"You Evaporated?" vs. "It Escaped": A Comparison of Students' Reasoning about Vaporization when Using Participatory and Non-Participatory Simulations

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Abstract

This study compares learning with a participatory simulation in which students play the role of particles in a fluid, and that of others who use the more common modality of model manipulation and observation. We explore the particular contributions of each modality for learning about phase changes in the context of the particle model of matter. We find that the participatory modality of simulation provides significantly greater learning gains in building some of the concepts - those related to inter-particle interactions and heat transfer. Other ideas were developed to a similar extent in both conditions.

Keywords: particle model of matter, complex systems, role-playing, participatory simulations**.**

Introduction

Role-playing is used to explore mechanisms in complex systems by putting the learners *inside* the model they investigate (Resnick & Wilensky, 1998). Role-playing can be used to study diffusion, or phase change (Strgulc Krajšek & Vilhar, 2011; Tsai, 1999) and has demonstrated positive effects on learning, compared to traditional, lecture-based settings (Tsai, 1999). Role-playing has also been used in computational environments where students are represented by avatars on the screen (Wilensky & Stroup 1999; Colella, 2000, Lindgren & Moshell, 2016). A major advantage of using computational environments instead of role-play without a computational component, is the built-in algorithm in the former, that can be used to compute the global properties of the system based on the actions of the individual agents. Such environments are often named *participatory simulations,* since the emergent behavior of the system is simulated based on the actions of the users who participate in it.

Despite the promise offered by role-playing for teaching science, its use in schools is limited. The much more common modality for learning about complex systems, is using dynamic computer models as demonstrations or as inquiry-based materials (Levy & Wilensky, 2009). Researchers argue that computer model exploration is more beneficial to learning than textbook-based or lecture-based instruction, when integrated into the curriculum properly (Smetana & Bell, 2012). The central advantage of computer models over textbooks results from their dynamic depiction of the mechanisms that induce change and explain patterns in the overall phenomenon.

In this study, we compare the learning of science concepts through two modalities: *participation* in a social simulation versus the more prevalent individual exploration and *observation* of models. We used the NetLogo computational environment (Wilensky, 1999) to create participatory and non-participatory simulations that model the liquid to gas phase transition. In the participatory simulation, students control and observe their individual avatars on their own computers, while in the non-participatory simulation, the students observe and manipulate the global properties of a computational model. In comparing the conditions for learning in these two modalities, we draw the following distinctions (Table 1). By presenting evidence regarding the relative strengths of each modality, we wish to accelerate the conversation regarding designs for learning about complex systems and promote a greater alignment between learning goals and designs.

Table 1. Comparison of participation in a simulation and manipulating a model

	Participating in a simulation	**Manipulating and observing a model**
What does the learner control?	Micro-level individual agent actions	Macro-level global variables or micro-level rules for all agents
Where is the user positioned?	Participant: Part of the model	Observer: Outside of the model
Where is the computation?	Shared between the participants and the computer	In the computer

Design

The MeParticle WeMatter participatory simulation (Langbeheim & Levy, 2016) was designed to support learning about phase change by having the students play the role of particles. As they move about and interact with other particles the forces are continually computed and result in emergent patterns in the global properties, such as cluster-formation and dissociation.

