Mathematical modeling with NetLogo: Cognitive demand and fidelity

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Abstract

The main goal of this paper is to present the case for a futuristic look at mathematical modeling that permits students to broadly explore models facilitated by technology that supports exploration of realistic constraints. Dynamic modeling available with the NetLogo environment may engage students at higher levels of cognitive demand, while maintaining mathematical, cognitive, and pedagogical fidelity. Some specific features of the NetLogo environment will be shared to highlight the mathematical, cognitive, and pedagogical power of this agent-based embodiment-modeling tool.

Introduction

> The relationship between mathematics and reality has always been both intricate and intriguing, as much complicated as interesting to deal with… [We may] never be able to analy[z]e it completely and thoroughly… [however] the increasing power of computers as manipulators of numbers, then symbols, then images… [accompanies] an increase in empiricism within mathematics, liberat[ing] …reliance on analytical solutions, and [bringing] new forms of modeling and representation. (Bonotto & Basso, p. 385)

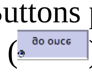
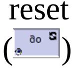
Whereas new technological innovations become available with a relatively rapid pace, the impact of the technology in the mathematics classroom continues to lag behind (Abdullah, 2007; Pearce & Stacey, 2001). While animation tools available in computer algebra systems, applets, *Geometer's Sketchpad*, *Cabri Geometry*, electronic spreadsheets, and other utilities facilitate the dynamic exploration of mathematics and mathematical models, modeling environments such as NetLogo facilitate a more comprehensive attention to constraints associated with realistic complex social systems.

Mathematical modeling uses mathematics as a tool to study complex phenomena in a non-linear approach from fields outside of mathematics in an attempt to make mathematics more meaningful (Abrams, 2001; Carreira, 2001; Zbiek & Conner, 2006). However, the breadth and depth of what mathematical modeling has to offer has typically not been realized in school mathematics due, in part, to a preference to relegate experiences to the controllable, predictable, and context-simple (Jacobson & Wilensky, 2006). Freudenthal warns "viewing context as noise, apt to disturb the clear mathematical message, is wrong; the context itself is the message, and mathematics a means of decoding" (cited in Bonotto & Basso, 2001, p. 388). Thus, when opportunities for mathematical modeling focus more on mathematics that is void of social contexts, many challenging and potentially exciting skills such as identifying assumptions under which mathematical operations are appropriate; challenging established theories; determining ways to represent real-world situations mathematically; and recognizing common structures may often be ignored in the traditional mathematics classroom (Abrams, 2001; Carreira, 2001; Wilensky & Reisman, 2006). For example, participants engaged in modeling with NetLogo in a biological context reasoned both forwards and backwards as they constructed theories and deduced consequences of theories "searching for confirming-disconfirming evidence" (Wilensky & Reisman, 2006, p. 172). It is these kinds of experiences we promote for the mathematics classroom in the 21st century, and hence we support Abrams (2001) in suggesting that we "move toward curricula that teach mathematics as a tool both for solving important problems from other disciplines and for making beautiful abstract discoveries" (p. 269). Thus, we join Wilensky and Reisman in their argument for using NetLogo as an agent-based "embodied modeling approach [that] connects more directly to students' experiences, enabl[ing] extended investigations as well as deeper understanding, and enabl[ing] 'advanced' topics to be productively introduced into the high school curriculum" (p. 171).

In the context of mathematical modeling we will highlight a blend of theoretical and conceptual frameworks that bring together characterizations of fidelity constructs of mathematical tasks and levels of cognitive demand (Henningsen & Stein, 1997). The fidelity constructs refer to the degree to which the mathematics explored in these modeling environments remains faithful to the mathematics content to be learned, the cognitive engagement of the experience, and the pedagogical goals set forth to enable the conceptual understanding of mathematics. The levels of cognitive demand of interest in mathematical modeling are basically the high levels identified by Henningsen and Stein: engaging in procedural tasks with connections to conceptual mathematics, or actually *doing* mathematics. When students are engaged in doing mathematics characterized by high-level tasks the learning typically has "not occurred in a vacuum; …multiple solution strategies, multiple representations, and mathematical communication [is evident; and] …thinking processes …[extend] to complex thinking and reasoning strategies" (Henningsen & Stein, pp. 525-526).

