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Mediating Students' Scientific Argumentation to Support Model Revision

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Abstract: Scientific argumentation and modeling are both core practices in learning science. However, they are challenging for students without support. There are limited studies on how engaging students in argumentation and modeling might be mutually supportive. Inquiring about their relations may inform educators of creating a learning environment to encourage both practices to foster learning complex systems. This study aims to explore how fifth graders can be supported by our designed mediators as they engage in argumentation and modeling, in particular, model revision. We implemented a virtual afterschool science club to examine how our modeling tool (Model and Evidence Mapping Environment), evidence resources, peer comments, and other mediators influenced students in learning about aquatic ecosystems through developing a model. Both groups that we examined constructed strong arguments and developed good models, but the mediators played different roles in helping them be successful.

Introduction

Scientific argumentation plays a critical role in learning and doing science (Duschl & Osborne, 2002). The term "argumentation" refers to discourse in which "learners take positions, give reasons and evidence for their positions, and present counterarguments to each other's ideas when they have different views" (Chinn, 2006, p. 355). Previous studies have highlighted the potential of argumentation to enhance student conceptual understanding and epistemic agency (González-Howard & McNeill, 2020). Indeed, the *Next Generation Science Standards* (NGSS) includes argumentation in the eight essential science and engineering practices (NRC, 2013). Scientific modeling is also an essential scientific practice, which develops and refines abstracted representations, i.e., models, of complex natural systems to predict and explain scientific phenomena (Forbes et al., 2015). Engaging students with modeling enables them to make their thinking visible and available for discussion, thus supporting them in making sense of phenomena (Hmelo-Silver et al., 2017). Specifically, in the process of constructing, using, evaluating, and revising models, students may ask questions, look for data patterns, generate explanations for their positions, and use criteria to justify competing models. In doing so, students develop their ideas, elaborate on reasons, convince others, and revise their own ideas (Passmore & Svoboda, 2012). Hence, argumentation is inherently indispensable for modeling and modeling provides opportunities for engagement in argumentation.

Regardless of the importance of both practices, argumentation still rarely happens in most science classrooms, and modeling practice is underemphasized as well (González-Howard & McNeill, 2020; Forbes et al., 2015). Furthermore, although there is considerable literature about scientific argumentation or modeling practice in K-12 science education, there are limited studies on how engaging students in scientific argumentation and modeling might be mutually supportive. Some researchers have noted that situating argumentation in modeling practice can potentially enhance students' authentic learning experiences and promote conceptual understanding (Passmore & Svoboda, 2012). Therefore, better understanding the relationship between argumentation and modeling has the potential to inform educators to encourage both practices to foster science learning. Our present study aims to explore how fifth graders can be supported as they engage in argumentation during model construction and revision. This study integrates both practices to help students learn about eutrophication in aquatic ecosystems. We focus on examining the key design elements in an online after-school science club providing students with opportunities for model construction and revision. Our software tool, instructional materials, and other elements serve as mediators that influence student interaction with the collective goals of their activities (Danish, 2014). Our research is guided by the following questions:

1. How do key mediators support/hinder students' scientific argumentation when engaging in modeling?
2. How, if at all, does argumentation affect model revision?

