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Evolution of an Integrated Technology for Supporting Learning about Complex Systems

David A. Joyner, Ashok K. Goel, Spencer Rugaber
Design Intelligence Laboratory, School of Interactive Computing, Georgia Institute of Technology
Atlanta, Georgia 30308
david.joyner@gatech.edu
{goel, spencer}@cc.gatech.edu

Cindy Hmelo-Silver[1], Rebecca Jordan[2]
Graduate School of Education[1]
School of Environmental and Biological Sciences[2]
Rutgers University
Newark, New Jersey
cindy.hmelo-silver@gse.rutgers.edu
jordan@aesop.rutgers.edu

***Abstract*—In this paper, we describe the evolution of an interactive technology called the Ecological Modeling Toolkit (EMT) that supports learning about complex ecological systems in middle school science. Authentic learning of science is facilitated by imitation, rehearsal and understanding of real-world scientific practices such as observation, experimentation, problem formulation, hypothesis testing, and model construction and revision. We illustrate how the tools in EMT work together to support many real-world scientific practices such as model construction, simulation and revision, and scaffold others such as observation, problem formulation and hypothesis testing.**

Keywords-educational technology, complex systems, science inquiry.

I. INTRODUCTION

Authentic science learning is facilitated by imitation, rehearsal and understanding of real-world scientific practices [5,6]. This suggests introducing students to the symbiosis among the various elements of scientific inquiry such as observation, experimentation, problem formulation, hypothesis testing, and model construction and revision. In science classrooms, this kind of science learning is situated in the interactions among the teacher, the students, the curriculum, and, increasingly, interactive technologies. Many of these interactive technologies may support a specific task, such as simulation for experimentation.

Scientific inquiry, however, is an iterative process such that these individual tasks do not exist separately from one another: they are inextricably intertwined so that the results from one process feed the others, which feed back again. For example, when observing a system, the observations one makes guide one's understanding of the system, and that understanding, in turn, continues to guide one's further observation of the system. Thus, rather than designing specific tools that address specific needs, it is important to design entire patterns of interaction and reasoning that address broad sets of goals [5,6]. Similarly, there must also be integration between the software and the curriculum as a whole, such that the software environment only exists to play some role in the classroom activity [3].

In this paper, we describe the evolution of an interactive technology called the Ecological Modeling Toolkit (EMT) that supports learning about complex ecological systems in middle school science. Looking back, we see that what was initially a collection of tools, each aimed at a particular task, such as providing background knowledge or facilitating experimentation, has the potential to support several real-world scientific practices like model construction, simulation, and revision, and scaffold others such as observation, problem formulation, and hypothesis testing.

II. REPTOOLS: HYPERMEDIA AND SIMULATION

The origin of the EMT project lies in the InteractiveKRITIK project at Georgia Tech in the mid-nineties that proposed use of Structure-Behavior-Function models for learning about complex systems [1]. Starting around 2000, empirical studies at Rutgers University showed that while aquaria experts and hobbyists understand aquaria in terms of their structures, behaviors and functions, novices focus on visible structures and show little understanding of functions and behaviors [2]. Thus experts on a system do not solely know more about the system, but that they have a different *kind* of understanding

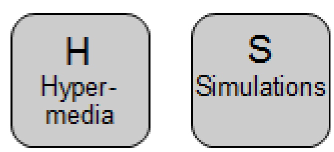

Figure 1. Illustration of the two initial components of RepTools.

This led to the design of a software tool called RepTools. RepTools comprised two tools: an interactive hypermedia [4] and a set of NetLogo simulations [8]. The hypermedia served as a virtual textbook where students could read about the various processes at work in an aquarium. Most importantly, the hypermedia presented its information with an emphasis on understanding invisible processes and how those processes led to observable trends at a higher level of abstraction. The NetLogo simulations provided an experimental environment where students could manipulate a virtual aquarium designed by experts. With these simulations students could control various variables to observe trends in the aquarium's behavior. Because this was just a simulation, students could experiment in ways that would be unfeasible with a real aquarium. Students could intentionally over- or under-populate the aquarium to observe what would happen, and could collect observations that would require several months with an actual aquarium. Figure 1 illustrates the two individual components that comprised RepTools.

