Implementing Multi-Agent Modeling in the Classroom: Lessons from Empirical Studies in Undergraduate Engineering Education

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This paper reports on a four-year empirical study of MaterialSim (Blikstein & Wilensky, 2004), an undergraduate material sciences learning environment based on multi-agent computer modeling built in the NetLogo (Wilensky, 1999b) simulation environment. This design-based research builds on previous studies that have suggested the benefits of complex systems, multi-agent and/or cellular-automata simulation for understanding how a variety of complex behaviors in science derive from simple, local rules (Langton, Minar, & Burkhart, 1995; Wilensky, 1999a; Wilensky & Reisman, 2006; Wilensky & Resnick, 1999; Wolfram, 2002). The design of MaterialSim emerged from a literature review on engineering and materials science education (e.g., Hurst, 1995; Lamley, 1996; Russell & Stouffer, 2005; Thornton & Asta, 2005), classroom observations, and extensive interviews with students. Our observations, supported by the literature review, indicated that students' understanding of the subject matter was problematic, and that the conventional teaching strategies and resources were not up to the challenge of the content being taught. Particularly, university-level Materials Science is exceptionally complex and interconnected, but the traditional teaching strategies are fragmented and "linear": Students are presented with different scientific phenomena, one at a time, with their respective sets of equations and mathematical models. In this "many-to-one" framework, many context-specific equations and models are necessary to explain one single phenomenon. The result, as our studies have suggested, is fragmented, overly specific, and inflexible knowledge, which students cannot utilize to explore new areas within the subject matter.

MaterialSim's design, conversely, follows a "one-to-many" framework (Blikstein & Wilensky, 2006), in which students are led to identify, by exploring previously-built NetLogo models, some common principles across entire content sections of a course. These few principles can be used to understand *many* different phenomena. After having mastered those basic principles, students are asked to author a new computer model of their choice. A core feature of this design, then, is that students can apply a small number of models to capture fundamental causal structures underlying behaviors in a range of apparently disparate phenomena within a domain. For example, the free-energy minimization model allows students to understand crystal nucleation and growth, solidification, annealing, recrystallization, phase transformations, diffusion, and many other phenomena in Materials Science, which are traditionally taught as separate topics, each with their own models.

Four user studies were conducted, in 2004, 2005, 2006, and 2007, with a total of 39 Material Science undergraduate students enrolled in an introductory Materials Science course. The first three studies were conducted in the lab, but the last study took place in a regular classroom, as a for-credit assignment. In this last implementation (n=18), each student was assigned the task of programming an agent-based model of any relevant topic in the course, run the model, collect data, and compare their results with published data. Students were given one month to complete the assignment and took approximately 20 (± 6) work-hours on average to complete it. Students were observed during three activities: learning the NetLogo language, learning how to build computer models with NetLogo, and running/analyzing multi-dimensional experiments with their own models. We videotaped all student sessions and captured their computer interactions. The first author also attended the Microstructural Dynamics undergraduate course, collected and analyzed class materials and related literature. At the end of the quarter, students filled up questionnaires about their motivation, their modeling experience, and time investment in different phases of the project.

The data demonstrate the usefulness of the complex systems perspective infused into MaterialSim design. All 18 students were able to successfully complete their models and data validations, most of which were able to identify agent rules with applicability in more than one phenomenon, and students' self-reported ability to create computer models increased significantly. We posit that, whereas the conventional, many-to-one approach leads to the accumulation of inert models, the one-to-many multi-agent simulation approach provided students with useful generative models to reflect on the unifying principles of the phenomena studied, and enabled them to build new models. However, the environment in an undergraduate engineering course presented challenges not present in the lab studies we had previously conducted. For example, issues such as time investment, intrinsic/extrinsic motivation, the usefulness (for students) of learning a new computer language, and the perceived usefulness of the activity to their school performance had to be constantly negotiated. From this experience, we identified design principles and important challenges for researchers making the transition from complex-systems-in-the-lab to implementations in regular classrooms.

Selected References

Blikstein, P., & Wilensky, U. (2004). *Materialsim: An agent-based simulation toolkit for learning materials science.* Paper presented at the International Conference on Engineering Education, Gainesville, Florida, USA.

Blikstein, P., & Wilensky, U. (2006). *From inert to generative modeling: Two case studies of multiagent-based simulation in undergraduate engineering education.* Paper presented at the Annual Meeting of the American Educational Research Association, San Francisco, CA.