NetLogo: A Brief Introduction as a Modeling Environment

NetLogo, a programmable modeling environment, which uses Java and a version of the Logo programming language (Papert, 2007) was authored by Uri Wilensky (1999). The term NetLogo is appropriate since it is a dialect of Logo which provides for a networked operation in two basic contexts: (a) HubNet, a network environment that allows for individual participants/students in a classroom to take part in a simulated activity designed with the NetLogo language; and (b) an interconnected, decentralized nature of the phenomena that can be modeled (Wilensky, 1999). Specifically NetLogo supports work in the field of complex systems, which can include such notions as fractals and dynamic demonstrations of real-world social, political, physical, and biological science phenomena.

The basic operational screen of NetLogo is the *interface window* (Fig.1), which typically includes a *graphics window*; one or more *plotting windows*; options for a three-dimensional view of the graphics window; and buttons, sliders, and switches as needed. Figure 1 shares a specific model of the percolation of an oil spill through soil identified as 50% porous. The system parameters enable the porosity probability variable to be manipulated by a slider to range from 0.0% to 99.0%. Buttons permit the user to reset the graphics window and run the model either one step at a time () or continuously ().

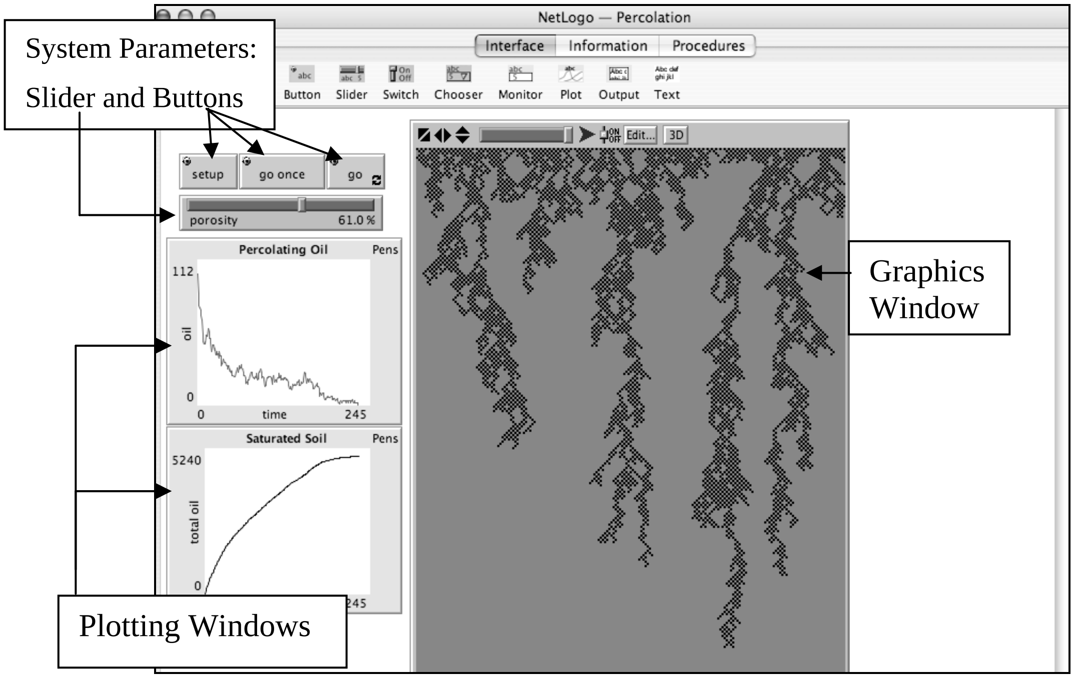


Fig. 1. The percolation interface window contains system parameters and plotting and graphics windows.

