Bringing powerful ideas to middle school students' lives through agent-based modeling[1]

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Abstract

Informed citizens in today's world need to be able to engage with pressing global and local issues that affect them. Many such phenomena are emergent; they are macro level patterns emerging from micro level interactions between numerous individual and independent entities. We argue that concepts and methodologies used by policy makers and scientists to make sense of emergent phenomena can be introduced to students at younger ages to help them make sense of the world around them. We present case studies from a pilot implementation of a middle-school unit on developing agent-based models of real world issues. We find that students collectively discovered powerful ideas about emergent phenomena through hypothesizing, creating models, conducting experiments, and discussing their findings with peers.

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1. Introduction

Becoming an informed citizen requires engaging with pressing issues of our world such as migrations and epidemics, as well as local issues that emerge from the particularities of local circumstances (United Nations, 2016; NRC, 2012). These, and many other social and natural phenomena, can be conceptualized as *emergent phenomena*; they are macro level observable patterns emerging from micro level interactions between numerous individual and independent entities (Mitchell, 2009; Wilensky and Resnick, 1999). Proponents argue that emergent phenomena should be introduced to students at precollege level to prepare them to deal with global and social issues of our world (Wilensky and Jacobson, 2014). However, studies have shown that people have great difficulty in reasoning about emergent phenomena due to inherent non-linearity, randomness, non-centrality, and multiple levels (e.g., Chi, 2005; Wilensky and Resnick, 1999). In this paper, we present case studies on how middle school students can be guided to discover powerful ideas about emergent phenomena through developing agent-based models of real world phenomena.

2. Theoretical framework

We present findings from a pilot implementation of a middle-school curriculum designed using Papert's (1980) theory of constructionism and the methodology of agent-based modeling (ABM). Below, we describe these theoretical frameworks and their relevance to our study.

Constructionism is a theory of learning that takes constructivism's connotations of "learning as building knowledge structures, and "to know an object is to act on it" (Piaget, 1972, p.20), and adds that this happens best when the learner is consciously engaged in constructing a public entity (Papert, 1980). According to Papert, constructionist learning environments can introduce *powerful ideas* to children through mediation of digital technology (2000).

Agent based modeling (ABM), a computer-based modeling practice that has emerged from the field of complex systems, uses simple computational rules as the fundamental modeling elements (Epstein, 1999; Wilensky, 2001). For example, a simple traffic model can be defined through two rules for cars: "*speed up if there are no cars ahead*" and "*slow down if there is a car ahead*". This model can be tested with various number of cars, and various speed-limits in order to explore how traffic jams emerge (Wilensky & Resnick,1999). Hence, ABM offers a better epistemological match to our intuitive notions of *parts* that make up systems as distinct individuals or entities (Wilensky and Papert, 2010). In this study, we used the NetLogo agent-based modeling environment, which is a low threshold-high ceiling modeling toolkit with roots in constructionist research that is widely used both in education and scientific research (Wilensky, 1999).

3. Methods

Setting: This study took place in an after-school program in a midwestern city in the US. The participants were eight middle school students in 6^{th} - 8^{th} grades (7 male , 1 female). Half of them reported their ethnicity as White and the other half as Asian. The names used in this paper are pseudonyms.

Procedures: The group convened for 2.5 hours once a week for a total of 8 weeks. In the first four weeks, the students learned how to use NetLogo and developed models of real-world issues, including epidemics and forest fires, among others. Each session began with a problem statement about one of these real-world issues, a classroom discussion on how to develop a relevant NetLogo model, and coding instruction. Sizeable time was devoted to students developing their own models, posing questions, making hypotheses, collecting data from the models, and testing hypotheses. In this paper, we focus analysis on the first four weeks, as students engaged in group work during this time. During the final four weeks, the students transitioned individual projects, which are not discussed in this paper.

Data collection and analysis: We collected teacher field notes and student artifacts created throughout the course. We conducted a preliminary qualitative analysis of these data, marking cases in where students explored or referenced powerful ideas about the practice of modeling, scientific inquiry or real world. We present two cases of students exploring powerful ideas in this paper: (1) the students' discovery of "*a tick*" as a powerful idea for computational experimentation, and (2) the students' discovery of "*order emerging from randomness*" as a powerful idea for the role of stochasticity in the patterns we see in our everyday lives.

