Impact of a Blended Immersive and Computational Modeling Tool on Elementary Ecosystems Science Learning

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Abstract

Integrating computational thinking and scientific modeling in elementary school is challenging, but provides opportunities to meet important 21st century learning goals. Furthermore, computational modeling deepens the level of understanding of the modeling process and the phenomena being modeled, making science content more accessible. This paper presents findings from EcoMOD, a research project that blends an immersive virtual ecosystem and a 2D modeling environment to support computational modeling and ecosystem science learning in 3rd grade. As part of the study, students filled out pre- and post- surveys about science content understanding, affective measures, and scientific modeling. Findings for the overall student gains across the three dimensions of the surveys suggest that the EcoMOD curriculum was effective in learning ecosystem science content and practice, as well as developing an understanding of the value of computational modeling.

Objectives

Curricular integration of computational thinking and scientific modeling is a complex and challenging endeavor that requires the adoption of new literacies (programming) along with disciplinary content learners find challenging (Lee et al., 2014; NGSS Lead States, 2013). Despite these issues, infusing computational thinking within the analysis of scientific phenomena offers the potential to meet important 21st century learning goals, including the development of deep understandings of science content and practice (e.g. causal relationships in complex systems and scientific inquiry) and the role of computational modeling in science (Sengupta, et al., 2013). In this research, we present EcoMOD, a 3rd grade curriculum that blends a 3D virtual ecosystem and a 2D visual programming and modeling environment to support the co-development of ecosystem science concepts and computational modeling.

Theoretical Framework

Immersive virtual environments are 3D graphical worlds that provide highly engaging and situated learning spaces (Dede, 2009; Barab et al., 2005), and can support problem-based learning pedagogies through inquiry, collaboration, and self-directed problem-solving (Hmelo-Silver & Eberbach, 2012; Metcalf et al., 2014). In the context of science education, learner exploration of the virtual space is supported through various digital objects, tools and computer-agents that scaffold learner engagement in domain-specific knowledge building practices, such as making and recording observations, taking measurements, and conducting experiments (Eberbach & Crowley, 2009; Kamarainen et al., 2015).

Recent research has shown that computational modeling, as a genre of scientific modeling, can make scientific concepts more accessible by allowing learners to tinker with and observe relationships between code and outcomes, thereby developing deeper levels of understanding of the modeling process and the phenomena being modeled (Sengupta et al., 2013; Weintrop et al., 2016). Considering young learners, prior work has shown that agent-based computational modeling platforms employing visual, block based programming languages are particularly effective in scaffolding scientific thinking and modeling, by grounding complex, aggregate-level phenomena in terms of simple, agent-level rules (Dwyer, et al., 2013; Klopfer, Yoon & Um, 2005; Dickes & Sengupta, 2013; Dickes et al., 2016).

EcoMOD blends these two forms of scientific representation – an immersive 3D virtual ecosystem and a 2D visual programming and modeling environment – in order to support learning of both ecosystem science concepts and computational modeling. In EcoMOD, 3rd grade students explore an immersive virtual ecosystem, form hypotheses about its phenomena, and represent those conjectures by constructing computational models. Through iterative cycles of model construction and revision, students test the impact of simulated environmental changes to uncover mechanisms of change within the ecosystem. In this paper we consider pre-post measures of student gains in ecosystem science understanding, affective measures, and student perspectives on modeling in science after using EcoMOD.

Description of Intervention

EcoMOD is a 14-day inquiry-based curriculum for 3rd grade that focuses on NGSS (NGSS Lead States. 2013) standards around ecosystem interactions, modeling and computational thinking. In EcoMOD, students explore a forest ecosystem, and learn about behaviors and causal interactions of two keystone species: beavers and woodpeckers. Students first encounter the ecosystem as a forest with a stream running through it. Over time, beavers construct a dam that creates a pond, with cascading effects on the landscape and other species: trout prefer fast-moving water and leave the ecosystem, mallards appear, and trees that are flooded by the new pond become snags (standing dead trees). These snags attract woodpeckers, which also play a crucial role in creating habitats, as abandoned woodpecker nest-cavities become homes for owls, squirrels, mergansers, and other animals.

EcoMOD provides a 3D immersive virtual world and a 2D modeling tool within the same web-based software tool. The 3D world (Figure 1) provides students with a space to explore, observe organism behavior, collect data, and travel in time to see changes to the ecosystem. The 3D virtual world also includes a point-of-view (POV) tool (Figure 2) that gives students the opportunity to experience an actor’s perspective (Jones & Nisbett, 1971) by learning to “be” a beaver or woodpecker via virtual embodiment of those organisms.