III. ACT 2.0: Adding Modeling

RepTools, however, did not support construction of knowledge, for example, construction of Structure-Behavior-Function (SBF) models of aquaria. In order to add support for model construction into RepTools, we created ACT: the Aquarium Construction Toolkit. Like RepTools, ACT served as a suite of tools to facilitate scientific inquiry on aquaria. The interactive hypermedia and the simulations remained, but ACT 2.0 added two new components: a model construction tool named SBFAuthor, and an electronic notebook [7]. Figure 2 illustrates the four components of ACT 2.0.

SBFAuthor was designed to support construction of SBF models. Students were to model physical relationships between visible structures of the system, invisible behaviors that showed variable changes within the system, and (observable) functions or outputs of the system. SBFAuthor is one example of a *modeling tool*; a modeling tool, broadly, is a user interface that facilitates the construction, manipulation, formalization, and persistence of a student's present model of how a complex system works. Here, formalization takes the form of asking students to consider separately the physical make-up of the system, the temporal changes it goes through, and the manifestation of those changes as observable phenomena.

The intention of this modeling tool was to provide students with a place to represent their current understanding of the complex system under a specific framework. However, students did not use the software as we had anticipated. Separating out a model of a single system into three separate parts, in a very short (two-week) unit, proved far too difficult for students to grasp, and instead they spent the majority of their efforts engaging again with the hypermedia and NetLogo. The models that students created did not always reflect an integrated understanding of the simulations and the hypermedia. Our analysis suggested that this was due in part to the way in which the task was presented to students and in part due to the complexity of the technology. Figure 2 illustrates the four components of ACT 2.0, and their initial lack of integration. As a result, it became necessary to simplify the modeling tool.

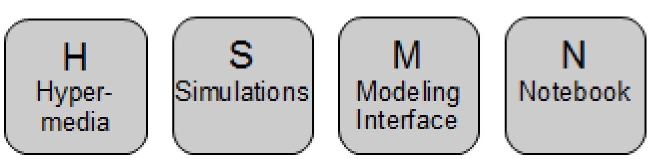

Figure 2. Illustration of the four components in ACT 2.0.

IV. ACT 3.0: Connecting Hypermedia and Modeling

In creating ACT 3.0, special attention was paid to the way in which ACT 2.0 was used in the classroom. Because ACT 2.0's SBFAuthor tool was too difficult for students to use, teachers resorted to a more classic pen-and-paper approach, asking students to brainstorm the various parts and relationships within an aquarium.

ACT 3.0 was created to better facilitate model construction. Students were to identify structures that impacted others, and to state the relationship between them. In addition to a graph-like visualization of this model, students were also given an organizational table to track their progress. ACT 3.0 was also distributed with RepTools' hypermedia and NetLogo simulations.

In use, ACT 3.0 worked much better in the classroom than its predecessor, ACT 2.0. Its simpler modeling view was easier for students to use without substantial advanced instruction, making it better for the short two-week unit. Throughout the unit, students used the modeling tool to externalize and structure their understanding of the material they gleaned from the hypermedia. Figure 3 illustrates the new connection between components of ACT 3.0. Additionally, the research findings from several classrooms using ACT 3.0 indicated, again, that students' understanding became more expert-like over time [7].

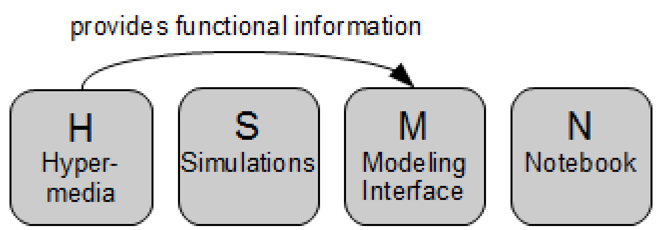

Figure 3. Illustration of the application components and integration in ACT 3.0. The annotation on the line can be read as "Hypermedia provides functional information to the student for use in the modeling tool."

However, ACT 3.0 also began to reveal more subtle and nuanced obstacles to integration. For example, while students used the simulations as an engaging tool for exploring the system, few of the observations were actually represented in their models. While the hypermedia was heavily used in the model construction process, students' reliance on the hypermedia as the authority for the material stifled sense-making; instead, their use of it was as a source of information to copy into the model. Learning still occurred when students restated the hypermedia information in terms of the modeling tool, but it was not the real scientific inquiry ACT was created to foster.