4. Case studies

4.1. The "*tick*"

A "tick" is a computational measure of time (diSessa, 2001). In contrast to real life, where time always proceeds at a fixed pace, one may want to speed up a computational model to run many experiments quickly or slow it down to analyze events in greater detail. Hence, the "*tick*" is an essential idea in describing any system that changes over time (diSessa, 2001; Wilensky and Papert, 2010). NetLogo has a built-in tick counter and a simple command called “tick” that increases the tick-counter by one. The powerful idea of “*a tick*” emerged in a group discussion during the second session of the course in response to a simple prompt:

> “Each year, many people get influenza (flu). It is one of the most contagious diseases because it is very easy to get flu from someone by just talking to them or touching them. Some questions that we can ask about the spread of such diseases are: (1) How fast can flu spread from just one person to a group? (2) What are the factors that affect the speed of spread? Let’s create a NetLogo model and see how it can help us make sense of the spread of a disease.”

After posing this question, the teacher asked the students for ideas on how to create the model and demonstrated how to convert their ideas to NetLogo code. Some examples were “*create 100 people*”, “*make them move randomly*”, “*make one of them sick*”, and “a *person gets sick if she touches the sick person*”. While the teacher demonstrated, the students developed their own models at the same time (Figure 1). Once the initial version was complete, the students started experimenting with their models and sharing their findings with their peers.

Morris was first to share his ideas, explaining that he clicked the “*create 100 people*” button more than once and ran the model. He used his phone's timer to measure how long it took the infection to spread. He found that “*disease spread much faster when there were more people*”. The teacher used Morris’ theory as an opportunity to start a classroom discussion. He asked the group to conduct their own experiments and share their findings:

1. Franz raised his hand: “*We need to keep the speed constant. If we make it run faster in one experiment and slower in the other, it won't be reliable*”.
2. Kenny said he ran his model with 800 and 1200 people and he “*found that it spread slower with more people*”.
3. Morris argued that Kenny’s result was “*due to randomness*”.
4. Wesley suggested “*a better experimental methodology*”. In the initial model, the “*move*” button repeated the actions continuously. Wesley made this button non-continuous, so that people only

> moved one step at a time. Then, he clicked it one by one to "*count precisely how many clicks it took for the disease to spread*".

Over the course of one session, a student came up with a compelling theory on the relationship between the size of a population and the spread of a disease. Other students collectively agreed that the theory was worth testing through further experimentation, yet they also noticed a flaw in Morris's initial methodology. They realized the necessity of reliable and comparable experimental designs and a standard way of measuring the outcomes of their experiments. The powerful idea of a computational measure of time was collectively discovered by the students themselves.

4.2. Order and randomness

People have great difficulty in making sense of randomness in emergent phenomena because random processes are often perceived as destructive forces acting against the goals of real world systems (Wilensky and Resnick, 1999). In reality, phenomena are considered random when a regular pattern of outcomes emerges across many repetitions of individual outcomes (Moore, 1990). For example, a single coin toss has an uncertain outcome, yet a regular pattern emerges when repeated many times: approximately half the tosses come up heads and half come up tails. In the third session, the powerful idea of order emerging from randomness was collectively discovered by the students while developing a very simple model of economy. The session began with the teacher posing the following simple prompt:

> "Think of a simple economy where everybody starts with the same amount of money. In this economy, people exchange money with each other based on the following simple idea: '*At each tick, I choose a random person and give him/her 1 of my dollars'*. What would happen in this economy?"

Once the teacher finished talking, almost all the students raised their hands, eager to talk about their own their hypotheses. The teacher asked the students to write their answers on post-it papers and put them on the board (Figure 2a). Then the teacher asked each student to pick one other idea on the board to provide feedback (Figure 2b). After each student wrote their hypotheses, the teacher developed a simple version of the model with the students' input. In the model, the amount of money a person has is represented by their horizontal position and richer people are bigger (Figure 3), which are ideas that were suggested by the students.

