# Bifocal Biology: Combining Physical and Virtual Labs to Support Inquiry in Biological Systems

Tamar Fuhrmann, Daniel Greene, Shima Salehi, Paulo Blikstein
Transformative Learning Technologies Lab (TLTL), Stanford University, 520 Galvez Mall, CERAS 232, CA, USA.
tamarrf@gmail.com, dkgreene@stanford.edu, shimasalehi87@gmail.com, paulob@stanford.edu

**Abstract:** In this paper we describe a pilot study of an approach to STEM inquiry learning called Bifocal Modeling (Blikstein, 2010) with a group of high school students studying bacterial growth. Students grew real bacteria, and then collaboratively designed a conceptual agent-based model of bacteria to mimic the observed growth. Observations and student notes suggest that the activity helped students demonstrate their knowledge of bacterial growth by formalizing it from a list of unorganized facts into an accurate pseudo-computational model. In completing their task, they also critically reflected on the assumptions built into the modeling activity itself, and demonstrated familiarity with some core principles of complex systems.

## Introduction

As computational tools continue to improve, virtual models and simulations of scientific phenomena have become increasingly popular options for science learning. Alongside this trend, a new opportunity has emerged: combining and comparing virtual and physical laboratories. Research suggests that a combination of virtual models and hands-on lab activities is more effective than either alone (Liu, 2006) and that sequencing a virtual model after a physical one is more effective than the reverse (Gire et al. 2010; Smith et al. 2010).

However, the literature has focused entirely on pre-designed physical and virtual models, overlooking the fact that creating and critically evaluating models is an important part of scientific practice and a valued learning outcome. (Levy & Wilensky, 2008; Blikstein 2010). Similarly, the literature has also under-explored the potential to support students' comparisons between the physical and virtual models (Blikstein & Wilensky, 2007, Blikstein, 2010). Smith and collaborators (2010) noted that particular scaffolds in virtual and physical models could foster discussion about the models and their content. In this paper, we present a pilot study to address both of these concerns. Using a type of scientific inquiry activity called *Bifocal Modeling*, high school students designed virtual and physical models of bacterial growth in order to develop both content knowledge and critical model-evaluation skills. This study is part of a larger project that investigates how students learn by examining the differences between ideal and real systems, normally by means of building and connecting virtual computer models and physical, sensor-enabled systems.

## Methods

The authors conducted a pilot study in a laboratory setting with four high school students, all female and ranging from $9^{th}$ to $11^{th}$ grade. Two had previously learned some general information about bacteria in class, but knew nothing about the growth patterns of bacteria. The workshop lasted for a total of about five hours, split across three afternoon sessions. In the first session, students were introduced to the goal of "understanding what makes bacteria grow". They designed an experiment to compare bacteria growth by collecting samples from different parts of their environment and preparing them in a Petri dish. They also watched a time-lapse video of bacterial growth. In the second session, the students were grouped into two pairs to do web research on the bacterial growth curve and write down the variables that they thought would be relevant. For the third and final session, the authors conducted a variation of "paper modeling" in which students collectively designed and ran an agent-based model of bacterial growth on a whiteboard. This required articulating the variables in the model and agent-level rules. The students would "run the model" by enacting its rules on the board to progress the model by a single time step at a time, and then stop to add or change rules and variables. The authors scaffolded the modeling session with minimal questions. After the whiteboard activity, students interacted with pre-made computer models of bacterial growth and were led in guided inquiry about the limitations of the models.

### Data and Discussion

Students were given two open-ended questionnaires about bacteria and the growth curve - once before and once after the entire session. They were also videotaped during all activities, their computer usage was documented with the screen-capture software, the researchers took field notes, and all of their notes and sketches in all three sessions were preserved. Based on these data, we observed four main themes:

### Iteratively improving the virtual model to resolve mismatch

The students used a strategy of iterative debugging by "running" their whiteboard model, comparing the results to the behavior of the physical bacteria, and resolving the perceived differences between the two by adding rules and variables to the virtual model. They repeated this process a total of four times in the 1.5 hours of the third session, developing an increasingly accurate model in the process. For example, a student observed at one point after "running" the virtual model that their bacterial growth curve was unlike the real one, which only began to increase after a short delay to acclimate. They used this to come up with the following rule: "If a bacterium is in the first generation, it has to wait two time steps before reproducing." Upon running the model again, the students could see from the resulting curve that they had successfully created the "lag phase" of real bacterial growth.

### Converging on appropriate variables

During their internet search in the second session, the students wrote down a large number of variables that are irrelevant to bacterial growth. However, during the whiteboard virtual modeling session, they consciously rejected most of the variables without prompting, and only included those that were necessary to define the shape of the growth curve. This suggests that the modeling activity helped them to clarify their understanding of the process of bacterial growth by understanding the relative importance of different variables.

### Critically evaluating the assumptions of models

The students in the workshop spontaneously reflected on the underlying assumptions of their models. For example, *time* in the whiteboard model (and in computer models) is represented as a series of discrete steps called "ticks". One student realized that they had no agreed conversion between ticks and real time. She asked, "Do bacteria get food and moisture each minute? …how can we translate the tick into real time?" Though they did not entirely resolve their questions about representing time and space in their model, the students were asking the "right" questions; that is, they were asking questions about the assumptions that models make about the world, which are at the heart of scientific critical thinking and modeling (Blikstein & Wilensky, 2007).

### Translating between micro and macro perspectives

A final theme that emerged was the continual switching of perspectives, from the rules for an individual bacterium to the emergent behavior of its entire colony. With no prior academic knowledge of agent-based modeling or complex systems, the students in this study described and manipulated a complex system at two levels. While Bifocal Modeling is not inherently bound to a complex-systems framework, the process of modeling a phenomenon and trying to match it to a reference pattern may be an effective way to engage with complex systems.

## Conclusions and next steps

Based on our observations, the opportunity to build and compare virtual and real models helped students improve and refine their theoretical models. In the process, we claim that they demonstrated content knowledge about bacterial growth and critical meta-modeling skills. Future work will keep developing Bifocal Modeling as a platform for real-time linking of physical and virtual models, and for collaborative programming with computational media.

## References

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