Middle School Students Modeling Viral Transmission

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Abstract: This study explores how middle school students build and share knowledge about viral transmission through scientific modeling. We built a framework for modeling based on the literature with a focus on the epistemic dimensions of the practice. In the framework, we identified five epistemic considerations related to modeling: 1) representation, 2) mechanism, 3) communication, 4) justification, and 5) limitation. We use these considerations to inform our analysis of how middle school students discuss and participate in knowledge construction around viral transmission through modeling. Our results indicate (a) students use several modeling considerations from the Framework for Modeling Principles and Performances to build and share knowledge about viral transmission, and (b) through the modeling experience, students came to appreciate the multi-dimensional nature of viral transmission and pandemics. The findings indicate that middle school students can engage with modeling as part of socio-scientific issues, such as pandemics, in sophisticated ways.

Introduction

The COVID-19 pandemic has highlighted a long-standing call for classrooms to be spaces where learners develop knowledge and practices for informed decision-making. Specifically, science educators saw the need for students to engage in learning experiences around public health issues, including the transmission of disease and methods for preventing epidemics. Unfortunately, the science education community was not well prepared to support student learning concerning viral outbreaks because of the complex, multidimensional nature of pandemics. As the pandemic spread across the globe and impacted the lives of students and their communities, there were limited curricular materials from which educators could draw and many teachers felt ill-prepared to design learning experiences that could address students' emerging questions (Trygstad, Smith & Craven, 2021). Pandemics, such as COVID-19, fit into a broader class of issues referred to as socio-scientific issues (SSI). SSI are complex social issues conceptually connected to science, such as climate change, antibiotic resistance, and pandemics (Friedrichsen et al., 2020). SSI positions learners to explore these complex issues through disciplinary practices such as modeling as a means of developing more sophisticated understandings of complex phenomena (Zangori et al., 2017).

Modeling as a pedagogical tool has long been included in classroom instruction (for a review, see Louca & Zacharia, 2012); however, since the dissemination and implementation of *Next Generation Science Standards* (NRC, 2012), modeling has gained much attention as a science and engineering practice. With this renewed popularity as a target for learning and an instructional approach, some research warns that the practice can be reduced to procedural routines, such as copying pictures, that do little to encourage productive disciplinary engagement and therefore does not leverage the epistemic potential of modeling (Ke & Schwarz, 2020). This essentialized method of modeling comes from an implicit trust that simply *doing* science practices will render scientific understanding. Unquestioned routines that mechanically focus on student attainment of pre-determined components or ideas are a pitfall of science teaching and learning that can be most evident in some modeling activities (e.g., making a cell model from candy with a list of required organelles). Berland and colleagues (2016) suggest that one way to mitigate this pitfall is to highlight the epistemic considerations of the practice and create learning environments where students actively construct and evaluate ideas. In response to this recommendation along with the broader modeling literature, we developed a Framework for Modeling Principles and Performances with the purpose of highlighting the epistemic considerations of modeling.

When used meaningfully, modeling is a powerful practice that can help learners visualize and make sense of their ideas and externalize them in a way that makes visible how their ideas fit into a broader context (Berland et al., 2016; Ke et al., 2021; Schwarz et al., 2009; Schwarz et al., 2022). Because of its value as a learning tool, many researchers have investigated how a modeling experience can be made meaningful to learners. For example, several researchers have explored the importance of providing a model as a physical representation of an abstract phenomenon (Winsberg, 2001), a tool to facilitate scientific discourse (Penner, 2000), and provide insight into systems' mechanisms (Zangori et al., 2017). We build on our prior research that models are made more meaningful when learners are active epistemic agents and engaged with phenomena that are relevant to their lives, such as the climate crisis (Zangori et al., 2017). Given the significance of the COVID pandemic for students and society more generally and the relatively limited knowledge base that we as a research community have about learner understandings of viral disease processes particularly in the context of use of this knowledge in disciplinary practice (Ke et al., 2021), we focus on student modeling practices associated with the transmission and spread of respiratory viruses like COVID. This proceedings paper describes our development of a Framework for Modeling Principles and Performances which informed our analysis of how middle school students discussed and participated in knowledge construction around viral transmission through modeling. The following research question guided our analysis: How do middle school students use modeling to build and share knowledge about viral transmission?