When the model was complete, students noticed that very few people became very rich, most stayed in the middle, and some became poor. The teacher ran the model a few more times and showed that this pattern was consistently observed. A group discussion followed:

1. Jenna: "*It is not realistic. People aren't giving each other money randomly. There are taxes, jobs, expenses, getting paid, buying food. In the model, they just get money.*"
2. Franz agreed that the model was "*not realistic*" and added: "*It doesn't make sense that they go in and out of existence if they have no money*".
3. Aaron: "*it wasn't supposed to be the real world in the first place but it was visualizing how real-world economy works*".
4. Micah: "*We sort of modeled the real world because some people get rich fast*".
5. The teacher: "*Why did some people get rich fast?*"
6. Franz: "*This is not the actual structure of economy. It is completely random. 1 person may give just 1 dollar out but may get more than 1 dollar at a given time. It makes a difference because they don't give back as much money*".

Franz's answer clarifies an important component of the model regarding the role of randomness, specifically the role of randomness in observing consistently similar outcomes with each run of the model. More importantly, his explanation was not solely a product of his own intellect, but a response he formulated through the class's collective hypothesizing, experimenting, and discussing the flaws and strengths of their findings and arguments.

5. Conclusions and future work

Real-world systems are complex and many real-world phenomena are emergent; they involve numerous independent actors, events, and details. It is neither sufficient nor effective to solely teach facts in simplified contexts (Pea, 1985). For students to become informed citizens, it is important to focus on bringing powerful ideas about emergent phenomena to students' lives (Papert, 1980; 2000). In this paper, we presented two case studies from the pilot implementation of a middle-school unit on developing agent-based models of real world phenomena. We demonstrated how group discussions in such classrooms can lead to the collective re-discovery of powerful ideas by students. While further study of the course trajectory and outcomes are necessary to fully understand the impact of using ABM to help students explore powerful ideas, these cases suggest there is utility to applying this approach to the understanding of complex phenomenon.

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Appendix: Figures

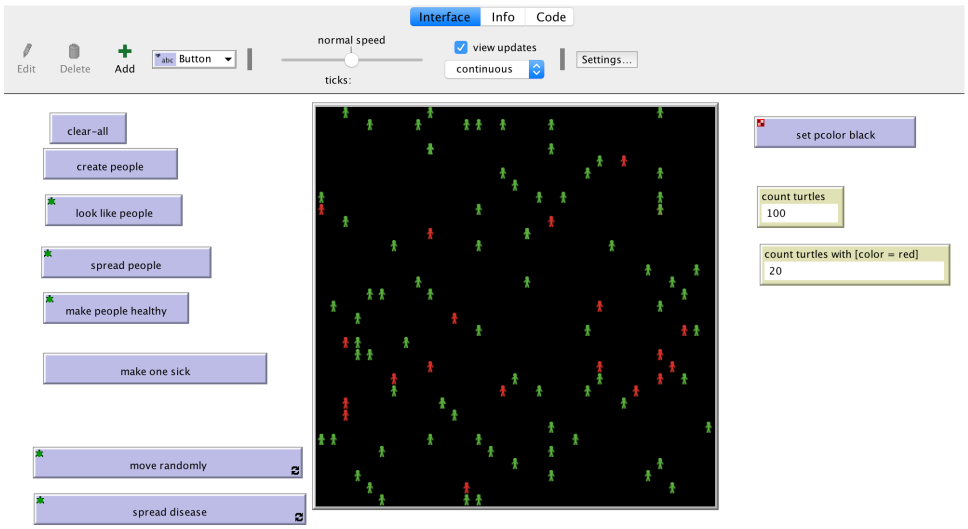

Figure 1: The initial version of the disease model created in NetLogo by the teacher with input from the students