V. EMT: Integrating Hypermedia, Modeling, Simulation and Observation

In order to facilitate greater integration among the parts of the software (and thus, better facilitate scientific inquiry), EMT made the shift of presenting all four tools as prominent objects: modeling, note-taking, simulations and resources (such as the hypermedia) were featured prominently upon program startup.

Integration was also handled by increasing the flexibility of the user interface. In previous versions, the students' workspace was highly restricted: one model at a time, one simulation at a time, one hypermedia page at a time, and one page of notes at a time. EMT opted for a multiple document interface, allowing students to freely open and rearrange all kinds of windows. By allowing students to simultaneously view different types of information at the same time and to customize their workspace as they see fit for the task at hand, we encourage them to integrate multiple resources. By referring to the hypermedia as a "resource" for exploration of the system, we encourage students to view it as a fundamental layer of concepts from which they can explore the system. By more closely linking the simulations with the modeling tool within the interface, we encourage students to view the two as interacting, rather than as disjointed parts of the experience.

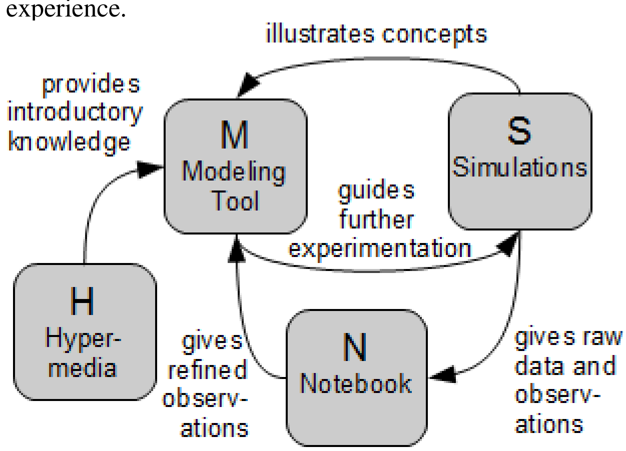

Figure 4. Illustration of the activity and integration in EMT 1.0. The line annotations be read according to the same convention as Figure 3.

EMT was first deployed in Fall 2010 to a middle school in New Jersey. Analysis of the data is on-going; however, based on our early analysis, we have already begun to notice some trends in new ways in which the students integrate multiple portions of the software. The electronic notebook, which has been present in some form since ACT 2.0, has begun to see use as a temporary place for observations about the simulation that are not yet ready to place into the model. Students have begun seeing interactions between substances as relationships that can be expressed in the model, and use of the hypermedia has declined to a more supportive role. Figure 4 illustrates the increased integration and synergy amongst the tools evident in EMT.

VI. Conclusion

In this paper, we traced the evolution of EMT from InteractiveKritik, RepTools and ACT to illustrate how we can design interactive technologies to support authentic learning about scientific modeling. In the beginning, design of these tools focused on addressing individual tasks of scientific inquiry such as experimentation. However, as the tools were used by students, we began to observe that it was not sufficient to design tools that address only specific tasks. In order to facilitate authentic scientific inquiry, we needed to design tools that addressed the entire spectrum of tasks and interactions among the tasks. We do not want to teach students only how to experiment with a simulation or how to read a hypermedia textbook: we want to teach students how these and other activities should be used *together* in the pursuit of scientific knowledge. Toward this end, we needed to design ideal patterns of reasoning in which students would engage, and subsequently design software to facilitate these reasoning strategies.

Moving forward, we can now attempt to abstract some design principles from this analysis. First, the interactive technology needs to support the full patterns of reasoning engaged in scientific modeling, not small, isolated tasks. Toward this end, we have begun to specifically articulate the ideal behaviors that we want students to perform, including model construction, use, and revision. New versions of the software and curriculum are, therefore, specifically tailored to facilitating these overall patterns of behavior. Second, the tools in the technology need to match the tasks at hand; regardless of software design, a major concern will always be the ways in which its usefulness is leveraged and presented in the curriculum.

VII. Acknowledgments

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VIII. Refernces

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