Identifying Reflective and Non-Reflective Group Consensus Strategies for Evidence-Based Scientific Argumentation

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Abstract: This study examines how students come to agreement on evidentiary data they collectively use to support scientific claims or explanations. Student groups were videotaped participating in high school biology units that were scaffolded in inquiry-based experimentation and argumentation with complex systems computer simulations. Interactions around the argumentation prompts revealed extraneous/non-reflective and generative/reflective strategies for collective evidence use. We hypothesize that access to recorded archived data along with access to dynamic just-in-time simulations promoted more generative/reflective strategies. Preliminary data on students' written responses reveal stronger written argumentation responses when students engaged in generative/reflective strategies compared to when students used extraneous/non-reflective strategies. Where extraneous/non-reflective strategies occur, we suggest that teachers be made aware of the tendency toward this kind of group decision making and that greater emphasis be placed on optimal evidence use through active modeling.

Introduction

A central scientific practice that has shown great promise and great challenge in supporting student learning is scientific argumentation. Argumentation enhances students' conceptual understanding of scientific phenomena, while also strengthening skills in scientific reasoning (Osborne, 2010). However, researchers have found that building argumentation skills and explanations based on evidence is not easily learned (Kuhn, 2010). Some research has shown that an emphasis on constructing explanations can prevent students from connecting evidence to claims (Kuhn et al., 2013; Kuhn & Katz, 2009). Due to a social aspect that can influence the argumentation process while defending claims, students may use persuasive discourse rather than objective appeals to evidence (Berland & Reiser, 2009; 2011). Similar non-content goals, such as task completion, have been shown to inhibit students' attention to meaningful data interpretation (Ryu & Sandoval, 2015). But considering the importance placed on group collaborative argumentation, surprisingly few studies have focused on understanding the mechanisms in evidence use. Examining how students come to agreement on evidentiary data can provide insight into developing instructional supports that can overcome the tendency toward persuasion. The research questions underpinning our investigation are: (1) What strategies do students working in groups use to come to agreement on the evidence they use to support claims? (2) What is the predominant strategy used? (3) How can more reflective and evidence-based strategies be supported? (4) What do students' written argumentation responses tell us about the use of reflective and evidence-based group consensus strategies?

Background

Manz (2016) summarizes the literature illustrating the struggle that K12 students have in constructing and using evidence, which includes not attending to relevant data, ignoring data that are inconsistent with their understanding, and failing to consider sources of uncertainty and error. However, as she points out, scientific knowledge is socially constructed, which underpins the central concern about the lack of accurate use of evidence in argument through persuasion that Kuhn et al. (2013) and others have raised. Thus, it is important to examine how groups come to consensus on their claims or explanations and how evidence is used in the process. Here we point to previous work that we have done on non-reflective and reflective decision-making strategies that can be useful in framing our understanding. Yoon (2011) suggests that non-reflective strategies promote *extraneous processing* (Stull & Mayer, 2007), in which learners make decisions in ways that are unrelated to the instructional goal. Reflective strategies promote *generative processing*, in which learners engage in deeper cognitive work and attend to relevant information. We anchor our analyses in this framing to better understand the consensual processes students use in performing argumentation tasks while using simulations of complex scientific phenomena.

Methods

Context and participants

This study is part of a larger project focused on developing curriculum and instruction to support learning about complex systems in high school biology conducted 2010–2015. The broader intervention involved implementation of units on the topics of genetics, enzymes, diffusion, evolution, ecology, and modeling. The 3-day units directed students to perform multiple experiments using different initial conditions such as varying population sizes, energy characteristics, and varying numbers of interacting simulation components. Students recorded their observations and responded to tasks based on their data collection such as constructing graphs. Each unit included prompts for students to come to consensus using the argumentation structure of claims, evidence, and reasoning (Novak et al., 2009). Figure 1 depicts an example of an argumentation prompt.