Framework

We built a framework based on the modeling literature (Berland et al., 2016; Forbes et al., 2015; Pluta et al., 2011; Schwarz & White, 2005; Schwarz et al., 2009) with a focus on the epistemic dimensions of the practice. In the framework, we identified five epistemic considerations related to modeling: 1) representation, 2) mechanism, 3) communication, 4) justification, and 5) limitation. For each consideration, we highlighted two dimensions: principles and performances. By principle, we refer to epistemic ideas about the nature of scientific models that students can use to guide their modeling work. For example, in the case of representation as a modeling consideration, principles that learners should understand include that models should represent key features of a phenomenon or system; models are not intended to replicate reality; model can take multiple representational forms; and the degree of detail included in a model will depend on the model type and the nature of the detail itself. By performance, we refer to modeling tasks students should be able to accomplish when they model for certain epistemic goals. For example, again using the case of representation as a consideration, a performance that learners should be able to engage with is the construction of models that represent key features of a phenomenon or system. The framework also suggests that students should be able to move flexibly between different representational forms as they use models. We further describe what each dimension entails in Table 1.

While this framework was influenced by prior work on modeling, it differs from other modeling frameworks or rubrics and contributes to the field in two major ways. First, the framework focuses on both epistemic knowledge (i.e., modeling principles) and practice (i.e., modeling performance) with the assumption that they are both important for students' learning and experiences with modeling. We contend that meaningful modeling practices involves students using modeling principles as epistemic criteria to guide their modeling performances. In turn, engaging in modeling performances gives students opportunities to reflect on the experience and revise their understanding about modeling principles accordingly. Second, existing frameworks for modeling account for ideas consistent with the first four considerations included in our work (representation, mechanism, communication, and justification)—we offer limitation as a new consideration for modeling practice. The limitation consideration addresses a critical research gap in the modeling literature, that is, how students evaluate not only individual models, but multiple models as well. We argue that it is essential for students to recognize the merits and limitations of different models, and how a combination of different models may better represent, explain, and predict the underlying phenomena or system.

Table 1
A Framework for Modeling Practice

Modeling Consideration	Modeling Principle	Modeling Performance
Representation	• Models represent key features (e.g., conditions, components, processes) of system/phenomenon/issue • Models don't replicate reality • There are multiple representational forms of models • The particular details necessary for a model depend on its purpose	• Construct and use models to identify/represent/simplify key features of system/phenomenon/issue in their models • Move flexibly between different representational forms of models
Mechanism (about how/why)	• Models are used to explain system/phenomenon/issue	• Construct and use models to explain system/phenomena/issue

	• Models can be used to make predictions (based on the mechanism)	• Construct and use models to predict system behaviors/scientific phenomena/issue dynamics
Communication	• Models are communication tools for conveying understanding/knowledge • Models are communication tools for supporting arguments.	• Construct and use models to communicate understanding
Justification	• Models should align with relevant evidence • Models are revised based on new evidence obtained.	• Construct/Revise/Evaluate models based on evidence • Select among models based on their evidentiary support
Limitation	• Different models have different merits and limitations • Multiple models combined could better represent/explain/predict system/phenomena/issue	• Recognize the merits and limitations of single models • Compare and evaluate the merits and limitations of multiple models

Method

Context and participants

This study was conducted as part of an afternoon outreach program for middle school (grades 6-8) students in the summer of 2022. During a three-hour session, researchers facilitated a series of curricular events designed to activate and investigate students' prior knowledge of COVID-19 and promote engagement with modeling viral transmission. These learning activities are the first iteration of a multi-year project in which researchers will investigate how middle school learners coordinate different types of models to make sense of multidimensional and profoundly complex phenomena, such as pandemics.