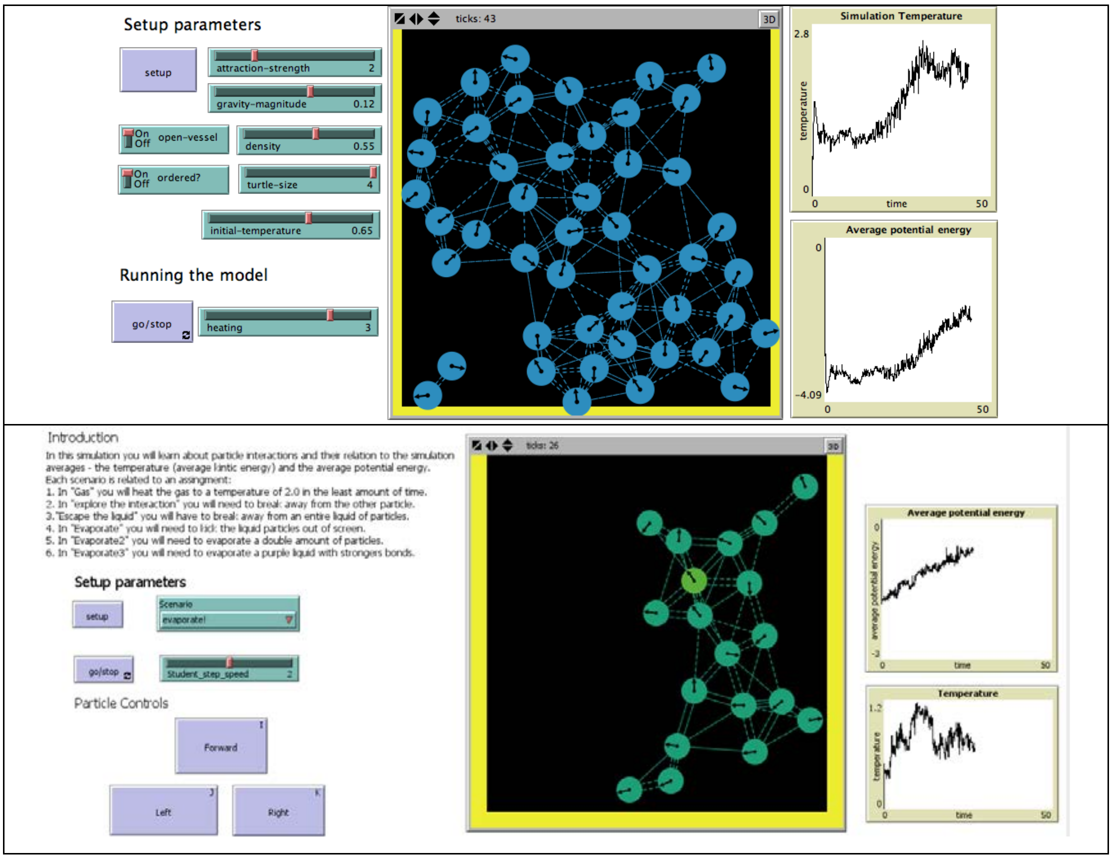

Figure 1. Screenshots of the computer model (top) and the participatory simulation (bottom). Both displays include the simulated system, the temperature, and the average energy graph are shown on the right. In the participatory simulation, the turquoise particles are controlled by the computer and the green particle is an avatar controlled by a student. The control keys are shown on the left side of the panel.

The particles are represented as circles with an arrow indicating the particle's direction of motion. The inter-particle attractive forces are represented as dashed lines with varying width that represent their strength (Figure 1). The force cutoff is taken to be 2.5 times the diameter of the particle, which is a common approximation in such models (Frenkel & Smit, 2002). The energy of the system changes when individual particles "kick" other particles and change their velocity.

We hypothesized that the increased attention students devote to interactions of individual particles in the participatory modality will result in a more nuanced mechanistic understanding of vaporization.

Methods

Our study employed a mixed-method approach, using quantitative analysis of questionnaire data and qualitative interpretation of classroom conversations. A quasi-experimental pretest-intervention-posttest comparison-group design was used. Four 8th-grade classrooms in a public school in the Phoenix metro area participated in this study. The population of the school was 47.5% Hispanic, with 69.5% of the students entitled for free or reduced lunch. Two classrooms (N = 60) were assigned the condition in which they used the participatory simulation. Two other classrooms (N = 59) were assigned the participatory condition, in which students explored a particle model, where they could vary the properties of the system such as the number of particles and the bond strength using sliders but did not have control over individual particles. All four classes learned with the same teacher, and the differences between average science grades in the two groups were insignificant. Each of the four classes participated in a weeklong learning unit. The learning unit included an experiment in which the temperature of water was measured during heating and boiling. This phenomenon was related to the particle model through interacting with the simulations (participation or observation modes), a short lecture, homework problems and in-class worksheets.

Identical pre- and post- conceptual knowledge questionnaires were developed. They include 11 items that span the following concepts: (1) the interactions among particles decrease in magnitude when particles move away from each other; (2) the system-temperature is proportional to the average speed of the particles; (3) the boiling point is proportional to inter-particle forces; (4) heat conduction is caused by molecular collisions through the liquid boundary. The lessons were audio-taped and transcribed for later qualitative analysis.

Analysis

Student answers to the conceptual knowledge questionnaires were coded based on the number of scientifically correct ideas expressed even if the answer contained also some problematic propositions. For example, in the answer : "*The water molecules have reached its boiling point* so *it stays at that temperature and the molecules continue to move around rapidly like they did before*." The student expressed the correct idea that the molecules continue to move at the same (average) speed during phase change, but incorrectly stated that the individual particles reach boiling point, when, in fact the boiling point is a collective property of the entire system. The correct idea in the answer counted for one point (out of two) in the scoring rubric. The two authors of this paper reviewed 20% of the answers independently. The inter-rater agreement was 80%, a discussion removed some of the disagreement, and the final agreement was 90%.