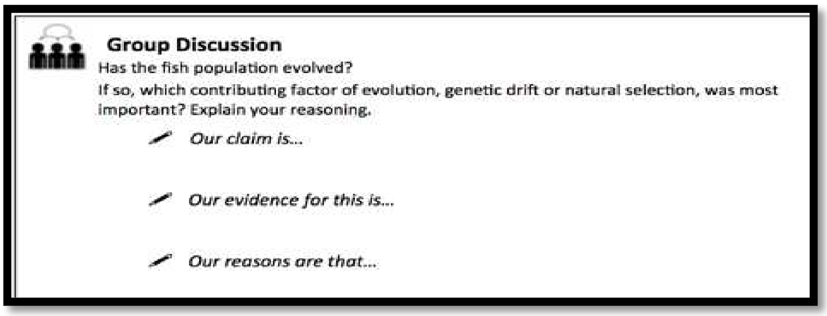

Figure 1. Argumentation prompt in the evolution unit.

In this study, we sampled 70 (35 females, 35 males) out of 361 students we worked with in the larger study.

Data sources and analysis

We conducted analyses on 33 videotaped interactions of student groups (mainly pairs). Coding was completed through a method of interaction analysis (IA). This involves analysis of video clips by a group of researchers to examine the details of social interactions (Jordan & Henderson, 1995). Codes and categories in IA are meant to emerge from multiple replays of video data and negotiation of coder interpretations. This is meant to mitigate individual researcher bias and enables mutual construction of meaning. While performing IA in this study, the research group (authors), referred to previous research findings that indicated content and non-content decision making processes. Codes emerged as either extraneous or generative in terms of content goals. Extraneous strategies showed non-reflective behavior where students did not engage with evidence previously collected. Generative strategies showed reflective behavior where students actively engaged with evidence in different ways. Codes, definitions and exemplars are presented in Table 1. We also present examples of transcribed footage that provide deeper insight into how students discussed the argumentation prompt and worked with evidence to put forth a particular claim.

To understand how students' claim selection strategies impacted their ability to construct an argument, we conducted a preliminary analysis that examined argumentation responses from their unit packet worksheets. We present two cases of students' CER (claim, evidence, reasoning) responses for two units that showed promising evidence of the relationship between generative/reflective argumentation strategies and correct scientific explanations. In the first case on the topic of sugar transport, students were asked to construct an argument from the following general prompt, *"What is responsible for the spreading of the molecules you just observed?"* In the second case with the unit on enzymes, students were provided a choice of claims to select from. The following directions were given on the worksheet:

> *How do the enzyme and starch (substrate) come together to interact? Discuss the following possibilities with your group, choose the ONE claim (either A, B, or C) you think is most likely, and write down your group's evidence and reasoning for that choice. Run the Experiment 2 simulation as many times as necessary to establish your claim. Claim A: Enzymes are drawn to substrates, like a hungry traveler without a map, in a new town, who smells pizza from a distance and heads towards the scent. Claim B: Enzymes find substrates, like a hungry traveler without a map, in a new town, actively looking for thick crust pizza as they walk down the street. Claim C: Enzymes find substrates, like a traveler without a map, in a new town, wandering the streets in no particular direction, until they bump into a pizza place. Pizza happens to be the only food they like, so they go inside to eat.*

Table 1: Codes and examples of collaborative decision-making strategies in argumentation and evidence use