The afternoon began with a modified version of a susceptible-infectious-recovered (SIR) model to encourage students to think about viral transmission at the level of a population (modified from Gaff et al., 2011). The SIR model was presented as a game which is essentially a simulation. The goal for students working with the simulation was to track how numbers of infected individuals within a population change over time. The simulation featured two processes: transmission, the process through which susceptible individuals become infectious ones, and recovery, the process through which infectious individuals become immune. Following engagement with the SIR model, we facilitated a conversation about respiratory droplets and their role in the transmission of viral infections between individuals. Students then completed four different stations where they participated in activities to inform their thinking about social distancing, how germs spread via objects, how masks are designed, and how particle size relates to the spread of viruses through different types of masks. In the social distancing and the particle size station, students completed an investigation answering driving questions: a) How does distance affect transmission, and b) are all materials effective barriers against transmission. The other two stations were a demonstration and an observation lab using microscopes to investigate the differences between the materials masks are made of. Following the activity stations, students worked in groups to construct a model, on whiteboards, based on the following prompt: *draw a model to explain how and why you may (or may not) get infected by a COVID-19 positive person in an indoor space, such as in a classroom, on a school bus, or in a restaurant.* The intent of the model creation exercise was to encourage students think about and share their knowledge of the mechanism through which respiratory viruses spread. As a final step, students were asked to reflect on the SIR model as it was given to them and the transmission model that they created and to critique both models.

The outreach served 14 students in 6th – 8th grades (ages 11 – 13 year old). Six of the 14 students identified as people of color. All names in used in this paper are pseudonyms. The students were divided into five learning groups designated by a color (i.e., yellow, purple, green, red, and blue groups). Students completed the SIR model, the activity stations, and the transmission model in their learning groups.

Data collection and analysis

The data for this study included videotaped recordings of the learning groups as they completed the modeling activities. A researcher facilitated activities within each group and employed a group interview protocol after the

SIR model, each station, constructing the transmission model, and discussing the critiques of the models. The researchers facilitated the interviews to allow learners to build on their group members' responses in order to capture a more authentic experience. Students were asked a series of questions that encouraged them to explain their models, what evidence they used to construct them, how they knew their models were correct, and to identify the limitations of their models. For the purpose of this paper, we focus primarily on the groups' creation and critique of their transmission models.

Through constant comparison (Glaser, 1965), the transcripts from the videotaped recordings were categorized based on modeling considerations from the Framework for Modeling Principles and Performances (see Table 1). These considerations were then further divided into themes that captured the nature of the students' modeling experience. For example, in the modeling consideration representation, students negotiated representation in terms of details, relationship to reality, and accuracy. These were each used as themes to inform how the learners built and shared knowledge about viral transmission.

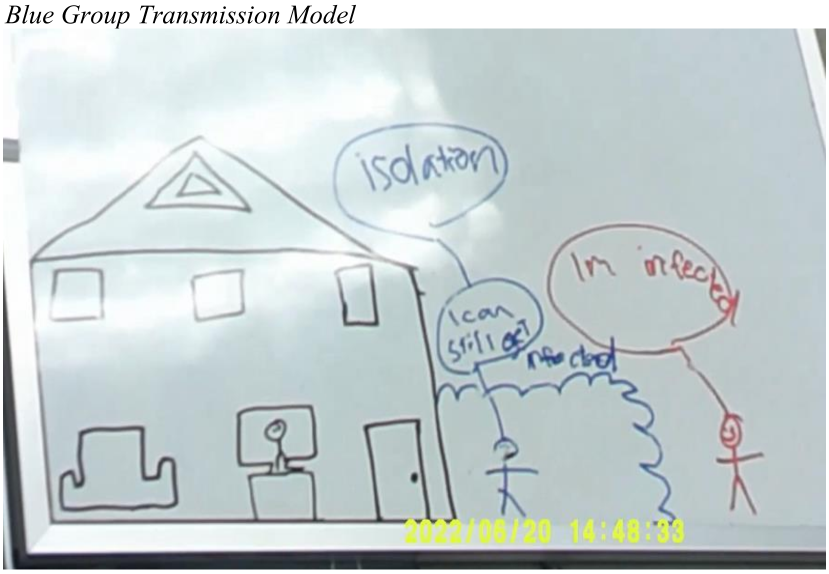
Results

Our results indicate two main findings: (a) students use several modeling considerations from the Framework for Modeling Principles and Performances to build and share knowledge about viral transmission, and (b) through the total learning experience, students came to appreciate the multi-dimensional nature of viral transmission and pandemics. Of the modeling considerations, representation was the most frequently discussed or demonstrated followed by limitation and justification. The other considerations (mechanism and communication) were reflected in some of the students modeling work. For example, Georgia, a student from the green group declared that "the messages will be different" when considering different models. However, this focus on communication was not as prominent as other considerations. Therefore, for the purpose of this presentation, we focus our analysis on how the groups worked with representation, limitation, and justification in their modeling experiences.

