The Link Between Physical Experiment and Computer Model in a Science Classroom

Tamar Fuhrmann
Stanford University
tamarrf@stanford.edu

Paulo Blikstein
Stanford University
paulob@stanford.edu

Abstract

The Bifocal Modeling Framework (BMF) is an inquiry-based approach for science learning that links students' physical experimentation with their use of computer modeling. Our study is among the first implementations of a BMF approach in a science class. The study consisted of three conditions implemented with a total of 75 9th grade high-school students. The first and second conditions were assigned two different implementation modes of BMF: BMF-with-model-design and BMF-without-model-design. Both groups conducted a physical experiment, utilized a virtual-model, and compared the results between the two. However, only the BMF-with-design participated in the design-module, which consisted of developing an on-paper model of the scientific phenomenon under investigation. The third condition, employed as a control, received instruction in the school's traditional approach. Our results indicate that students who participated in both implementations demonstrated better understanding of the content as well as improvement in their meta-modeling knowledge. However, only for the "BMF-with-design" group was the improvement statistically significant for both content and meta-modeling knowledge.

Keywords: Bifocal Modeling Framework, inquiry-based, design-based learning, virtual model, model-based reasoning.

Introduction

The Bifocal Modeling Framework (BMF) is an inquiry-driven science learning approach that challenges students to design, compare, and examine the relationships between a physical experiment and a computer model. This dual focus on a physical experiment and computational model motivated its name, Bifocal Modeling (Blikstein, et al., 2012; Blikstein 2012, 2010). Figure-1 maps out the process by which students explore natural phenomena such as diffusion, bacterial growth and the properties of gases. They design and conduct physical experiments (image "1"), in parallel they design and develop computer models (image "2"), and compare the measured and simulated data from running both the experiment and the model (image "3").

Figure 1. BMF, linking a physical experiment and a computer model

Depending on the nature of the phenomenon under investigation, students may use different computer languages to implement their models. The most common language and the one used for this study is NetLogo, a free and open-source environment for scientific modeling (Wilensky, 1999). The range of learning possibilities with BMF experimentation can be quite wide (Fuhrmann et al., 2012, 2014). There are many ways for the implementation of this framework in classrooms. In this study, we examined two implementation-modes of BMF: BMF-with-model-design and BMF-without-model-design. Both groups conducted a physical experiment, utilized a virtual model, and compared the results between the two; however, only the BMF-with-design participated in the design module. The study aim to better understand how the BMF approach could be integrated into science learning at high schools and to examine what did students in the different implementations learn about the content, and modeling.

Methods

Participants and Settings

The study was conducted in a K-12 charter school that employs constructivist-inspired approaches and serves an educationally at-risk student population. The participants of the study were the students of three 9th grade classes taught by a single science teacher. Each class consisted of 25 students (for a total of 75 participants). Diffusion and Osmosis are presented several times throughout the curricula of most introductory biology textbooks (Freeman, 2002). In this school, these concepts are taught repeatedly in the science curricula of many grades. However, both processes are frequently difficult for students to understand, and students often have misconceptions about them (Odom, 1995; Sanger et al. 2001). Typical difficulties concern the operation of the processes at the molecular level (Meir et al. 2015) and this was one of the reasons we thought that BMF would be suitable for that particular topic.

Study Design and Instructional sequence

The main goals of this unit were twofold: 1. Facilitate content learning about osmosis, and 2. For students to learn about modeling. The total time frame designated for the unit was four class periods of 80 minutes each. Three conditions were employed in the study:

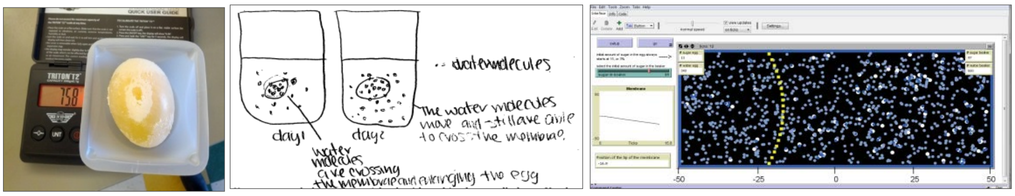

Figure 2. The physical experiment, the paper-model and the computer model of the same phenomenon.