Theoretical framework and design of mediators

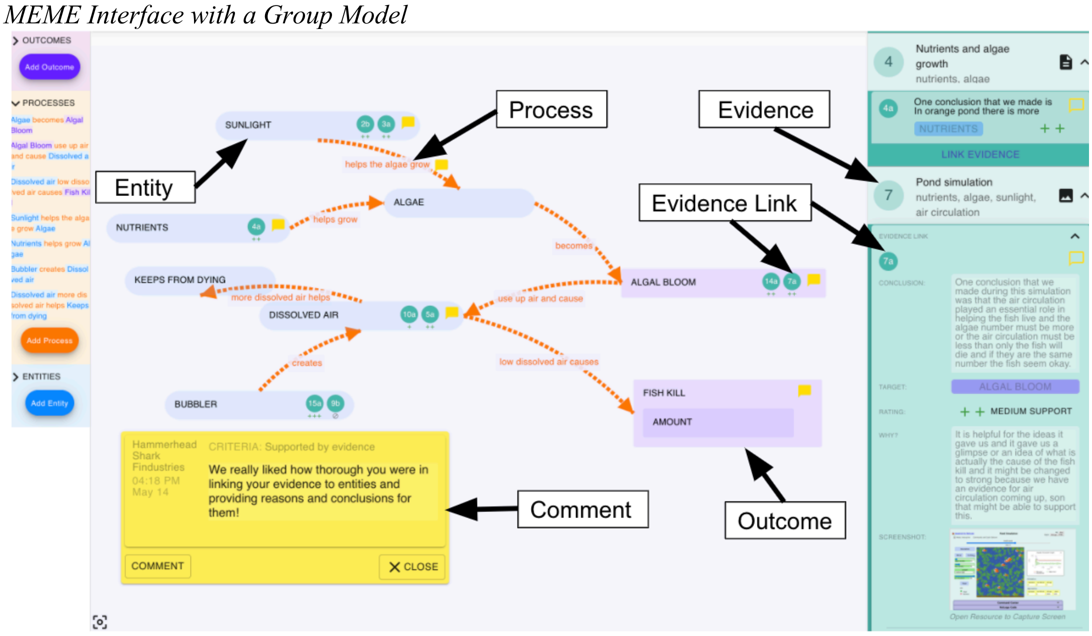
Our study draws on activity theory of learning (Engeström, 1987) with a particular focus on mediation. The concept of mediation deals with the idea that the interaction between participants (*subjects*) and their shared goal (*object*) of a collective activity is always influenced and transformed by cultural artifacts, known as *mediators* (Danish, 2014). Mediators refer to physical tools (e.g., a software tool) and conceptual tools (e.g., students' ideas about ecosystems), as well as *rules*, and *division of labor* within the *community*. Attending to key mediators in an activity helps direct researchers to closely look at elements that possibly impact how students learn (Danish, 2014). In this case, students were oriented to develop an evidence-based model explaining the phenomenon of more fish kill due to eutrophication in one pond than in another. Their interaction with modeling practice was mediated by *tools*, *rules*, and *division of labor*.

Although important, both argumentation and modeling practices are challenging for students. Research has shown that students had difficulty in using evidence (e.g., making claims without justifications), production of arguments of high-quality content, and dialogical argumentation (e.g., not recognizing contrasting argumentative positions) (Fischer et al, 2014). Meanwhile, engaging in modeling practice also poses various challenges, such as students having insufficient evidence to engage with (Duncan et al., 2018). Previous studies have also found that students need facilitation in understanding how to use evidence to support models and claims; and they did not iteratively revise their models unless they were prompted to do so (Danish et al., 2021). On the other hand, research has suggested that elementary students could productively engage in scientific practices, if they are provided with scaffolds (Forbes et al., 2015).

Given the challenges of argumentation and modeling, we need to design effective mediators to support students to engage in both practices. In this study, we provided students with a modeling tool that we developed – Model and Evidence Mapping Environment, or MEME (Danish et al., 2021) to help them collaboratively construct, revise, and evaluate models. In MEME, students can create a model by adding "entities", "processes", and "outcomes", access evidence resources in the "resource library", "link evidence" to the model, and make notes and descriptions (see Figure 1). MEME also enables students to view models made by others and offer comments on any feature of models, hence focusing their attention on those features that receive comments. In this way, the MEME interface serves as a single unified space where students can create, revise, discuss, and argue about their models. Table 1 illustrates the mediators, including MEME, that we designed for this study.