Modeling consideration: Representation

All of the modeling principles within the consideration representation (presented in Table 1) were evident in the video that captured group participation and/or the models they created, and the most common theme observed related to the first principle: how students represented key features of viral transmission in their models. Although students varied in how they approached representing the key features of their transmission model, they each generated a strategy (not provided to them) to distinguish the key features of the system. In all but one of the models, the students identified COVID-19 positive person using a different color, usually red. In most models, the susceptible person was represented in blue, while the background context was typically black or a neutral color; see Figure 1 as an example.

Figure 1
Blue Group Transmission Model



The need to provide a context to show viral transmission presented a challenge for the learning groups. Here we are classifying contextual details as background information that was not necessary for representing the key features of viral transmission. For some of the groups, the context of their model was as important as what might be considered the key features of transmission. In these cases, groups devoted a lot of time to negotiating contextual details like where transmission might be taking place and specifics associated with these places. For example, the yellow group immediately decided on a COVID-19 positive person sneezing as a means of infecting a susceptible person; however, there was extended discussion about what context they would represent in their model. The below excerpt captures a brief part of their conversation.

Yandy:	Somebody sneezes, and it goes through the mask.
Gabriel-Yosuf:	No, the kid's not wearing a mask.
Yasir:	No, the kid's not wearing a mask, and he has huge snot particles.
Yandy:	You can see it through a microscope.
Yolanda:	It's on a school bus.
Gabriel-Yosuf:	It's the chef. Okay, whoa, whoa, whoa, whoa, he's sneezing all over the food. Then they eat the food, and the people get COVID. Let's do that.
Yolanda:	Yeah, okay. Let's just draw two pictures.

Ultimately, the yellow group drew two representations of the transmission of COVID-19 from one person to another through a sneeze in two different contexts, a restaurant and on a school bus.

While constructing these two representations, the group members further debated which illustrations to include to capture the key features and contextual details in their model. For instance, Yolanda critiqued the restaurant representation and suggested a simplified version; "make the chef delivering your food and sneezing because it's easier to understand," indicating a desire for models to be simplified representations. This is further supported by an interaction between the yellow group and their facilitator about their decisions representing COVID-19 in their models.

Yolanda:	Maybe it shows that that's not what COVID looks like at all. It looks like it is extremely small, and it doesn't have color.
Yasir:	You can't see it.
Facilitator:	Okay. It's extremely small. It doesn't have color. Probably can't see it.
Gabriel-Yosuf:	It probably does have a color
Yolanda:	It's grey.
Gabriel-Yosuf:	Right, but grey is a color.
Facilitator:	So, can I ask you all about a decision? You said you can't see COVID. Why did you draw all of the dots?
Yasir:	As a representation to show
Yolanda:	To show where it is going

This interaction highlights the yellow group's understanding that representation is separate from reality but serves a visual purpose.