Figure 1: 3D immersive virtual ecosystem

Figure 2: Beaver POV tool

The 2D modeling tool supports computational modeling activities; students program an agent-based model of a beaver building a dam (Figure 3), using customized programming blocks for the beaver agent, such as “move toward tree,” “bite tree,” and “pick up log.” Model outcomes are visible in a 2D sandbox that represents an abstracted version of the immersive ecosystem. The 2D environment includes simplified representations of other species (e.g. mallards and trout) as well as various setup variables, such as the width of the stream, tree density, or the presence of a predator. As students build and test their computational models, they interpret the outcomes of their model by observing agent interactions within the 2D sandbox and by interpreting graphs of change over time (Figure 4). Students validate these outcomes against the observations and data they collected while in the 3D virtual environment.

Figure 3: 2D tool: example code for model of a beaver building a dam

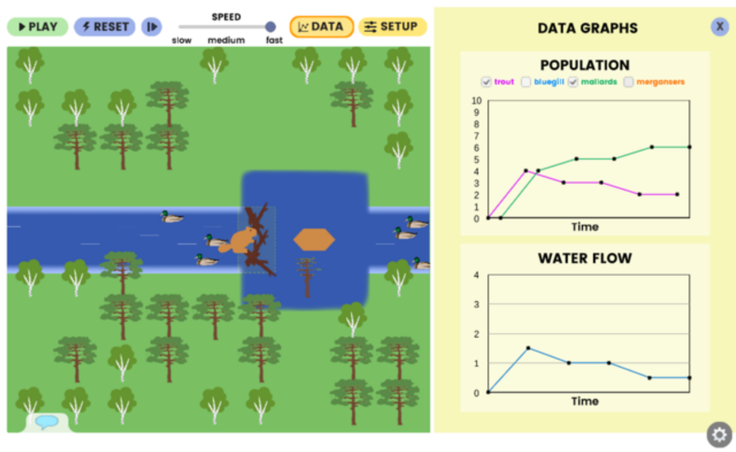

Figure 4: Sandbox and data graphs showing model outcomes in 2D tool

Students make inferences about causal relationships among the elements of the ecosystem both through observations of changes over time in the 3D world, and via modeling simplified, continuous interactions in the 2D world. The curriculum also includes paper-based representational activities by which students can make sense of the data collected in the 2D and 3D tools. At three key points during the curriculum, students create concept maps that represent the complex relationships in the ecosystem, both individually and as a classroom activity.

Methods

The EcoMOD curriculum was tested in classrooms during March-June, 2019 with 7 teachers and 8 classrooms, including approximately 150 students. Three teachers had participated in pilot testing during the prior year and four were new participants. Researchers were present for observation and video recording, but teachers taught the curriculum independently with minimal involvement by researchers. Teachers were supported with 6-8 hours of professional development, including multiple pre-study face-to-face sessions as well as check-in meetings during implementation. Curriculum materials included a teacher's guide, detailed daily lesson plans, paper-based materials, and student notebooks for recording data, observations, and reflections.

This paper focuses specifically on data collected through pre-post assessments for all students along three dimensions: science content understanding, affective measures, and understandings of scientific modeling.

The *science content survey* consisted of 11 multiple choice items assessing three core understanding goals of the curriculum taken from NGSS and Massachusetts state standards: the nature of habitats and ecosystems that require different adaptations, why and how some organisms survive well in certain habitats, and how to analyze and interpret data about changes in a habitat. These items were modified from a variety of sources, including the 5^{th} grade Massachusetts Comprehensive Assessment System (MCAS) test and the Trends in International Mathematics and Science Study (TIMSS) grade 4 science assessment. The content pre-survey achieved a Cronbach's α of 0.64.

The *affective survey* consisted of 16 Likert items on a 5-point scale, allowing students to self-report their confidence in science, confidence in programming, and their interest in continuing to learn ecosystem science and programming skills. These questions were formatted similarly to the affective surveys used in prior ecosystem curricular research (Thompson et al., 2016), but language was modified for relevance and simplified for the younger population. The affective pre-survey achieved a Cronbach's α of 0.88.

The *science modeling survey* consisted of three examples of scientific models with several free response questions asking students to evaluate how the model is similar or different than a real item or phenomenon, what scientists could learn from the model, and how the model might be improved. A subset of 76 student responses were hand-coded by expert raters according to a rubric that assessed how much students focus on function over superficial form and understanding of the reasons that scientists use models. The coding attained an inter-rater reliability of 91%, and the modeling pre-survey achieved a Cronbach's α of 0.69.

