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Investigating Student Learning about Disease Spread and Prevention in the Context of Agent-Based Computational Modeling

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Abstract: COVID-19 has brought increased attention to the importance of health literacy, including understanding of the transmission and prevention of disease. This study presents data from a project aimed at developing a computational modeling microworld to help middle school students learn about these topics. Specifically, the microworld is meant to help students model and test their ideas about how a disease spreads through a population and how an epidemic can be prevented. The paper analyzes one student's knowledge refinement through the building, testing, and debugging of a disease spread and prevention model. We model student refinement of thinking through steps of building initial models and predicting results, testing initial models and making sense of the results, debugging and retesting models, observing final models, and explaining results. Our findings suggest adolescents can learn about strategies for disease prevention through computational modeling.

Introduction

COVID-19 has brought increased attention to the importance of health literacy in society. This involves making the public aware of issues related to public health, such as disease transmission and epidemic prevention. Epidemiology is the study of population-level health-related behaviors and outcomes, including disease causation, transmission, and prevention. Castagno et al. (2020) found that computational models could support the teaching and learning of topics in epidemiology. Their study was limited to undergraduate and graduate students and there is therefore a need to study how adolescents learn about epidemiological topics through computational modeling.

Agent-based computational modeling microworlds are a powerful tool for helping students learn about complex systems phenomena, including the spread of disease (Wilensky & Abrahamson, 2006). The value of their application has been described in many research studies, including studies that specifically describe their impact on students' understanding of scientific phenomena (Levy & Wilensky, 2009; Wilensky & Reisman, 2006, Wilkerson-Jerde, Gravel, & Macrander, 2015). We aim to offer middle school students block-based modeling microworlds, which allow them to represent their ideas in the program code and refine their thinking as they debug their program. We lower the threshold of this type of coding by using NetTango (Horn, Baker, & Wilensky, 2020). NetTango makes the computational power of NetLogo (Wilensky, 1999) accessible to modelers by using a block-based programming language curated to a particular phenomenon. NetTango blocks are not a full programming language, but domain-specific blocks relevant to the modeled phenomenon. This paper examines how our *Disease Spread* microworld can support student learning about agent-level behaviors that can lead to the prevention of an epidemic. Specifically, we show how a middle school student refined his thinking about disease prevention strategies using an agent-based computational microworld.

Theoretical Foundations

Constructionism informed the development of the instructional environment for this study. Constructionism asserts that learning occurs best through the construction and refinement of publicly shareable artifacts (Papert, 1980). Constructionist pedagogy helps students gain knowledge and skills by creating, reflecting on, and discussing these artifacts. In the case of our study, students used a computational agent-based model to articulate their thoughts on disease spread and prevention. They refined their ideas as they tested, debugged and refined their models. The theory of Knowledge in Pieces (KiP; diSessa,1993) informed our analysis of the engagement and refinement of naive knowledge. Knowledge, according to KiP, is a complex system made up of knowledge elements. Learning happens through the reorganization and refinement of the learner's knowledge networks. KiP instruction is constructivist, focusing on eliciting and refining students' prior knowledge.

Methods

This paper draws data from a larger study focused on developing a computational modeling microworld to help students construct an understanding of the spread of disease (Figure 1). The present work investigates the question: "*How does the computational block-based modeling microworld help students move from their initial thinking to their later thinking, with respect to disease prevention strategies?*" In order to address this question, we employed a lab-based case study approach (Yin, 1998). We conducted a one-on-one 1.5-hour interview through Zoom with a 12-year-old student we call Max. During the interview, Max was asked questions about the spread and prevention of disease and then invited to model and test his ideas in the microworld (Figure 1).