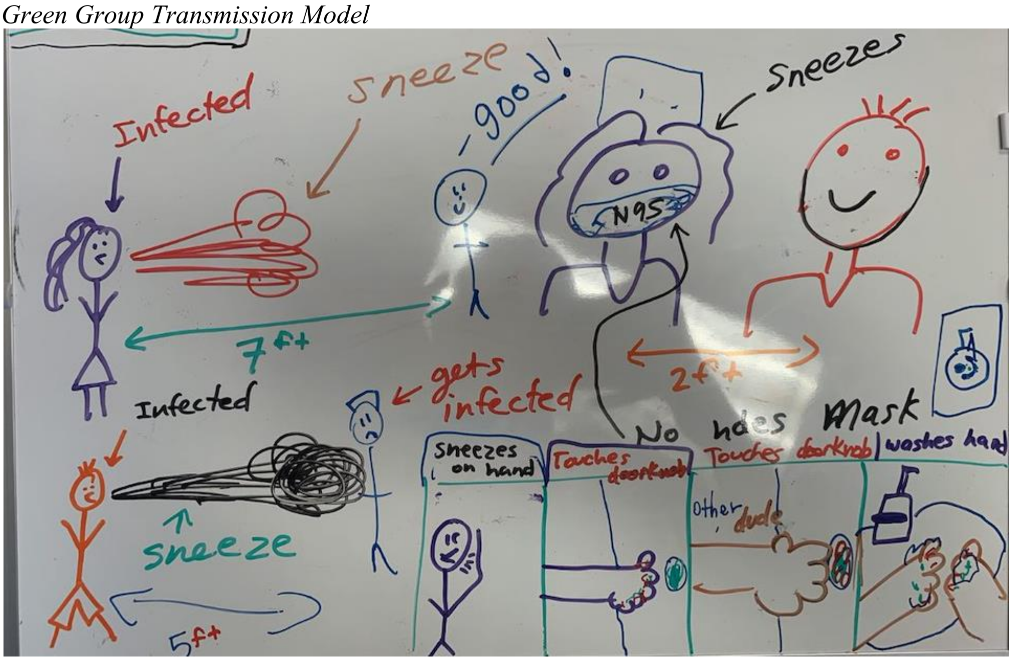
Additionally, upon reflection, the yellow group pointed out that their model was good because it fulfilled their representational goals. Yandy said, "They [models] do their purpose by showing the spreading of germs." He placed the value of their model on its ability to show the spread of COVID-19. So even though they spent time negotiating contextual details which were not essential for the representation (like the fact that the infected individual was a chef) of their models, when pressed to reflect on the purpose of their model they were able to recognize and discuss mechanistic aspects of the model. Along with the attention to distinguishing key features, this implies that the learners value the context of the model; but they see the purpose of the model is to represent a simplified version of COVID-19 transmission, not to deliver a broader narrative for which contextual details may have been more significant.

Modeling consideration: Limitation

Students mentioned the limitations of their transmission models throughout the entire experience. At times, they expressed dissatisfaction with their model's inability to fully explain all aspects of viral transmission. Groups tended to initiate model creation with a single figure or representation, but as they considered dimensions of transmission not accounted for in this initial representation, they would start adding scenes to account for additional aspects transmission. In some cases, the additional representation did not necessarily expand a model's account of transmission mechanisms. For example, the yellow group started their model by drawing a possible transmission scenario in the context of a restaurant (with an infected chef spreading respiratory droplets to customers). Some group members were dissatisfied that this initial attempt only showed transmission in one context so they added a new scenario showing how a virus might spread to multiple individuals in a school bus.

In contrast, the green group added to their representation as a way of expanding the mechanistic explanations accounted for in their model. Figure 2 presents the final model from the green group. The group started with scenes on the left with the intention of showing how respiratory droplets spread through sneezes and highlighted the significance of distance as a factor influencing transmission. They were concerned that this initial representation did not show enough so they next added the figures to show the importance of mask wearing (Figure 2, top right). Next, the conversation shifted to the potential for viruses to spread on objects, and in response, the group added a final scene (Figure 2, bottom right) that showed how viruses might spread on objects and the importance of hand washing. When asked by the facilitator what the model did not show, Georgia responded, "it's hard to tell why some masks are good, and others aren't." If space on the white board remained, it seems likely that the group would have added another scene to account for variation in mask quality. This pattern, which was observed in other groups as well, reveals that the students could recognize model limitations and sought strategies for expanding what their models could explain. In some cases (e.g., the yellow group), the changes to the models added contexts but did not necessarily expand the ability of the models to account for transmission mechanisms. In other cases (e.g., the green group), the changes broadened the explanatory power of the models. In all cases, the learners remained focused on specific examples (spreading viruses in a restaurant, on a bus, at different distances, with/without a mask, etc.) and responded to perceived model limitations by adding new examples. An alternative strategy could have been to consider aspects of transmission in more abstracted ways that could apply across specific examples, but the students did not appear able to take that step, at least not with the scaffolds provided.