Cognitive Fidelity. Cognitive fidelity refers to a faithful representation of the authentic and natural in the mathematical model (McDaniel et *al*., 2007). NetLogo includes an increasingly growing Model Library of examples of mathematical models from various social, political, scientific and mathematical perspectives, which permit users to explore many of the constraints of authentic phenomena. For example, in the model depicted above (Fig. 1) the dual representation in the plotting windows helps students to see how the increase in the probability index of oil percolation compares with the saturation of the soil. Consider the excitement in a high school classroom in which a study of probability includes such an authentic scenario along with the simple coin and die toss experiments. Here, with an element of excitement, students get an opportunity to explore the content of probability in ways that facilitate higher levels of cognitive demand in a realistic context.

In the interface window students are able to directly observe interactions impacted by the changes of variables and other constraints as buttons, sliders, and switches are manipulated. The graphics window helps students to synthesize the relationship between the changes in those parameters and the visual representation of the subsequent interactions. If the HubNet participatory simulation option of NetLogo is employed, students may also *join* the model as a single "agent" represented in the graphics window. (Note: HubNet simulations use a networked computer or networked calculator system such as the TI-Navigator. See http://education.ti.com/educationportal/sites/US/productDetail/us_ti_navigator.html.)

Pedagogical Fidelity. Pedagogical fidelity refers to an operable alignment between the original intent for teaching and students' subsequent learning. Zbiek and Conner (2006) identified some components in the mathematical modeling process, which may also be deemed as critical to achieving pedagogical fidelity. The process includes attention to skills and actions for which the teacher should play a role as students engage in mathematical modeling: exploring to gain new information and observing mathematically to describe it; specifying conditions and assumptions, then mathematizing the properties and parameters; combining the new information that matches with the properties and parameters, then highlighting, interpreting, and examining as needed to determine a good fit between the model and the real-world phenomenon. To assist the classroom teacher in use of the model to facilitate instruction in a powerful way as just described, the NetLogo environment, accompanies the *interface window* with an *information window* for the interested user. The *information window* (Fig. 2) shares documentation identifying the essence of the model, how to use it, things to notice, tips for extending the model, NetLogo features embodied in the model, related models, credits, and references.

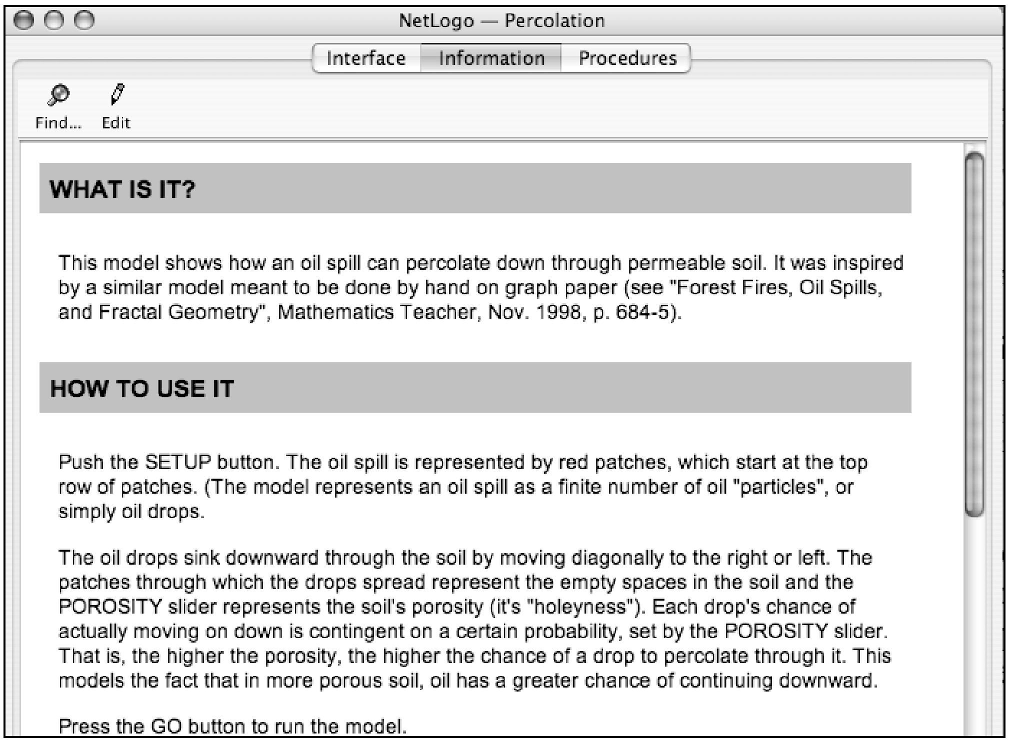


Fig. 2. The information window contains information about the design and implementation of the model.