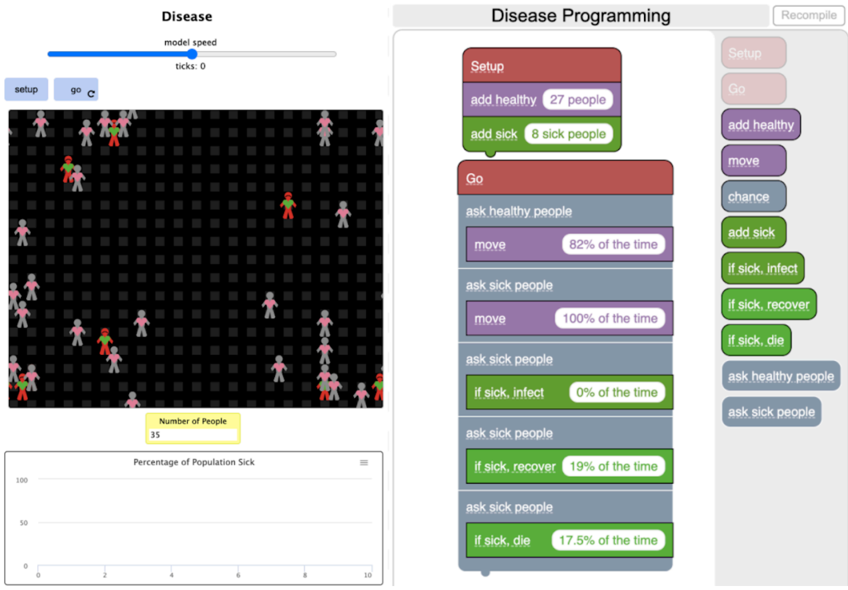

Figure 1: Screenshot of the *Disease Spread* microworld (Martin et al., 2021).

The box on the left side of Figure 1 represents a space where agents interact with each other. The modeling space on the right side of the interface has blocks including "setup," "go," "add sick," "add healthy," "ask healthy people," "ask sick people," "move," "chance," "if sick, infect," "if sick, recover," and "if sick, die." These blocks can be used to model the spread of disease by dragging and arranging them in the modeling space. The microworld is agent-based, meaning each agent is asked to behave, at each tick of the clock, according to the blocks assigned to them in the "go" procedure. For example, healthy agents might be asked to move randomly throughout the world and become infected with some probability if they cross paths with an agent who is sick. Sick agents might be asked to die or recover with some probability.

Max was invited to model and test his ideas in the microworld. Instead of writing text-based programs, he used blocks to build and test models and examine how emergent patterns arose at the system level from simple rules and interactions at the agent level. Specifically, he could build and test a model representing the spread of disease to explore how the individual-level interactions could give rise to a pandemic, and how individuals' different protection behaviors could make an impact on the overall health of the public.

We audio-recorded and transcribed Max's interview. We conducted a microgenetic analysis (diSessa, Sherin, & Levin, 2016) to produce a temporal decomposition of Max's trajectory of thinking with respect to disease prevention and protection strategies. First, we reviewed the recording of Max using the modeling microworld to build models of two different disease prevention strategies. We noted times during which he built, tested, debugged, and made sense of his models. These episodes were marked on the transcript, which was then analyzed to understand his process of knowledge refinement. This process included four steps: 1) building an initial model and predicting its results, 2) testing the initial model and making sense of its results, 3) debugging and retesting the model, and 4) observing the final model and explaining its results. We then tracked the shifts in Max's ideas over the course of these steps in order to understand how engagement in computational modeling helped Max refine his thinking.

Findings

We present an episode from Max's interview to illustrate how he refined his thinking as he refined his models. In the beginning, Max thought the best strategy for preventing a pandemic was for everyone to stay at home. By the end of the interview, in contrast, he had developed a sense that strict quarantine may not be more effective than allowing healthy people to move around with protection (such as masks), while sick people stayed at home most of the time. In this way, he may have developed his thinking and arrived at a more nuanced understanding of disease prevention.

The interviewer wanted to focus Max on two tasks toward the end of the interview and asked: “Could you arrange the blocks or modify the parameters of the blocks to create two situations? The first situation is the case where everyone stays at home, the second situation is the case where only sick people stay at home, but healthy people are free to move with protection.” The steps below describe Max’s trajectory through the modeling activity, highlighting his shifts in thinking.

The “Everyone stays at home” model

The interviewer asked Max to build a model of a strict quarantine, in which everyone stayed at home.

Step 1: Building the initial model and predicting its results

Max set up the world with 27 healthy people and 8 sick people. He asked healthy people to move with 82% probability and sick people with 100% probability. He set the probability of infection at 0%, the probability of recovery to 19%, and the probability of death to 17.5%.