1. **BMF with model design (BMF-with-design):** students conducted a physical experiment and collected data, following they designed a model on paper. The design task was an instance of a "paper modeling"[1] instrument, which, consisted of the conceptualization of agent-based models on paper and served as a visual representations of the natural phenomenon (Blikstein 2014). Specifically, students were asked to draw the particles involved in osmosis, and to "animate" these particles on paper with verbal explanations and arrows. Finally, students interacted with a premade computer model and were asked to compare the data from the computer and the results of their physical experiment (figure-2).
2. **BMF without model design (BMF-no-design):** students conducted a physical experiment and interacted with a premade computer model to examine the scientific phenomenon of osmosis. They also compared the premade model to the physical experiment and

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[1] Despite the obvious differences between the paper and computational media, we thought that paper modeling would be a good instrument for 9th grade students who lack programming backgrounds.

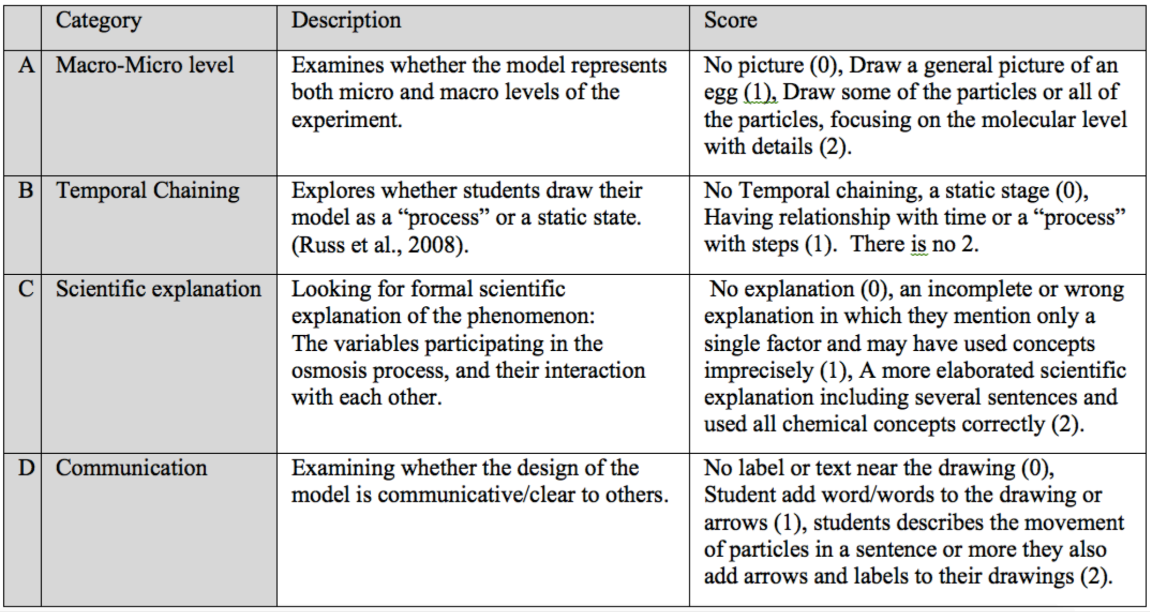
manipulated it. Their curriculum was designed within the Bifocal Modeling Framework, but without the model design module.

3. **Control:** students designed and conducted the same experiment as the other conditions; they discussed the results; and were requested to devise an explanation for the natural phenomenon observed in class. These activities included many of the components of progressive, research-based education, and allowed considerable time for hands-on experiments.

Data sources and analysis

To address our research goal, we administered two paper-and-pencil tests: a conceptual content test on diffusion and a meta-modeling assessment that focused on students' understanding of modeling. The content test incorporated items designed to detect common diffusion misconceptions (Blikstein, 2012). In addition tests included an open-ended question were students' task was to draw models explaining the naked egg experiment. The meta-modeling test was adapted and customized based on Schwarz et al. framework (Schwarz and White, 2005). Using the data from all tests, we calculated students' overall scores and utilized paired Wilcoxon-signed-rank tests to determine whether the statistical means were significantly different. In order to assess student drawings of the models, we developed a rubric. The rubric includes four categories described in Table 1.