Figure 1

MEME Interface with a Group Model



Methods: context and participants, data collection and analysis

This study was conducted in a virtual afterschool science club for fifth graders (n=11), who were from a school in the Northeastern United States. Students participated in six weekly 75-minute sessions using videoconferencing software. They were assigned to three small groups to use MEME to develop a comprehensive model based on a given partial model to explain what caused more fish kill in one pond than in another. From Session 1 to 4, we

Table 1

Designed Mediators Coding Scheme

Type of mediator	Description	Example
Tools	**MEME features** The model interface; comment on the model; resource library: evidence link, rating the evidence and providing reasons, writing conclusions	"We think that the bubbler increases the amount of dissolved air, we have to add that to our model…First, we have to put that step and then we have to link the evidence."
	Evidence Scientific reports referring to nutrients and algal growth, dissolved oxygen, other topics, and embedded pond simulations	"That's what we saw from different evidence. And this is what's causing (low) dissolved oxygen."
Division of labor	**Peer comments** Comments that each group made on other groups' models using MEME sticky notes	"Sunlight is not the only thing that algae needs to grow. It also needs nutrients that the rain helps with. Look on evidence."
	Peer models The models made by other groups	"We should revise our model cause I think we learned a bit from this model, so that we could maybe put a little thing."
Rules	**Criteria for good models** A list provided by researchers noting that good models should be 1) supported by evidence, 2) understandable, 3) show all steps, 4) consistent.	"I noticed that they didn't really make it very detailed. Like I didn't see how we wrote those evidence and stuff."
	Social norms Engaging everyone in the discussion; providing constructive feedback.	"We do all agree that that's medium?"

gave students 2-3 scientific reports per session related to sunlight, algae, nutrients, dissolved oxygen, and other topics and had them play with pond simulations in one session. Based on this evidence, students constructed their models in MEME within small groups and had brief discussions with the whole class. In Sessions 5 and 6, students participated in 3 structured activities where they 1) gave feedback on peer models, 2) addressed comments, and 3) made sense of new evidence.

The data sources include all video-recorded meetings, associated chats, and models developed by the three groups. We watched videos of all three groups (A, B, and C) and focused our attention on the last two sessions, which involved considerable argumentation and model revision. We selected Group A (3 girls and 1 boy) and B (2 girls and 2 boys) as our focal groups to compare their use of mediators in argumentation and modeling practices. Prior to Session 5 their models were rather different in terms of quality (see below), and yet both ended with high-quality models that were well-supported by evidence. Therefore, it was valuable to look at how the designed mediators helped students progress along different pathways and yet ultimately produce successful models.

We transcribed the video data of the two groups (180 minutes in total). Our data analysis involved three steps. First, inspired by how Berland & McNeill (2010) examined argumentation, we segmented the transcripts into episodes of argumentation. An episode is a sequence of turns that may include more than one simple or complex argument so long as they were all about the same topic. A simple argument includes a claim without a justification (e.g., "I think we should keep the 'rain'.") A complex argument included a claim that is supported by evidence and reasoning (e.g., "I think we should link our evidence since it helps a lot to coming to our conclusion of orange pond.") Second, we coded mediators (see Table 1) that were present in each argumentation episode. Next, we conducted video analysis of selected argumentation episodes to investigate student argumentation to see how claims were articulated, defended, questioned, evaluated, and revised within two groups.

Results

Research question 1: How do key mediators support/hinder students' scientific argumentation when engaging in modeling?

This question focused on how our designed mediators affected the mutually supportive relationship between argumentation and model revision. We found that our three structured activities revolving around model revision (i.e., giving feedback on peer models, addressing comments, and making sense of new evidence) provided considerable opportunities for both groups to generate productive arguments and counterarguments. We identified 48 episodes of argumentation, of which 40 were spontaneously initiated by students (see Table 2). More importantly, both groups had several lengthy argumentation episodes (3-5 minutes). The analysis of argumentative products revealed that both groups were able to generate complex arguments and counterarguments around the content and scientific modeling. Group A tended to support claims with evidence and reasoning, and rebuttals occurred frequently. Group B sometimes missed using evidence or did not engage in reasoning.

Table 2
Overview of Argumentation Episodes

Structured activities	Giving feedback	Addressing comments	Making sense of new evidence	Total episodes
Group A	7	7	8	22
Group B	6	16	5	26
Total count	13	23	13	48

The MEME features, evidence resources, and peer comments appeared as salient mediators that promoted student argumentation in these activities. These mediators frequently worked synergistically with other mediators, such as disciplinary rules of argumentation, including the criteria for good models, social norms of collaboration and making good comments. In this paper, we present examples from the activity where students engaged in different division of labor, addressing peer comments left on their models, to illustrate the relationship between the tool, rules, and division of labor on students' scientific argumentation.