Figure 2
Green Group Transmission Model



Modeling consideration: Justification

Students discussed the justifications that supported their models primarily by pulling evidence directly from that day's activities. When asked how they knew what they were modeling was true, they responded with particular reference to the station activities. They reflected on the fact that the stations showed the complex nature of viral transmission, such as not all masks offering adequate protection from the virus. When asked why the green group labeled the mask as "N95," Grace responded, "because, in the microscope, it had no holes." She later described how the "gaiter masks" are ineffective because she saw large holes under the microscope, which would not offer protection to a susceptible person. In the microscope station, students looked at an N95 mask, a surgical mask, a homemade double layered cotton mask, and a neck gaiter. Grace was referring to the porous, loose weave of the neck gaiter she observed under the microscope. Additionally, in the blue group, Bill said he used what he learned from the "6 feet apart" station which showcased the inverse relationship between spread of respiratory droplets and distance, to build his model showing isolation (Figure 1).

Evidence emerged that the students also justified their models based on personal experience. For example, Grace from the Green Group referenced her own experiences wearing a mask to protect herself and the people around her as a justification for including masks in her group's model. The attention to protecting others through wearing a mask, which was not discussed in the stations, indicates that Grace is bringing personal experience to her understanding of viral transmission. In a separate conversation, Yolonda similarly responded that the yellow group's model was good because it showed possible scenarios from real life, "Yes, people can sneeze on your food, and people can get sick from riding the bus." At another point in the modeling experiences, Yolanda expressed dissatisfaction with the SIR model by saying, "if there's a pandemic, you're most likely not just going to be walking around without anything on"—a reference to her own experience wearing masks in public places throughout the COVID pandemic. In the case of the SIR model, the students used a fixed simulation, and the fact that this simulation did not account for evidence from Yolonda's experience was a source of her critique for the model.

Conclusion

This research shows that, with a limited, short intervention, middle school students can effectively use models to better understand viral transmission. Moreover, both their transmission models and their discussions of the models include a variety of critical components that support the development of scientific literacy. In each group, we saw evidence that students engaged in informed decision-making through collaboratively creating, reflecting on, and critiquing the models.

The learning activities and interview questions prompted students' engagement with the representation, limitation, and justification dimensions of modeling. At the same time, these designed experiences were less effective at eliciting communication and mechanism dimensions of modeling. The activities that students participated in around the modeling exercises provided students with opportunities to gather evidence of (a) the best types of materials to use as a mask, (b) why social distancing is an important strategy for limiting transmission, and (c) how germs spread through objects. The limited attention on the part of student groups to other modeling considerations, namely mechanisms and communication, may have resulted from the design decisions our team made in creating the overall set of learning activities.

Notably, the findings suggest that middle school students can engage with modeling as part of socio-scientific issues, such as pandemics, in sophisticated ways, which is consistent with explorations of young learners modeling competencies in the context of strictly scientific phenomena (Duschl, Schweingruber, & Shouse, 2007; Louca & Zacharia, 2012; Zangori & Forbes, 2016). These young learners articulated scientifically appropriate criteria for modeling as the practice is ambitiously outlined in the *Next Generation Science Standards* (NRC, 2012). Students authentically engaged in building their transmission models and, as a result, navigated between complex decisions of what to include and for what purpose (i.e., superficial details, context, and simplified illustrations, as seen in the representation section). For example, although the yellow group included multiple contexts representing the same type of transmission, they ultimately decided that their model was appropriate because it showed the spread of germs. Additionally, all the groups identified limitations of their transmission and SIR models to conclude that COVID-19 is too complex to be singularly represented. Their dissatisfaction with what one model could accomplish shows an understanding of the pandemic that can be useful for supporting scientific literacy, most importantly in this case, informed decision-making for a healthy lifestyle.

Understanding how middle school students engage in modeling viral transmission may guide future researchers in clarifying how young learners use modeling to make sense of other complex SSI. Educators may also leverage the modeling considerations to encourage the types of learning environments that allow for all five considerations to flourish for meaningful epistemic engagement.

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