For users who are curious about the programming of the model, whether they wish to revise some of the coding, or simply gain insight on the manner in which the model was programmed, NetLogo provides a *procedures window* (Fig. 3) just a click away from the interface window. “NetLogo stresses natural language programming, and …[with the use of] the on-line tutorial many students are able to design novel models in less than a week… Moreover, the procedures listed in the procedures window are fully annotated with concise comments that explain how the particular code used results in the observed behavior of the interface window” (Steiff & Wilensky, 2003, p. 289).

<u>Content Fidelity</u>. Content Fidelity addresses the faithfulness of the embodiment with regards to the behavior and properties of the chosen mathematical concepts. Students who gain facility in writing the NetLogo code must call upon their knowledge of mathematical concepts in ways that involve them in actually doing mathematics, as they must use procedures that connect mathematical concepts to rather unique real-world situations. Although an investigation of the code certainly brings a closure connection to the mathematical concepts, students who choose to ignore the programming code will still benefit from the manipulation of the system variables to

gain increased understanding of the mathematics in the model. Zbiek and Conner (2006) suggest the use of the term "curricular mathematics" to identify the mathematics content that students are expected to learn in the classroom—separate from the study of mathematical modeling. They further suggest that close scrutiny of this type of mathematics requires a look at the underlying assumptions about how students acquire an understanding of the mathematics that may be learned while engaged in mathematical modeling activities. With a background of support from Neo-Vygotskian sociocultural perspective and Moschkovich's discursive perspective, Zbiek and Conner, provide an avenue for supporting content fidelity as their research highlighted opportunities for learners to challenge their previously held notions about mathematical concepts, and add new or revised knowledge based upon their experiences with an episode of mathematical modeling.

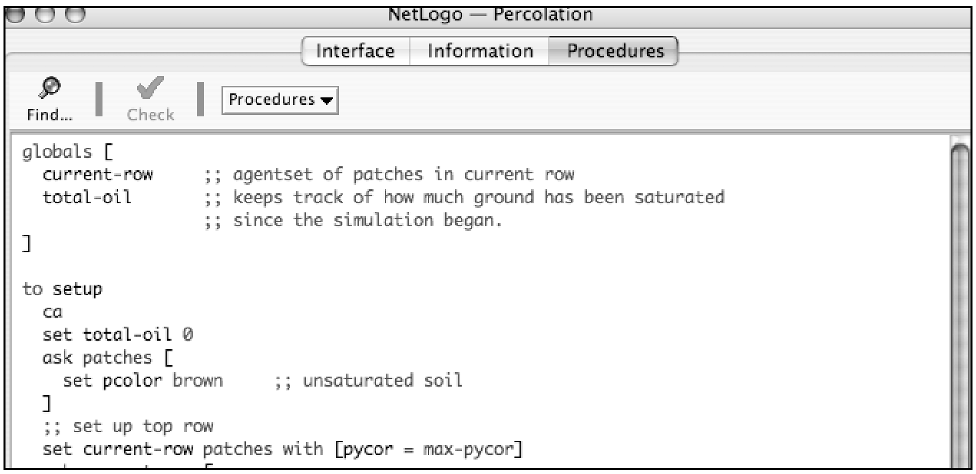


Fig. 3. The procedures window shares annotated programming code for the model.

Conclusion

The mathematical modeling experiences provided with NetLogo models engage students in doing mathematics, while maintaining fidelity in mathematical content, cognition, and pedagogy. As educators become more aware of this productive tool the potential for the development of more models specifically appropriate for the mathematics classroom may be realized.

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