MEME features (tool) helped create the environment for co-constructing arguments within groups and ensured that the process of addressing comments was fluid. We observed that many features supported both groups in similar ways. For example, the availability of the "resource library" promoted students revisiting evidence, reinforcing their understanding, and making claims supported by accurate evidence. Both groups often were very cautious in making decisions on how to respond to peer comments without reexamining the evidence. Although sometimes some students were reluctant to review evidence because they were confident in their memory (e.g., "we have seen oxygen five times"), others still insisted on seeing the evidence one more time because it would be "very quick", thus convincing group members to do so. Nevertheless, some MEME features were not used equally by the two groups. For instance, the criteria list in the comment box asked reviewers to select one criterion when giving comments, thus making their understanding of a specific criterion visible to the reviewee group. We noticed that students in Group A paid particular attention to the reviewer group's selection of criteria, whereas Group B dismissed it. After reading a comment with the selected criterion "understandable," Aiden, a Group A student, read aloud the comment as well as the criterion "understandable" and immediately questioned: "Understandable? How is that not understandable?" hence eliciting his counterargument and driving the group's negotiation. In contrast, although Group B also received a comment with "understandable," they only focused on the comment, without attending to the criterion. Therefore, this feature did not mediate their discussion.

The *evidence (tool)* served as a key mediator in most episodes of argumentation (40/48) and supported both groups in the same way. The evidence that provided in the MEME "resource library" enabled students to have sources to use in their arguments, most of which were well supported by one or more pieces of evidence. Also, students' frequent reference to evidence numbers like 4, 5a, 14 demonstrated their shared understanding of the previous evidence. In evaluating and addressing comments, evidence was the privileged consideration within each group's discussion. For example, in Group A, after reviewing the evidence, Aiden was more confident with his opinion: "the whole thing is about dissolved oxygen, why do we put one part about the fish kill?" He used this evidence to support his argument and eventually convinced the group to ignore the comment not supported by the evidence. In Group B, when they discussed which evidence should be linked to which part of the model, students often referred to several pieces of evidence. For example, Bodhi stated that "5 and 6 should be linked to dissolved air," and then gave his reason "because they come out of dissolved air," which was immediately accepted by other members. Although Bodhi's explanation was simple, the group's immediate response revealed their shared understanding of the evidence as well as where they disagreed, as shown in Excerpt 1.

Excerpt 1

Group B's Discussion on Linking Evidence to the Model

	Speaker	Speech turn	Mediator
1	Brenda	We can give evidence for oxygen.	Evidence
2	Belle	Maybe we can give the evidence for oxygen with "algae and oxygen".	Evidence
3	Brendan	I feel like we should give the same evidence we give to the bubbler to the oxygen because it's like the bubbler equals oxygen, so.	Evidence
4	Belle	But I think to the oxygen we should give the "algae and oxygen".	Evidence
5	Brendan	I think we should go put the process (pointing to oxygen and bubbler).	Evidence
6	Belle	I'm pretty sure that this evidence should be linked to here (pointing to oxygen).	Evidence
7	Brendan	(Asking the facilitator) Um, can we go quick? I want to go quickly see it before you link it.	Evidence MEME (Evidence link)

In Excerpt 1, in response to Brendan's proposal of linking some evidence to "oxygen" (line 1), Belle suggested using the evidence "algae and oxygen" (line 2). Yet Brendan proposed a different piece of evidence that they discussed for "bubbler" (referring to the evidence "water circulation") and provided his justification that "the bubbler equals oxygen" (the evidence demonstrates how the bubbler increases dissolved oxygen) (line 3). But Belle disagreed and insisted on her claim of using "algae and oxygen" without giving a reason (line 4). Brendan then said to put the evidence on the process between "bubbler" and "oxygen" (line 5). Again, Belle repeated her claim with an affirmative tone (line 6). Consequently, these disagreements led the group to reexamine the evidence as requested by Brendan (line 7). These examples illustrated that the evidence was leveraged as the authority to warrant students' arguments.