> Max: …Basically like this. You can't infect anybody. Mmmm. [Max runs the model] Yeah. Nobody is dying. So basically, if they are quarantined, they can't touch each other, so they can't infect each other. Yeah, all the people would like to recover eventually.

He constructed the model to have a high rate of movement and a 0% chance of infection based on his initial assumptions about how strict quarantine would affect the rules of disease spread. Instead of lowering the rate of movement to represent a strict quarantine in which everyone stayed at home, he reduced the infection rate to zero to create a condition in which “no disease may spread among individuals.” Even though this model did not accurately depict people’s behavior, it was consistent with his prior belief that “strict quarantine would be the most effective way to safeguard the population.” Before he tested his model, he predicted that no one would die. His initial thinking was: “Everyone stays at home is the most effective disease prevention strategy.”

Step 2: Testing the initial model and making sense of the results

Max ran his model and watched five people die. He said he was surprised by the outcome of the model run. This reaction was evidence that he built this model with the expectation that a strict quarantine would be the most effective disease prevention strategy. He tried to understand what was happening at the agent level that would have caused the aggregate-level outcome, in particular, why five people died even when the infection probability was 0%.

Step 3: Debugging and retesting the model

In response to the interviewer’s prompt, Max started debugging the model.

> Max: Hmmm. Oh, yeah, move! Move rate should be 0%. [Max decreased the probability of moving to 0]. I will try to increase this [Max increased the infection probability to 49.8%, then recompiled the code and tested the model].

Max decreased the probability of movement from 100% to 0% and increased the probability of infection from 0% to 45%. These two moves indicate that he debugged his thinking regarding how to use the blocks to represent a strict quarantine and the probability that a disease would actually transmit. His updated model represents a more normative way of modeling a strict quarantine, by more accurately representing the rules governing individual agents and their interactions.

Step 4: Observing and explaining the results

Max tested the effect of his modified parameter and watched as 6 sick people died, even though no one moved in this model. Max appeared to be surprised by this result, saying, “Oh no, more people died.” This is evidence that the outcome of the model-run did not match his expectations. It suggests that he expected this modified model to work out differently, producing a result where fewer people died. It is interesting to note that Max did not continue to debug his model and find the cause of the unexpected deaths, which was the 17.5% chance of dying faced by every sick individual, each tick of the clock.

The “Sick people stay at home” model

Next, the interviewer asked Max to model a situation where only sick people were required to stay at home, while healthy people were allowed to move around the world freely, wearing protection such as masks. Max indicated that he expected this approach to lead to more sick people and deaths ("So basically, healthy people can move 100% of the time so that more people would die"). As in the previous activity, he engaged in steps of model building, testing, debugging, and explaining his observations. He left most of the model from the previous activity intact, changing only the probability of movement for healthy people (increasing it from 0% to 100%). When he ran the model, four people died. He was surprised by this result, as he expected more people to be infected and die. When asked if he thought there were any issues with the parameters left over from his previous model (probability of infection, recovery, and death) he replied, "I don't think so."

His final thinking on the effectiveness of the two disease prevention strategies was "I am not sure now. I mean, the outcomes of healthy people moving around and staying at home is a tie." This is evidence that engaging in the modeling activity played a role in shifting his thinking about the relationship between agent-level interactions and aggregate-level outcomes. While at the start of the activity, Max expressed certainty in his assertion that strict quarantine would be the most effective prevention strategy, after modeling the two approaches, he felt less certain, hinting that there may be more to consider given the two approaches produced similar results. Though this is a small shift in thinking, it is still a shift, and it is possible that further exploration of the model would lead to more debugging of the model, and in turn, refinement of thinking.

Discussion

This study investigated how a middle school student refined his thinking about disease prevention strategies using an agent-based computational microworld. Findings suggest that computational modeling can help students refine their thinking through building models and predicting results, testing models and making sense of the results, debugging and retesting the models, observing models, and explaining results. Our findings offer insight into how adolescents can learn about disease prevention through computational modeling. A high-level goal of our work is to develop microworlds in which students build models using a language they understand. Analyses show that our representations work as expected. Though somewhat abstract, Max was able to build and refine his model based on ideas drawn from his everyday experiences of the phenomenon he was trying to model.

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