Table 1. The "Model drawing rubric"



	Category	Description	Score
A	Macro-Micro level	Examines whether the model represents both micro and macro levels of the experiment.	No picture (0), Draw a general picture of an egg (1), Draw some of the particles or all of the particles, focusing on the molecular level with details (2).
B	Temporal Chaining	Explores whether students draw their model as a "process" or a static state. (Russ et al., 2008).	No Temporal chaining, a static stage (0), Having relationship with time or a "process" with steps (1). There is no 2.
C	Scientific explanation	Looking for formal scientific explanation of the phenomenon: The variables participating in the osmosis process, and their interaction with each other.	No explanation (0), an incomplete or wrong explanation in which they mention only a single factor and may have used concepts imprecisely (1), A more elaborated scientific explanation including several sentences and used all chemical concepts correctly (2).
D	Communication	Examining whether the design of the model is communicative/clear to others.	No label or text near the drawing (0), Student add word/words to the drawing or arrows (1), students describes the movement of particles in a sentence or more they also add arrows and labels to their drawings (2).

Data and discussion

Data is discussed here under two main headings: 1. Learning outcomes related to content and meta-modeling knowledge. 2. Students' model drawings assessment using the rubric.

1. Content & meta-modeling knowledge

Table 2: below summarizes the results from the paired Wilcoxon signed-tests:

Table 2. Results from the pre and posttest

	BMF-with-design			BMF-no-design			Control		
Task	Diff	% Diff	p-val	Diff	% Diff	p-val	Diff	% Diff	p-val
Content	1.81	15.1%	*0.0019	2.43	20.3%	*0.00048	0.04	0.3%	0.93
Modeling	1.29	10.8%	*0.0056	0.78	6.5%	0.21	-0.36	-3.0%	0.29

According to the results only in the BMF-with-design condition, the differences between the pre and post-test are statistically significant for both content and meta-modeling knowledge (content: $p < 0.0019$, meta-modeling: $p < 0.0056$).

2. Students' model drawing

We use the developed rubric to examine model-based reasoning on the basis of student drawings. The graph below represents the average grade differences in learning gain for each condition. The following are the four categories constituting the rubric:

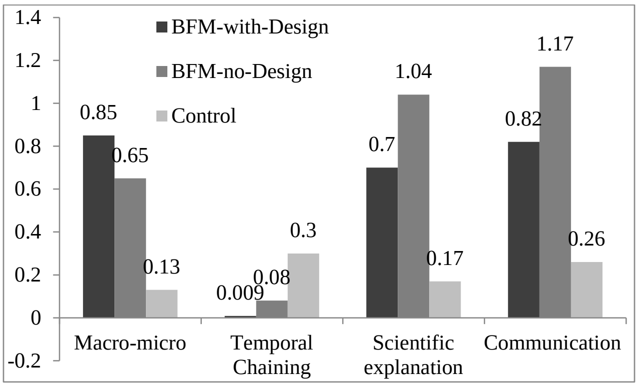


Figure 3. Difference in model drawing for each condition according to the rubric

- *Macro to micro level:* The transition from macro level to micro level is unappreciable in the control group, yet students who designed their own model improved considerably in this category, as did the students who interacted with models without designing them.
- *Temporal chaining:* The "temporal chaining" category, examines the students' sense of temporal progression and connection between sequential events and their ability to construct a step-by-step story of a scientific process. For this category, both BMF groups showed no gain at all, while the control group improved considerably.
- *Scientific explanation:* this category showed a large gain in both BMF groups, with the highest score in the BMF-no-design group. This suggests that students in this condition were able to offer a better formal explanation of the scientific phenomenon.
- *Communication:* This category showed a large increase for both BMF groups. However it was interesting to see that the BMF-no-design group received the highest score in this category. When students in this group understood the reasoning behind the experiment and

could explain it formally, they began adding more labels, arrows, and content-related descriptions to their model.

The drawing below was selected as a representative example for the **BMF-with-design** condition. In this group students produced a rich, detailed model that displayed the interactions of particles and molecules' interaction as well as their movements on the micro level. As shown in the graph from the above section elaborating our rubric's categories, students in this group were better at drawing the molecular level of the phenomenon, but were less productive providing formal, written explanations.