Peer comments (division of labor) explicitly stimulated students' argumentation as they deliberated on whether and how to address them as well as affected students' argumentative products in both groups. In making sense of the comments they received, both groups engaged in argumentation due to differing interpretations of the comments. For example, in Group A, Anya tried to understand the comment: "in the description it does not make sense that you put the sentence fish need to breathe the air. also you should put it in fish kill." She brought up a series of questions, such as "Are they saying that we did not put the sentence, or are they saying that we did put the sentence?" thus pushing her group to closely read the comment and make their thinking visible. Excerpt 2 shows their subsequent discussion.

In Excerpt 2, Aiden strongly expressed his disagreement with the comment (line 1) and gave his evidence and reasoning (line 3). Anya did not explicitly address this, instead, she attempted to understand the comment and push Aiden to explain (lines 4 & 6) and then proposed checking the evidence before making a decision (line 8). This proposal led students to revisit the evidence. Similarly, in Group B, after reading a comment, Brendan suggested that "we can annotate in them." Rather than directly correcting this idea, Belle clarified what the comment actually asked for: "since we could annotate, maybe it's our note they wanted to see." Thus, discussion of the comments ensured that everyone developed a shared understanding before moving on.

In dealing with comments, both groups generated complex arguments and counterarguments with respect to the comments. The distinction was that Group A had more discussion on evaluation of comments, whereas Group B primarily focused on the discussion of revising the model based on comments. We did not find any evidence that Group B disagreed with peer comments but identified some cases in which group members debated which evidence should be linked to their model to address the comment. These examples revealed that peer comments served as a catalyst that promoted students' argumentation.

Additionally, the rules (e.g., the criteria for good models and social norms) also affected argumentation to different degrees. For example, while not always being explicitly stated in discourse, the criteria for good models were implicitly adopted in addressing peer comments. We noted that both groups relied heavily on the criterion "supported by evidence", which invisibly guided their thinking; and the criterion "understandable" selected through "criteria list" in MEME on one comment elicited Aiden's counterargument, which suggested that it shaped his understanding of what counted as an understandable model.

Excerpt 2

Group A's Discussion about a Peer Comment

	Speaker	Speech turn	Mediator
1	Aiden	I disagree with putting in fish kill, this whole	Peer comment
2	Anya	I don't understand what they're asking us to do.	Peer comment
3	Aiden	This whole evidence is about dissolved air. Why should we put it in fish kill then? I don't get that.	MEME (Evidence link), Evidence
4	Anya	What are they asking us to do?	
5	Aiden	They're asking us to put into Fish Kill and reword.	
6	Anya	Put what in Fish Kill?	
7	Aiden	This evidence, dissolved oxygen in tanks……	
8	Anya	Yeah, but we have to hear them out. Let's hear them out. Let's just, let's just see what they're talking about. If we don't agree with it, then we don't take their suggestion. This is as easy as that.	MEME (Comment on model), Peer comment

Research question 2: How, if at all, does argumentation affect model revision?

Based on our prior research, in this study we specifically emphasized model revisions through designing peer critique activity that allowed students to give comments on groups' models and address their received comments (Danish et al., 2021). We consider revising models as including adding and deleting entities on a model, linking evidence to models, adding descriptions of entities and processes as well as conclusions in evidence, using provided evidence and MEME.

We present the similarities and differences between models made by the two groups (see Figures 2 and 3). By examining the final models of two groups, we can clearly see that the two comprehensive models nicely explained the phenomenon of fish kill. Furthermore, both final models met our criteria for good models (see the criteria list in Table 1). In particular, both models had nine evidence links totally. By comparing models made before peer critique and after these structured activities, we found that both groups made considerable progress in refining models, hence indicating the positive effects of peer critique and model iteration. It is also important to note the major distinctions between the two groups. Prior to peer critique, Group A had linked several pieces of evidence to their model, rated the strength of each piece of evidence, and provided reasons for ratings. On the "link evidence" box, they also typed "conclusions" for evidence. Their initial model, which was already sophisticated, revealed their mastery of linking evidence to the model and extensive use of MEME features. So, peer comments helped them make minor edits to their model. By contrast, Group B did not link any evidence to their initial model and made few annotations. Following suggestions from peer comments, they discussed and added the evidence, and made model revisions, thus achieving the same desired outcome as Group A had.

