ (*Jan starts the simulation and traces the constant concentration of water in the plot.*) and this. (*She points to graphics window and follows a hydrogen molecule as it travels across the screen. Two hydrogen molecules and two oxygen molecules can be seen on the screen, all others have reacted to form water, as in Figure 3b.*)

Maria: Nah, those eventually go back down.

Jan: Yeah, but more come back up, you can see it. (*She points to the graphics window.*)

Maria: (*In disbelief.*) Really!?^

Sheila: Hmmm…that looks pretty straight or does that mean it's reaching zero? (*She points to the plot. Jan and Maria lean forward and stare intently at the graphics window.)*

Maria: They will all go down eventually. (*Sheila looks over at the graphics window as two molecules dissolve into the water.*)

Sheila: Ah... *(Two molecules of oxygen evaporate out of the water.*) NOPE! (*All laugh.*)

Maria: I know^ it's IRREVERSIBLE! (*One hydrogen collides with an oxygen to form a water molecule. One hydrogen molecule and one oxygen molecule remain dissolved in the water and neither is discernable on the graphics screen.*)
All: OOOOHHHHH!
Sheila: There they go!
Maria: YES! (*The last hydrogen and oxygen molecules evaporate and become noticeable.*)
Jan: LOOK! ARE they going back up?
Maria: Huh? But, maybe those are just/ (The *molecules collide and form water*.)
Sheila: Ok! There we go!
Maria: SEE!
Jan: Ok, it is irreversible.

Jan explicitly states the problem to Maria: the evidence offered by each student, from the graphics window and the plot, is inconsistent. Although Maria is convinced that the reaction is irreversible, Jan and Sheila do not agree; they decide to run the simulation longer to gather more evidence for each respective claim. As the girls attempt to understand the reaction, an interesting shift in each student's source of evidence occurs. Jan focuses on the behavior of the molecules in the graphics window, which Sheila noted earlier. In contrast, Sheila focuses on the decreasing value of the hydrogen and oxygen traces on the plot, highlighted earlier by Jan. As the simulation runs, Sheila correctly notes that the concentration of hydrogen and oxygen are close to zero and not increasing; this is an important observation as it is strong evidence from the plot that the reaction is irreversible. Concurrently, Jan draws attention to the behavior of the four remaining reactant molecules to determine whether they are indeed interconverting between reactant and product or simply evaporating. The group's careful attention to the behavior of the molecules allows them to observe the moment when the hydrogen and oxygen molecules react to form (and remain) water molecules. In effect, each half of the pair was able to convince the other half to attend to information in a different representation and reconcile her observations to reach a consensus claim that the reaction is irreversible. Importantly, Sheila discredited Jan's evidence from the plot, and Sheila's evidence from the graphics window was discredited by Jan. As a unit, the dyad effectively and efficiently coordinated among the representations in the display to reach a conclusion.

Conclusion

The case study presented here offers two theoretical and methodological contributions to research on (meta)-representational competence with multi-representational displays. First, Jan and Sheila's collaborative coordination across representations in the display indicate that representational competence should not be conceived solely as a characteristic of individual students working with multiple representations. Rather, coordination across representations can occur through collaborative problem solving and pairs or groups of students can display representational competence that might go unnoticed in studies that focus on an individual student's behaviors alone. In the present work, the disagreements between Jan and Sheila led them to attend to information in multiple representations and support a shared claim. This finding is consistent with other research that has illustrated how groups coordinate representations (e.g., Stahl, et al., 2006; White & Pea, in press), and offers that coordination can occur when groups are working with one shared display that includes multiple representations. Thus, analyses of representational competence should include observations of students working together with multi-representational displays and avoid hasty claims about an individual's competence.

Second, each student's content knowledge and skill at interpreting representations can certainly provide a partial explanation for the observations. It is important to note, however, that in contrast to prior research on representational competence (e.g., Kozma & Russell, 1997; Russell, et al., 1997; Wu, et al., 2001), the students here displayed some basic competence interpreting, evaluating and coordinating across representations. While each student certainly displayed a bias for using one representation to support her claims, each attended to information present in other representations and attempted to reconcile conflicting interpretations. Of course, the underlying reason for each student's preference is not clear from the present analysis; certainly, there is no evidence that the bias is due to individual differences in media preference. Thus, as others have argued (e.g., Hammer, 1996; Stieff, et al., 2011), future research should focus on the competencies students bring with them to the classroom as opposed to skills that students lack.

Presently, the results of this study inform the design of activities using multi-representational displays. Perhaps the most obvious pedagogical implication is that curricular materials that incorporate multi-representational tools must include scaffolding to guide student attention to different representations. Indeed, this scaffolding needed might be more elementary than helping students to coordinate multiple representations: it must support students in attending to each displayed representation. As Sheila and Jan illustrate, individual students display preferences for using information in specific representations; working in isolation, each would need significant guidance in attending to non-preferred representations. However, the case illustrates that when working together from the same display, students are able to coordinate across representations to problem solve successfully. As seen here, inquiry activities that encourage students to provide multiple pieces of evidence from a multi-representational display to support their claims can foster representation coordination through planned argumentation. Simply put, the simultaneous displays of multi-representations do not afford 'discovery' of relevant information, nor are students easily able to use one representation to explain another. By devoting more attention in curricular materials to enhancing students' ability to attend to each displayed representation and coordinate between them *with their peers*, such technologies may result in the improved student understanding they are believed to promote in the science classroom.

Endnotes

(1) Transcription notations: / interruption or self-interruption, (.) one second pause, (*italics*) nonverbal actions, CAPS emphasis on word, ^ rising tone, > falling tone

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