Thinking Like a Butterfly: Leveraging Students' Embodied Intuitions in Elementary Ecology Classrooms

Problem

Embodied modeling is a particular form of modeling in which students themselves act as individual agents in a complex system (e.g., an ecosystem). Such a pedagogical approach connects scientific phenomena directly to students' lived experiences and enables them to deepen their understanding of the phenomena. Embodiment – in both real and virtual environments - allows the learner to be both the source and processor of information as they experience first hand the complex aggregate-level outcomes that emerge from simple agent-level decisions (Colella, 2000; Wilensky & Stroup, 1999).

Several scholars have shown that models or modeling-based curricula based on multi-agent-based models, or MABMs, can help novices understand complex systems and emergence by recruiting their embodied, agent-level intuitions (Resnick, 1994; Wilensky & Resnick, 1999; Klopfer, Yoon & Perry, 2005; Klopfer, Yoon & Um, 2005). The use of MABMs in elementary science curricula is relatively recent and from the studies that have been conducted we have learned that: 1) These models can help students bootstrap their intuitive knowledge to develop understandings of emergence (Wilensky & Reisman, 2006) and 2) They can serve as mediating tools in understanding ecological phenomena (Danish et al, 2011). Overall, the classroom studies that have utilized MABMs have placed less emphasis on the development of mathematical representations. Furthermore, the relationship of learning using MABMs and the development of representational practices in Ecology has yet to be investigated.

The present study is an investigation in the field of elementary ecology education and reports findings from a study conducted in a 3^{rd} grade classroom. This study is grounded in a science as practice perspective (Lehrer & Schauble, 2006) in which the concepts and tools of science are considered to be deeply intertwined. From this perspective, developing explanations is not simply a matter of stringing together the logical entailments of information; rather, it involves struggling with posing questions, arranging conditions for seeing, developing measures, structuring data, and understanding the entailments of that data.

From a design perspective, the goal of the study was to design a learning environment that successfully integrated embodied modeling and MABMs through the generation of mathematical representations that are common to both forms of modeling. Specifically, the study investigated the following research question: How do students develop understandings of structure-function relationships through the generation of mathematical representations of embodied modeling activities?

Procedure

The setting of the study was a 100% African-American charter school located in a metro school district of a Southeastern state. The study was conducted in one 3^{rd} grade classroom of fifteen students. Data was collected over a period of two weeks and totaled approximately 10 hours of instruction and activity. To accomplish our design goal, we designed a hybrid learning environment that integrated two kinds of agent-based modeling activities – a participatory embodied modeling activity and an MABM - through the generation of mathematical representations. At the start of the learning sequence, students investigated structure/function relationships by participating in an embodied modeling activity of butterflies foraging for nectar.

Students recorded their energy gains and losses on worksheets. The rules of this activity were carefully designed to leverage students' intuitive understanding of the relationship of energy consumption due to physical activity. On the next instructional day, students completed a second iteration of this activity with key variables altered. The goal of these two iterations was to familiarize students with agent-based thinking and to focus students' attention to the role of variation in the system.

After completing each iteration of the embodied modeling activity, students created bar graphs of what their energy as a butterfly looked like over time. Students were also provided with maps of the classroom and articulated the differences in their foraging strategies across iteration 1 and 2 by generating spatial energy maps of their foraging behavior. The foraging maps helped to make explicit the role of variation in the system by allowing the students an opportunity to step back and reconstruct their history from a different perspective. After completing both iterations of the embodied modeling activity and creating their mathematical representations of energy, students interacted with two different multi agent-based computational models designed in the Netlogo modeling platform that allowed students to manipulate the variables that affect how successfully butterflies are able to forage for nectar.

Findings & Analysis

In order to better understand how students developed their understandings of structure-function relationships through the generation of representations, we analyzed the development of the students' mathematical representations of energy as they progressed through the learning sequence. In addition to providing whole class data, we have also provided an analysis of one representative student – Jamar – as he progressed through the activity sequence. This analysis can be found below in Table 1.