	Category and Definition	Example
Extraneous/ Non-Reflective Group Argumentation Strategies	Follow the Leader One student (the leader) answers the question and the other group members write down what the leader says.	A student asks the other students in her group if they know the answer. The other students don't know the answer and do not show any initiative to find out the answer. First student reruns the experiment but is the only one looking at the screen and then proceeds to tell the other three students the answer to the argumentation question. The other three students simply write down what she said. (Teacher ID 1, Group 1-2, Diffusion Unit, 2/11/14)
	Work Independently Students work on their argumentation responses independently without collaborative discussion.	Two students work on their own worksheets. One student in the pair says "it's claim A." He waits for the other group member to catch up who says "so, its claim A?" and the two independently complete their answers to the argumentation question. (Teacher ID 9, Group 3, Genetics Unit, 12/10/2013)
	Teacher Facilitated: Non-Reflective Where students seek help from the teacher, they copy down or do not engage with what he/she says.	Teacher encourages the pair of students to "Play [the simulation] again and see what you see." Student B sits quietly and waits until student A has figured out the answer. Student B does not engage with the teacher's questions. (Teacher ID 9, Group 2 Genetics Unit, 12/10/2013)
Generative/ Reflective Group Argumentation Strategies	Use of Already Collected Evidence Students either look back at data they collected or discuss with their partner what they observed from the simulation.	Two students discuss the argumentation prompt. During their exchange the students point to the graph on the screen to confirm their understanding. (Teacher ID 9, Group 1 Genetics Unit, 12/10/2013).
	Collect New Evidence Students rerun the simulation as directed or modify the directions and rerun the simulation to collect new evidence.	Before selecting their group's claim, they rerun the simulation and discuss how the enzymes are acting. Eventually the students agree that the enzymes show random motion based on what they collectively see on the screen. (Teacher ID 1, Group 1, Enzymes Unit, 11/22/2013)
	Teacher Facilitation: Reflective Where students seek help from the teacher, he/she asks generative questions to scaffold student understanding rather than telling students the answer. Students engage with the content and construct their response.	Teacher encourages the pair of students to "Play [the simulation] again and see what you see." Student A replays the simulation and the teacher directs the student's focus to the relevant information. (Teacher ID 9, Group 2 Genetics Unit, 12/10/2013)

Results

In total, 38 codes were assigned to the video interactions of students in their argumentation groups of which 5 were double coded. Figure 2 shows the distribution of strategies across codes. In general, student groups used more generative/reflective strategies. Of those codes, the highest number, 14 (38%), was found in the *Use of Already Collected Evidence* category. We believe that the curricular layout with scaffolded experiments and argumentation prompts enabled students to refer back to archived and easily retrievable information. A relatively high number of codes, 7 (18%), also emerged in the *Collect New Evidence* category. Here, it is likely that the use of simulations enabled the dynamic, just-in-time feedback to occur where group members could watch the same screen and agree on the same evidence. However, a large number of codes, 9 (24%), was found in the *Follow the Leader* category, which we hypothesize may have negative consequences on some students' learning.

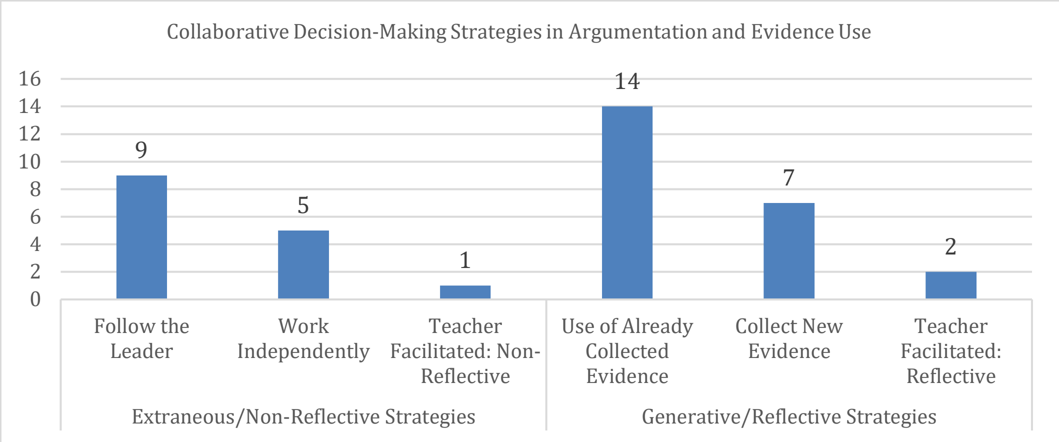

Figure 2. Graph of strategies across codes.

In Figures 3 and 4, we show excerpts and commentary from discussions as students engaged in the two highest categories of generative/reflective strategies to come to consensus on the argumentation prompt (see endnote for discourse analytic conventions). In the first excerpt, shown in Figure 3, two students, B (boy on left) and G (girl on right) converse with each other and use previously collected data to understand how gene regulation occurs.