Model revision occurred in all three structured activities, particularly in addressing comments and making sense of new evidence. Peer comments stimulated students to construct arguments and facilitated revising models. We recognized that model revision tended to occur after argumentation (among 29 episodes that related to the discussion about model revision, 23 finally ended with revision). This transition was promoted by the synergy of several key mediators, including students' shared understanding about the evidence, the group's agreement with peer comment, and MEME's support. Group members' agreement with constructive peer comments promoted an easy transition to model revisions in both groups. For example, Group A received a comment that indicated: "sunlight is not the only thing that algae needs to grow. It also needs nutrients that the rain helps with. Look on evidence 4." Aiden initially rebutted it because he assumed that the comment suggested linking evidence piece #4. However, Anya defended the comment and pointed out that it was asking for adding "nutrients" rather than linking evidence, thereby persuading Aiden to add "nutrients" to the model. Therefore, the peer comment that provided a specific suggestion and combined with the clarification discussion, was valuable for model revision. The example also highlighted that the MEME interface enabled the missing entity "nutrients" on the model to become salient to both reviewers and Group A. Similarly, peer comments also supported Group B in transitioning from engaging in argumentation to making multiple revisions. A comment calling for linking

Figure 2

Models Made by Group A

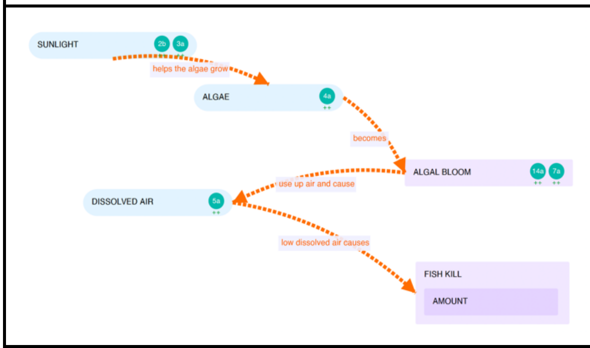
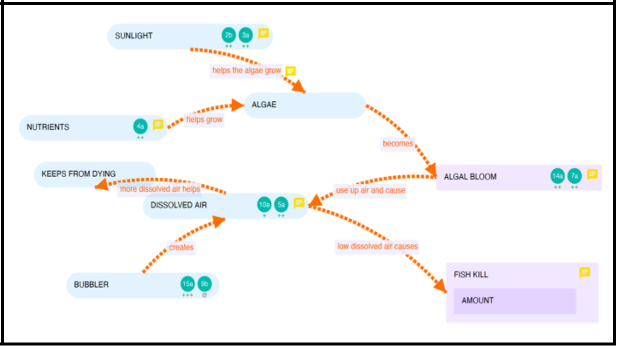
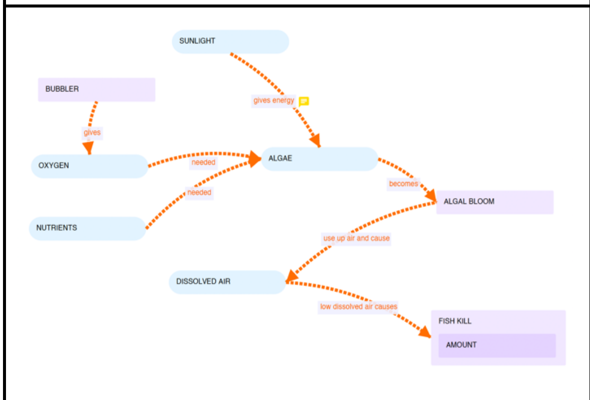
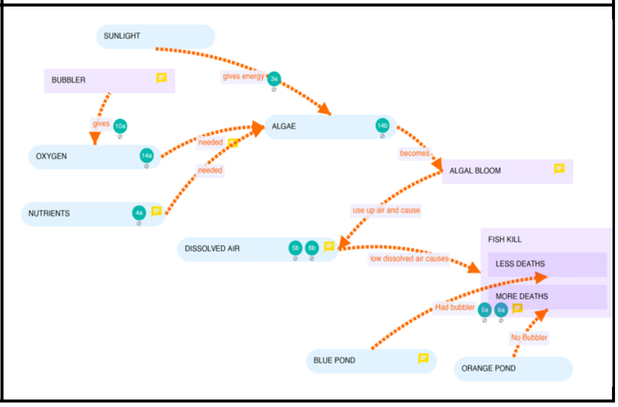
Model before reviewing	Final model
	