Based on our results, our findings show that students' conceptual development was deeply intertwined with their development of authentic representational competencies. In generating their mathematical representations of energy over time, the students modified their foraging behavior based on new ideas of energy in terms of both the structures of agents and the location of food sources within the environment. Students' ideas regarding agent/environment relationships emerged as a result of the embodied modeling activities and were additionally refined based on the representations students created. By providing students opportunities to both embody foraging activities of biological agents and make decisions as agents within the ecological system, the systemic limitations due to the structure of agents, the structure of food sources and the spatial location of food sources within the environment emerged as determining factors in agent survival. Additionally, the representational activities provided students an opportunity to reflect on their foraging decisions and then refine those behaviors in subsequent modeling activities.

Activity	Sample Student Talk	Analysis
Embodied Modeling & Energy Graphs I	 **Researcher:** Talk to me about what you did? **Jamar:** I walked around and I had a short proboscis	During the Iteration 1, Jamar states that while foraging he simply 'walked around'. Due to his short proboscis length, Jamar was not able to drink from all of the flowers he visited and his overall energy suffered as a result. While foraging for nectar, Jamar realized he needed to visit small flowers and his energy went up. The effect of his foraging decisions is evident in his energy graph as his first few foraging trips yielded little energy while subsequent flowers provided

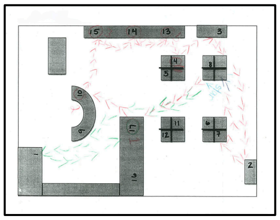
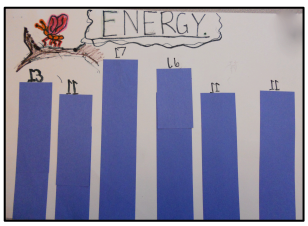
	and I wasn't able to drink from the big flowers and then I was just wasting my energy and that's how my energy went down and down and then I went to small flowers and my energy went up.	greater yield.
Making Maps	 **Researcher:** Why was your second time better? **Jamar:** Because the first time I had a short proboscis and I couldn't get that much energy.	Examining Jamar's Spatial Energy Map, his non-strategic foraging pattern during Iteration 1 (red path) is explicit. During Iteration 1, Jamar visited flowers due to proximity only rather than proximity and flower type. His more strategic foraging decisions in Iteration 2 (green path) are clear. In Iteration 2, we can see that Jamar chose to travel to not only flowers that were near each other, but those flowers that were near each other AND that he could drink from.
Embodied Modeling Energy Graphs 2	 **Researcher:** What's important to a butterfly when it's looking for nectar? **Jamar:** Some butterflies have a small proboscis and they can't drink from a big flower and they waste energy if they go to a big flower. **Researcher:** What does a butterfly think about it's energy? **Jamar:** It doesn't want to waste it. **Researcher:** How does it not waste it? **Jamar:** It chooses closer flowers that are its size.	During Iteration 2 of the embodied modeling activity, Jamar utilized the knowledge of agent-environment relationships and energy conservation he gained during Iteration 1 to inform his foraging decisions for Iteration 2. Jamar optimized his foraging strategies through his understanding of agent structures and the location of energy sources. His different foraging choices are evident in his energy graph. Jamar's second energy graph depicts a much more stable loss and consumption of energy than in the first iteration. This stability is due to Jamar's understanding of energy conservation within an environment.
Computational Activity 1	**Researcher:** How did the butterflies survive? **Jamar:** Because the birds were full? **Researcher:** What could be another reason? Why do you think the butterflies survived when you made the flowers red and the butterflies are red? **Jamar:** They blend in! When the butterflies are the same color as the flowers, they blend in with the flowers.	Our analysis of the first computational activity revealed that Jamar initially had trouble programming the butterflies to stay alive. He arrived at camouflage after manipulating the variables he knew were important – flower size and proboscis length. After he saw that those factors did not help the butterflies stay alive he began playing with flower color and butterfly color and happened onto camouflage as the solution.
Computational Activity 2	**Researcher:** What is the graph showing you? **Jamar:** The butterfly's energy going up and down. It's energy along the way.	Our analysis revealed that students had little trouble interpreting the computer-generated graph and used the knowledge they had gained through generating their own representations to interpret the correctly determine and predict the energy output of the virtual butterflies.