Discourse Interaction Excerpt	**Commentary**
B (boy on left) and G (girl on right)	
1. B: ((Reads question aloud.)) Ummm…Claim A, a gene regulatory system is like a home heating system that is controlled by a thermostat. Is not like a…((Laughs))…ummm ok 2. G: What do you mean? 3. B: A gene regulatory system is like a home heating system…so you turn the heat up…and then it like goes up? 4. G: Oh no it's like the one when you, it does it itself…kind of, no wait. What? 5. B: I dunno what you're talking about. 6. G: Cause the heat at my house, when it gets like, too hot, it turns off. But if it's too cold, it turns on, right? Right? 7. B: Ok. So, you're like…ok, I think that's how heating systems work. 8. G: Ok, so it is like that, right? 9. B: Well is that like that, though?	The group starts their discussion off by first figuring out how a home heating system works (lines 1-8).
10. G: Yeah… (2) 11. B: You sure? So when it makes, so when there's a lot… 12. G: So when there's a lot of lactose… 13. B: So when it's up, it goes… ((Gestures with hands going up and then down)) (19) 14. B: Ok, so when it makes mRNA, right? 15. G: Yeah…yeah	In line 9, B asks the important question of whether gene regulation works in the same way that a home heating system (that they described) works. In response, G asserts that gene regulation is like a home heating system, but has difficulty explaining why when pressed by B (lines 11-12).

16. B: Then enzymes get made to eat the lactose ((Gestures with both hands where one hand is engulfing the other hand))…but the lactose pulls away the stuff 17. G: Yeah, yeah so it is…yeah! And mRNA eats the lactose. 18. B: Yeah.	As the conversation ensues, B starts to explain how "enzymes get made to eat the lactose" (line 16) and G agrees (line 17).
19. G: So it is. 20. B: I dunno. 21. G: It is! Cause when there's too much, it sends something out to stop it. That's why you don't have hair on your liver cells. 22. B: Okay. 23. G: Right? ((Laughs)) 24. B: I guess? ((Laughs))	At this point, it seems that G is convinced that, in gene regulation, "it sends something out to stop it," (line 21) which is similar to a home heating system's feedback loop. However, B is not quite sure (lines 20, 24).
25. G: Claim A. 26. B: So our evidence… (5) 27. B: …for this	In line 25, G asserts that Claim A is the correct possibility and B asks for the evidence.
28. G: It tries to like, get a medium. 29. B: Is that our evidence, or our reasoning? 30. G: That's my reasoning. 31. B: So our evidence is that…the enzymes eat the lactose? 32. G: The evidence is that like…when the RNA polymerase goes in the DNA…((Points her pen to the simulation that had been previously run and paused)) 	When G explains that the system is trying to get to a medium (line 28), B asks her if that is the evidence or the reasoning, to which G responds that it is the reasoning. Knowingly or unknowingly, B seems to push G for the evidence for their claim (line 31) and G responds by pointing to the previously collected evidence (line 32).
33. B: Oh it's like feedback! Like positive feedback…or negative feedback. 34. G: Yeah, so it's…ummmm….which one is it? I was thinking earlier, but I forgot the name. 35. B: Ok. I forget the difference…like, I know what the difference is…but I forget the...like which one's which. 36. G: Negative's when you add something. I mean, negative's when you take something away and positive's when you add something. 37. B: So, positive, it'll just like go up…right? So then negative…it has to be negative then.	This reference back to the simulation seems to cause B to be thoroughly convinced as he exclaims, "It's like feedback!" (line 33). The pair ends their conversation by coming to the consensus that gene regulation is like a home heating system and that it uses negative feedback to accomplish this.

Figure 3. Discourse interaction excerpt 1 (25:20-28:00) where students are using already collected evidence

In the second excerpt shown in Figure 4, two pairs of students discuss how enzymes move and they come to consensus using newly collected evidence on the argumentation prompt that used three different analogies of a hungry traveler looking for pizza in a new town.