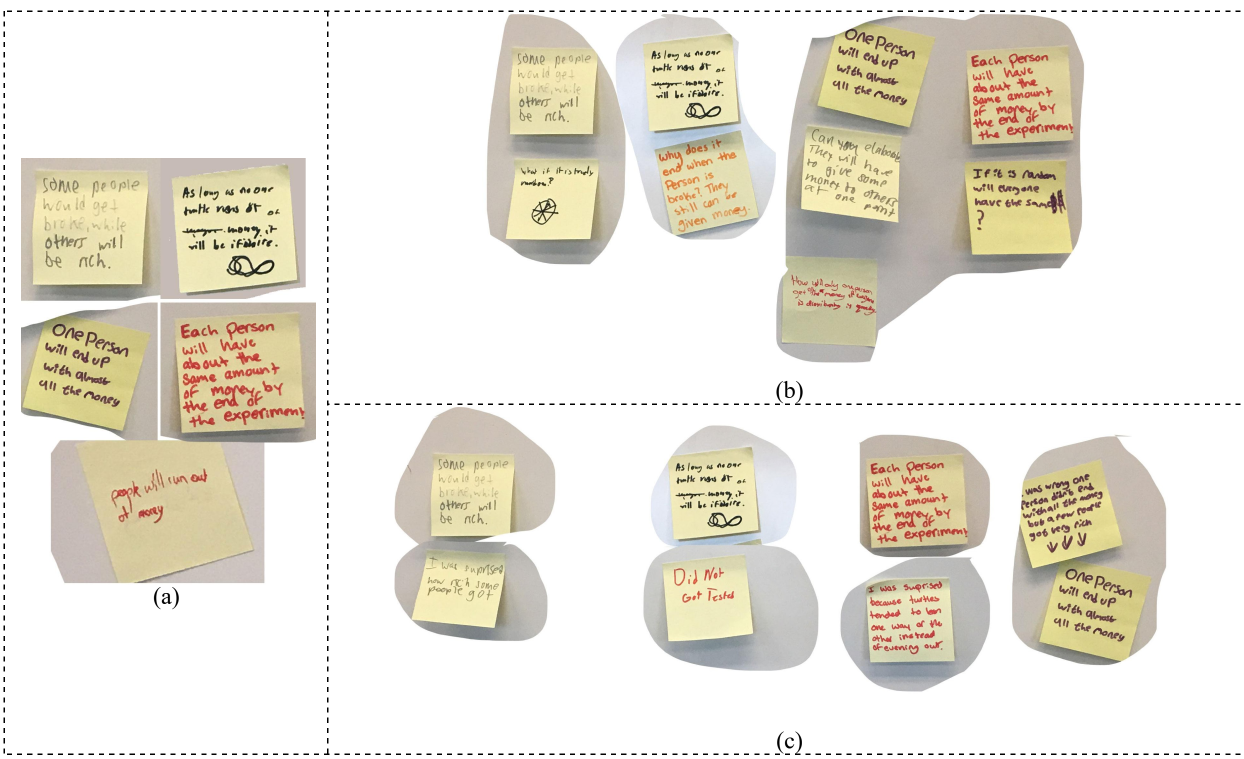

Figure 2: The students' hypotheses and reflections on simple economy screenshots (a) the students' initial hypotheses, (b) their initial feedback to other hypotheses, (c) their reflections to their own hypotheses after discussion.

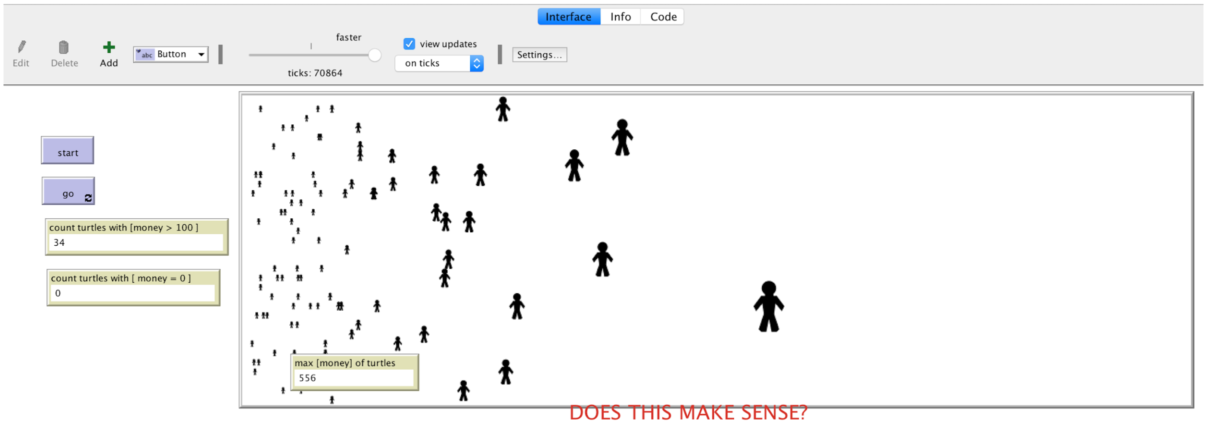

Figure 3: The initial version of the simple economy model created in NetLogo by the teacher with input from the students