Mike's model: In the pretest Mike's model consisted of a simple drawing of an anthropomorphic egg (A = 1). It depicts only a single state, and does not represent a temporal process to describe how and why the egg's mass changed over time (B = 0). No scientific explanation is mentioned regarding the process. In addition to this general drawing, he simply wrote "they move," with no further specification or explanation regarding what should be moving or why (C = 0). Finally, he provided no labels, arrows, or any kind of description (D = 1). On the other hand, Mike's post-test resembles more closely a scientific model, in which he dove in at the molecular level with details regarding the particles and their size (the sugar molecules are bigger) (A = 2). There is still no sense of any temporal sequence or timeline (B = 0). Mike wrote that "Sugar doesn't leave, but new sugar can't come in. Only water can, water can also leave," but he does not mention the mass change, i.e., the egg becoming heavier. However, he does explain the movement of the two types of molecules that participate in this process. In his explanation he elaborates that sugar molecules cannot go through the membrane (C = 2). His drawing includes labels for the water and sugar molecules and arrows that show the direction of particle movement into the egg (D = 2). From pre- to post-test, for Mike, there is a marked improvement in the design and understanding of the scientific process. The main differences before and after are the awareness to the microscopic level and the scientific explanation that was added to the drawing. This model was ranked with our rubric as 2 out of 7 on the pre-test and as 6 out of 7 on the post-test.

This type of quantitative analysis was conducted for all drawings and exemplifies in details the changes in drawing for each condition.

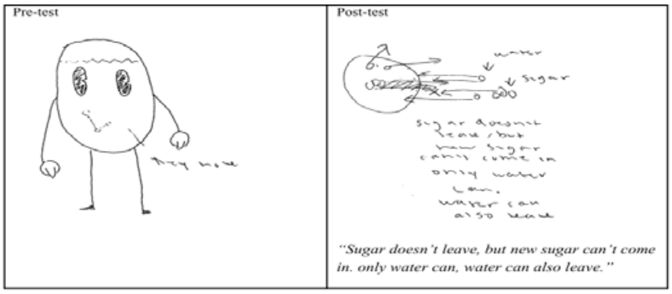


Figure 4. Mike's pre- and post-test models BMF-with-design

Summary and conclusion

This study describes the use of the Bifocal Modeling Framework (BMF) as a way to engage high school students in learning about diffusion and osmosis and constitutes one of the first attempts to implement it in a school setting within the constraints of a typical science class. As part of this study we developed a rubric for assessing model-based reasoning on the basis of student drawings. The BMF curriculum was significantly more effective in increasing students' knowledge of osmosis than the unenhanced traditional approach utilized in the control group. Either by designing the model or manipulating premade models, students were able to explore and develop ideas in greater depth. Analysis of model drawings correlated closely with the MCQs results; improvement occurred in student model designs in both BMF implementations.

Students in the BMF-with-design group scored the highest in the macro to micro-level category. It appears that engagement in a design process on paper led to increased focus on micro-level behaviors. Without the model design, students in the other groups were less aware of the molecules and the elements constituting the system. In the BMF-no-design condition, the relatively low gain in the macro to micro-level category was compensated with the highest gains in two categories: 1. "Scientific explanation", and 2."Communication". The results suggest, first, that there was a relationship between students' understanding of the content and their willingness to add labels, arrows, and descriptions to their drawings. Second, the results might indicate that the time not spent designing the model, and exploring the pre-made model instead, has converted into higher learning gains in more conventional areas such as explaining the phenomenon and building a complete diagram. Further, it is interesting to see that as for the rubric's "temporal chaining" category, which measures student's ability to understand the propagation of causality in physical processes along temporal sequences, both BMF conditions showed no gain at all but a gain was evident in the control group. The results might indicate that both BMF groups required emergent, dynamic sense making that might have prevented students from focusing on the macro-level timeline and the process. In terms of meta-modeling knowledge (Schwarz & White, 2005), the improvement was statistically significant only for the BMF-with-design condition. It seems that the extra time spent designing a model (even a simple model on paper) was reflected in higher meta-modeling learning gains. During the multistep design process of the model, students embraced the role of model-designers. This experience of perspective-taking (Ackermann,1996) engaged them with challenges from a designer's view of the process. The insights inspired them to consider the limitations and advantages of models and, to become aware of the underlying assumptions of models in general terms—which was not possible with pre-made models. It may be that exposing students to computer models, in isolation, without time devoted to model design (even if only conceptually), teaches students a partial lesson. As a consequence, while they might understand the content quite well, they would gain no understanding of the deeper nature of science as a model-building activity. We believe this would be an important direction for research, and one that would increase understanding regarding the use of models in science classes.

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