Discourse Interaction Excerpt	**Commentary**

B1 (boy on left), B2 (boy on right), G1 (girl on left), and G2 (girl on right). 1. B2: ((Reads question aloud.)) How do the enzyme and starch substrate come together to interact? Discuss the following possibilities with your group. Choose the one claim, either A, B, or C, you think is most likely and write down your group's evidence and the reason for that choice. Run the experiments/simulations as many times as necessary to establish your claim. Claim A: enzymes are drawn to substrates like a hungry traveler without a map in a new town who smells pizza from a distance and heads toward the site. 2. B1: That's an interesting analogy. 3. B2: Yeah, that's interesting. 4. G1 and G2: ((inaudible, looking at worksheet))	
5. B1: Oh God, I find that way too funny…((inaudible)) 6. B2: So, claim B? I kinda want to run this again… ((Leans over and clicks several times with the mouse and runs the simulation)) 7. G2: I am running it again. 8. B1: ((Looking at the simulation that B2 is currently running)) Huh, intriguing. 9. B2: Well, it's not like the en … not like the enzymes are following the…ummm… 10. B1: Emzymes?	Initially, B2 believes that Claim B (enzymes find substrates by actively looking) is the correct explanation (line 6), but decides to run the simulation again. Similarly, G2 states that she is also running the simulation again.
11. B2: Enzymes… Yeah, they're not following the starch molecules…they're just going back and forth.	After having looked at the new evidence together, B1 and B2 decide that the enzymes are just "going back and forth" and "moving randomly" (lines 11-12).
12. B1: They're just moving randomly. So, so ok, it can't be this one… ((Pointing to the worksheet)) because they are moving randomly…they're not just following them. Ready, run it for 30 more seconds just to see…ready? ((B1 now takes control of the mouse and clicks on the computer to re-run the simulation…both boys look at the computer screen together.)) Like follow one of these things…they're not following a particular…or maybe he is!	B1 decides that he wants to re-run the simulation and collect more evidence; this time, focusing on following one particular enzyme for more specific information (lines 12-14).
13. B2: Wait, run that again. ((B1 then clicks to re-run the simulation again.)) 14. B1: Follow that one ((points to the screen)). No, okay, it's not following. It is completely random. 15. B2: No… so it was following this one ((Points to the screen at a specific enzyme)) and then it was going and then just completely shot off this way… 16. B1: Yeah… 17. B2: So it is random.	Through this, both B1 and B2 affirm that the enzyme movement is random (lines 15-16). Later on in their discussion, they come to consensus that Claim C is the correct explanation, which is the claim stating that enzymes are like a traveler that wanders the streets in no particular direction, moving randomly until it happens to hit a pizza place. This is the correct claim and a shift from when B2 stated Claim B as the answer in the beginning of the discussion.

Figure 4. Discourse interaction excerpt 2 (1:02-3:00) where students are collecting new evidence.

In the next section, we present two cases that show that students' claim selection strategies may have had an impact on their ability to construct an argument. Table 2 illustrates the strategy used, the claim selected by each student, and their evidence and reasoning rationales. The first group consisting of two students in the discussion excerpt in Figure 4 (B1 and B2) wrote their claim, evidence, and reasoning in response to the prompt, after they collected new evidence. We can see in the table that they agreed on the claim, which was the correct one. The evidence and reasoning they used to arrive at the claim were also similar. Conversely, the second group wrote their claim, evidence, and reasoning after they worked independently. We can see that their responses to all three CER sections were different. In addition to that, student 1 in the second case did not accurately describe the mechanism by which molecules spread in their evidence and reasoning. We hypothesize that, because students worked independently in Group 2, they did not check and challenge each other's understanding vis-a-vis the simulation they had previously run.