Table 1: Jamar's Conceptual Progression

In addition to analyzing students' understanding of structure/function relationships through the generation of representations, we also analyzed student energy graphs for changes in representational *practices*. Student generated bar graphs of energy were coded along two dimensions: 1) Scale and 2) Narrative Fidelity. Scale was defined as energy graphs that demonstrated a graduated range of values resembling a standard system of measurement.

Narrative Fidelity was defined as energy graphs that represented the change in the students' energy over time, depicting both the order of their foraging path and how their energy changed with each forage.

Our analysis of these two features revealed that student use of narrative fidelity increased from five graphs in Iteration 1 to eleven graphs in Iteration 2. Additionally, student use of scale increased from three graphs in Iteration 1 to ten graphs in Iteration 2. Examining student energy graphs more closely, we found that the number of graphs that demonstrated neither use of scale nor narrative fidelity decreased from ten graphs in Iteration 1 to three graphs in Iteration 2. Similarly, graphs that demonstrated use of both scale and narrative fidelity increased from three graphs in Iteration 1 to nine graphs in Iteration 2.

	Iteration 1	Iteration 2
No Scale/No NF	10	3
Scale/ No NF	0	1
No Scale/NF	2	2
Scale/NF	3	9
Total Use of Scale	**3**	**10**
Total Use of NF	**5**	**11**

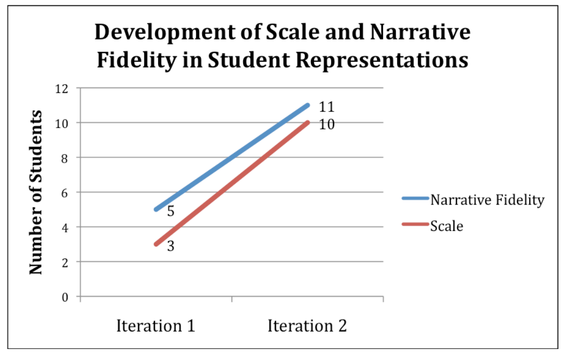


Figure 1: Summary of student use of Scale and Narrative Fidelity across Iteration 1 and 2.

These changes in students' representational practices are important since they mirror the more sophisticated understanding of agent-environment relationships students had developed by completing a second iteration of the embodied modeling activity. Students used the energy graphs they had created during Iteration 1 to inform the foraging decisions they made during Iteration 2. The different foraging patterns seen in Iteration 2 were reflective of students' increased understanding of specific structure/function relationships.

Finally, we found that in their interactions in Model 1, students used the understanding of variation they had developed through the embodied modeling and representational activities to design and conduct experimental investigations with Model 1 to figure out the role of camouflage in butterfly survival. Through trial and error, students systematically eliminated variables previously identified as important to a butterfly's survival – such as the location of flowers. After eliminating known variables, students then were able to identify color as integral to survival. In their interaction with Model 2, students explicitly used their experience generating mathematical representations to interpret the computer graph.

Variable	**Percentage of Students who Identified variable as important to Survival**
Location of Flowers	73%
Length of Proboscis	60%
Flower Type (Tall or Short)	53%

Table 2: Percentage of students that identified key variables as important for survival

Scholarly Significance & Relevance to NARST Community

Although multi agent-based models have been successfully used as instructional tools in high school and college level biology classes (Wilensky & Reisman, 2006), there exists little research on their integration with elementary science curricula. Our study proposes a possible pathway to integrate MABMs with embodied modeling and graphing activities. Furthermore, our study presents a new instructional approach for learning emergent ecological phenomena through modeling practices designed to bootstrap students' naïve, embodied intuitions. By designing a learning environment that supported the "doing" of science through the integration of embodied modeling, the use of multi-agent based models and representational practices that leverage naïve intuition, our findings suggest that novices as young as 3rd graders can develop a sophisticated understanding of key conceptual issues such as structure-function relationships and some of the complex inter-agent and agent-environment relationships within an ecological system.

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