Results

Science Content Survey

95 students completed both the pre- and post-survey on science content. The pre-score mean of 65% ($SD = 21$) differed significantly from the post-score mean of 76% ($SD = 20$, $t = 4.83$, $p < 0.0001$). Largest gains were seen on questions pertaining to the nature of ecosystems and interpreting population graphs over time.

A*ffective Survey*

105 students total completed both the pre- and post-survey on affective dimensions of the curriculum. The affective survey was comprised of sub-constructs measuring science self-efficacy, computational self-efficacy, and interest in science. Overall increases on the 5-point Likert scale items (pre mean = 3.58, pre SD = 0.73, post mean = 4.05, post SD = 0.70) were significant ($t = 6.00$, $p < 0.0001$). Within the subconstructs, students showed significant gains in science self-efficacy ($t = 6.35$, $p < 0.0001$) and computational self-efficacy ($t = 7.02$, $p < 0.0001$). No significant changes were seen from pre- to post-survey in interest in science.

Modeling Survey
76 students total completed both the pre- and post-survey on scientific modeling. Significant increases were observed on expert-coded free response questions asking students to evaluate examples of scientific models ($t = 5.90$, $p < 0.0001$). Student successfully learned that effective models focus on function over form and that additional aesthetic features or details may not necessarily improve the quality of a scientific model.

Discussion

As science educators, researchers, and learning designers continue to push for curricular integration of STEM and computing, our analysis offers encouraging findings towards this goal. In particular, our findings demonstrate gains across all three surveys, suggesting that the EcoMOD curriculum was effective in supporting learning of ecosystem science content and practice, in particular in developing a more nuanced understanding of scientific modeling, as well as supporting growth in young learners' science and programming self-efficacy.

While large gains were seen on some questions within the content survey, others were not observed due to a ceiling effect. For example, 91% of students correctly defined a habitat on the pre-survey. As we were working with a new age range, some of these questions may have been too simple for our sample of 3rd graders. As studies of this curriculum continue, refinements to the granularity and difficulty of questions can be made.

Within the affective survey, a ceiling effect on student interest in science was also observed. The average pre-survey score for the interest subconstruct was 4.16, indicating that the majority of students in the sample already agreed with statements on liking science and wanting to learn more. The mean post score of 4.26 was not significantly higher. Research on student interest in science has shown that student under 10 years old are generally interested in science, but that their interest either remains high or declines with age, with opinions typically solidifying around 14 years old (van Griethuijsen et al., 2014.)

Beyond a perceived ceiling effect, there are other reasons why an intervention such as EcoMOD might not cause significant gains in student interest in science. While a 15-day-long curriculum sounds extensive, it is a small portion of students' net science instruction for the year and is unlikely to completely change their opinion of the entire subject. That being said, the ability to empower students and make them feel self-efficacious demonstrated by EcoMOD may lead to long-term changes if similar open-ended curricula are used widely and over longer periods of time.

Some meta-modeling objectives were "reach goals" for EcoMOD and will be investigated further in future work. The modeling survey contained an experimental section on how scientists use scientific models, as well as a section where students weigh in on a mock debate between classmates on model use in science. While not analyzed here, these responses may give insights into how students think about the applications of models in the real world.

This evaluation of student learning is supported by other analyses of research data. We identified gains in student understanding of ecosystem science and causality through analysis of the concept maps constructed at three points during the curriculum (Metcalf et al., in submission, a), and gains in student fluency in the use of computational thinking constructs during student programming activities (Metcalf et al., in submission, b). Teachers reported high engagement from their students, and felt that the curriculum was feasible and supported students in inquiry-based learning, science content, causality, and programming (Jeon et al., 2020).

Significance

The Next Generation Science Standards presents a vision for K-12 science teaching grounded in essential practices and cross-cutting concepts (NGSS Lead States 2013). Many of these practices (e.g. Developing and Using Models, Analyzing and Interpreting Data) are familiar to K-12 science educators as core elements within the discipline of science. However, practices such as "computational thinking" are less familiar, leaving many science educators uncertain how best to achieve the image of K-12 science teaching outlined in the NGSS. We believe that EcoMOD provides a promising pathway for supporting the integration of science and computing within the elementary grades by situating computing within a familiar and accessible context (ecosystems) and providing a rich computational environment for students (and teachers) to express agency in designing computing artifacts for their own purposes. Such a high-ceiling, low-threshold learning environment is, we feel, essential for supporting access to and equity across high quality STEM+C learning.

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