Figure 3

Models Made by Group B

Model before reviewing	Final model
	

evidence on Group B's model did not trigger much negotiation within their group. Belle's statement "that's why I was saying we should have fixed that model first, so they wouldn't say that" indicated her agreement with the comment. The ensuing discussions about which evidence should be linked to the model in multiple episodes further suggested their recognition of the problem identified by the comment. While agreeing with this comment, Group B sometimes disagreed with how to revise the model, as noted in Excerpt 2. To resolve disagreements, students subsequently revisited evidence, looking at #14-Algae and oxygen, #4-Nutrients and algae growth, and #10-Water circulation, linking several to the model as they went before eventually reached consensus to link #10 to the process between "bubbler" and "oxygen".

We also closely examined those episodes in which students discussed model revision but did not end up revising. We identified distinct reasons for Group A and Group B. For Group A, the major reason was group members' disagreement with peer comments and with each other. The result of Excerpt 2 was that all members unanimously disagreed with making the change on the model, after reexamination of the evidence. In another case, the "understandable" comment: "it does not make sense but you could change it to sunlight helps grow," asked the group to delete the words "the algae" on the process between "sunlight" and "algae" to avoid repeating. However, Aiden strongly disagreed with the comment by saying "it just doesn't make sense," whereas Anya was inclined to take the comment's suggestion to make the change and attempted to persuade Aiden that "it's a quick change." Due to Aiden's resistance, they did not make any revisions, but this decision also would not affect the model accuracy. In contrast, in some cases Group B did not revise the model because of their common misinterpretations about evidence. For example, pond simulations were mentioned twice in their discussions, but not all members counted simulations as evidence, thus deciding not to link it to the model.

Discussion

Scientific argumentation and modeling practices are mutually supportive for students to learn about complex systems. The findings from our study suggest that students were able to spontaneously co-construct complex arguments and counterarguments supported by evidence and reasoning, and iteratively revise their models, in this CSCL environment facilitated by multiple designed mediators. In pursuit of developing a good model, MEME features significantly contributed to building the collaborative space for students to make models and critique others' models. Those features played an important and sometimes invisible role in supporting students' argumentation in addressing peer comments by helping to make students' thinking visible for discussion.

The comparison between the two groups helps deepen our understanding of how students used these different types of mediators, thus informing the future design. Our findings reveal that the designed mediators, especially the explicit links between evidence, comments, and the model in MEME supported scientific argumentation and model revision within both groups in a similar way, but peer comments benefited the two groups in distinct manners. Peer comments enabled Group A to spend more time on critically evaluating them and debating how to address them, and their disagreements with the comments and with each other usually led the group to review the evidence, confirm or calibrate their interpretations, thus reinforcing their conceptual understanding of the phenomenon. By contrast, peer comments helped Group B fix the model's major issues (e.g., not linking evidence, not writing conclusions from evidence). During this process, students revisiting evidence also helped enhance their conceptual understanding. Finally, we found that some confusion caused by peer comments could be addressed if students had opportunities to ask reviewer groups for clarifications. In the future, we will provide opportunities for students to seek clarifications either through MEME or face-to-face interactions and will aim to explicate both pathways to success as we continue to examine the different approaches that groups use to construct their evidence-based models through argumentation.

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