Findings

Table 2 illustrates two representative segments from students' activities during both participatory and non-participatory modes of exploring the simulation. These vignettes aim to capture key features that characterize and distinguish between the activities: students' sense of being part of the model, the teacher's role, the extent of interactions among students and the playfulness of the simulation activity.

Table 2. A comparison of student talk in each condition

Participatory Simulation Condition	Non-Participatory Simulation Condition
Student 1: Get off there! Go go go! Student 2: You evaporated? - Student 1: Yea.. Student 2: Hahahaha Student 1 (re-starts the simulation): Yooooh, charge! Student 2: Push! Go under!	Student B: How did you do this? Student C (background): Wooo, wooo Students giggling in the background Student A: ok, let's start. And… Student C : haha Student A: there we go… Student B: look what he did. Hihihi Student A: it (the particle) escaped, escaped!

These excerpts indicate the playfulness of both environments as laughter intermingles in both conversations. The main distinction between the two conversations is the students' sense of being part of the model: In the first, student 2 asks "you evaporated?", representing the student's role as a particle in the simulation. In the right column, student A says "it escaped" referring to the particle "escaping" from the fluid which he observes as a separate entity on the screen. The different perspective, represents the major difference between the ways students utilized the simulation in each condition.

In terms of learning, significant gains from Pre to Post-tests were indicated in both groups. Table 3 shows that the treatment group who used the participatory simulation had, on average a larger gain from pre-test to post-test, whereas the comparison group who used the non-participatory simulation had a smaller gain. T-tests reveal that this difference is significant.

Table 3. Mean Student scores on the pre-test and post-test

	Participatory model exploration (n=52) mean (sd)	Non-participatory model exploration (n=50) mean (sd)	p-value (t-test)
Pre-Test	3.71(1.89)	3.02(2.14)	0.091
Post Test	6.65(2.22)	5.28(1.86)	0.001

ANCOVA analysis shows that the effect of treatment on post-test score is significant even when controlling for the pre-test score as a covariate ($F(2) = 8.14$ $p = 0.005$). There is a moderate effect size of $\eta^2 = 0.076$ attributed to the difference in the participatory compared to the non-participatory group

A fine-grained analysis of the questionnaire data revealed that students who used the participatory simulation made significantly greater progress in conceptualizing the properties of the particle level interactions (Concept 1). In addition, they made significantly larger progress in explaining heat transfer using particle level collisions (concept 4). In the other aspects, namely, relating particle-speed and system-temperature (concept 2); and relating boiling point to inter-particle forces (concept 3) both groups made similar progress.

Conclusions and implications

The comparison revealed a significant advantage in learning gains for the participatory simulation condition with respect to the non-participatory model-exploration one. It is important to note limitations to this type of learning. While understanding of the particle level motion and interactions increased, understanding more sophisticated ideas such as the relationship between particle motion and the steady temperature during phase change was expressed by only a small portion of the students. Understanding this idea requires more scaffolding in coordinating between the micro- and macro-levels of the emergent processes.

References

Colella, V. (2000). Participatory simulations: Building collaborative understanding through immersive dynamic modeling. *The journal of the Learning Sciences*, *9*(4), 471-500.

Krajšek, S. S., & Vilhar, B. (2010). Active teaching of diffusion through history of science, computer animation and role playing. *Journal of Biological Education*, *44*(3), 116-122

Langbeheim, E., & Levy, S. T. (2016), ConfChem Conference on Interactive Visualizations for Chemistry Teaching and Learning: Learning by Being – Playing Particles in the MeParticle–WeMatter Simulation, *Journal of Chemical Education*, *93*(6), pp 1145-1147

Levy, S. T., & Wilensky, U. (2009). Students' learning with the Connected Chemistry (CC1) curriculum: navigating the complexities of the particulate world. *Journal of Science Education and Technology*, *18*(3), 243-254.

Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education*, *95*, 174-187.

Resnick, M., & Wilensky, U. (1998). Diving into complexity: Developing probabilistic decentralized thinking through role-playing activities. *The Journal of the Learning Sciences*, *7*(2), 153-172.

Smetana, L. K., & Bell, R. L. (2012). Computer simulations to support science instruction and learning: A critical review of the literature. *International Journal of Science Education*, *34*(9), 1337-1370.

Tsai, C. C. (1999). Overcoming junior high school students' misconceptions about microscopic views of phase change: a study of an analogy activity. *Journal of Science Education and Technology*, *8*(1), 83-91.

Wilensky U (1999) NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Wilensky, U., & Stroup, W. (1999). NetLogo HubNet Disease model. [computer software] Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University.