Table 2: Students' argumentation responses from unit worksheets

Strategy Used to Come to Consensus (Group)	Biology Unit	CER Question Wording	Student	Students' CER Response		
				Our claim is…	Our evidence for this is…	Our reasons are that…
Collect New Evidence (Group 1)	Enzymes	How do the enzyme and starch (substrate) come together to interact?	Student 1 (B1)	Enzymes find substrates, like a traveler without a map, in a new town, wandering the streets in no particular direction, until they bump into a pizza place. Pizza happens to be the only food they like, so they go inside to eat.	Enzymes movement are random	No real pattern to their movement
			Student 2 (B2)	Enzymes find substrates, like a traveler without a map, in a new town, wandering the streets in no particular direction, until they bump into a pizza place. Pizza happens to be the only food they like, so they go inside to eat.	The enzymes are randomly moving around the screen, bumping into starch molecules to turn them into sugar.	The enzymes follow no specific pattern. They move randomly and randomness causes all kinds of motion.
Work Independently (Group 2)	Sugar Transport	What is responsible for the spreading out of the molecules you just observed?	Student 1	Diffusion (random/constant motion) is responsible for the random movement of the molecules.	The molecules moved to areas of low concentration from high concentration.	Diffusion moves molecules from high concentration to low concentration.
			Student 2	Diffusion is responsible for spreading out.	No energy and movement is random.	Diffusion is random.

Significance of the study

As previously stated, researchers have found that building argumentation skills based on evidence is often difficult for students (Kuhn, 2010), in part due to social dynamics that can influence how students defend their claims using persuasion rather than appealing to the evidence (Berland & Reiser, 2009; 2011). This study fills a gap in the research on scientific argumentation by identifying how students come to consensus on what evidence to use when making claims or constructing explanations. Where we saw a large number of generative/reflective strategies in our study, we hypothesize that this was due to the use of carefully scaffolded inquiry-based computer simulations that required students to engage in sense-making using evidence they collected from experimental iterations. Where we also found a large number of codes in the extraneous/non-reflective categories, we see how a portion of our students were unable to link evidence to their claims, and suggest that teachers need to become aware of these strategies to emphasize and model optimal evidence use.

Furthermore, in response to our question of how reflective and evidence-based strategies can be supported, we offer two possible strategies. First, it may be important to ask students to re-run the simulation while comparing results that were already collected. In the second discussion excerpt, B2 decided to run the simulation again, perhaps in response to following the simple instructions on the worksheet that encouraged students to run the simulation as many times as they wanted,. However, as Figure 2 shows, this was not the case for every group. By having a specific task that asks students to re-run the simulation, they can be directed to collect new or more evidence to support their claim but this should be emphasized in instruction. Second, similar to B in the first discussion excerpt, assigning an individual in the group as the "evidence manager" or "evidence boss," who directs the conversation of the group to the supporting evidence for the claim they chose, may further remind students to continually engage with the evidence.

Finally, in response to the fourth research question, we identified promising evidence that reflective group consensus processes such as collecting new evidence produced more accurate CER responses compared to non-reflective group consensus processes such as working independently. Fundamentally, science is about explaining the world around us—scientists look at evidence to develop claims and to negotiate their ideas about the validity of each claim (McNeill & Krajcik, 2011). As is true with scientists, if a group of students engage in a "follow the leader" or "work independently" approach, they are not negotiating their ideas and ultimately may not arrive at the best explanation for a particular scientific phenomenon. For this reason, it may be important to name and scaffold reflective group strategies when preparing students to engage in scientific argumentation. However, as these are only two cases of students' argumentation responses, further analysis of all students' worksheet responses will need to be conducted in the future, using a topic-specific rubric for each of the units as described by McNeill and Krajcik (2011) in order to see broader, more generalizable trends. Nonetheless, this study has provided some evidence to support the development of more explicit instructional prompts that can direct students to appeal to evidence via scaffolded experiences using dynamic computer supported simulations. We suggest that doing this can support stronger argumentation skills—both in verbal discourse and written explanations.

Endnotes

In the written discourse account, gestures and descriptions of ongoing dynamics are encased in double parenthesis, e.g., (()), direct utterances are written in normal text, and time elapses are marked in single parenthesis with the number of seconds that have gone by, e.g., (5).

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