Tortuga: Building Interactive Scaffolds for Agent-based Modeling and Programming in NetLogo

John Chen, Michael S. Horn, Uri J. Wilensky
civitas@u.northwestern.edu; michael-horn@northwestern.edu; uri@northwestern.edu
Northwestern University

Abstract: Agent-based Modeling and Programming (ABM & P) is widely used in educational settings to promote computational thinking and complex systems thinking. In this paper, we introduce Tortuga, a novel technical system for building interactive scaffolds for ABM & P. Tortuga lowers the threshold and raises the ceiling for constructionist curricular designers. It allows designers to build interactive scaffolds with simple NetLogo commands. These scaffolds can be aware of computational models' emergent behaviors and can react to learners' interactions in modeling spaces. We introduce its technical structure and start to explore how that structure supports learning designs. To understand Tortuga's design affordances, we implemented three types of interactive scaffolds for eight NetLogo models in out-of-school, online learning contexts. Our preliminary quantitative analysis points to potential benefits of content-specific and programming-oriented scaffolds to engage learners with ABM & P.

Introduction

Agent-based Modeling (ABM) investigates scientific phenomena by computationally modeling the behavior of individual autonomous computational agents. This approach is particularly valuable for learners as a way to investigate and understand complex phenomena (Wilensky & Resnick, 1999). Building agent-based models necessitates the learning of agent-based programming (ABP), wherein learners need to program rules for individual agents.

With many studies of ABM & P in classroom environments, less work examined learners' use of ABM & P in informal contexts. In such environments, there is a greater need for technology-enabled scaffolds to support students in engaging with ABM & P. Yet the design of such scaffolds can take significant expertise and effort to implement. The desire to engage learners in online, informal contexts brings opportunities for engaging diverse learners from different socio-economic-cultural backgrounds and further challenges for designers.

To address the challenges, we introduce the design of the first technical platform, Tortuga, that 1) focuses on the learning of ABM & P; 2) lowers the threshold and amount of effort of designing and implementing cross-platform interactive scaffolds; and 3) flexibly supports multiple paradigms of design and diverse learning needs. Through enabling scaffolds to react to the modeling space (i.e., what is happening in the model) and learner interaction, Tortuga naturally invites both learner-adaptable and learner-adaptive scaffolds.

Due to page constraints, we could only briefly explore the affordances of Tortuga. Turtle Universe (TU, Chen & Wilensky, 2020) was launched as a ubiquitous, mobile-first incarnation of NetLogo that aims to engage online, out-of-school learners. On this platform, we implemented sample learning designs on 8 models with 3 paradigms: **content-agnostic**; **content-specific**; and **programming-oriented**. Our preliminary analysis mainly explored: 1) *Were our interactive scaffolds helpful for learners' meaningful engagement with ABM or P?* 2) *Were the impacts of the three paradigms of interactive scaffolds different?*

Related Work

For the past decades, NetLogo has helped educators and learners understand topics of complex systems, such as feedback, emergence, critical parameters, and sensitive dependence (Tisue & Wilensky, 2014). One of the main goals of the NetLogo ecology is to bring ABM & P to a broader audience. The widespread availability of mobile devices for youth brings opportunities for engaging young learners in out-of-school, informal learning contexts (Chen & Wilensky, 2020). Reciprocally, it brings new challenges to scaffold engagement and learning for diverse audiences and generates fresh and urgent needs for technology-enabled scaffolds: learners' time could be more fragmented, their engagement could be more interest-driven, and instructors could be less available.

In this paper, we adopt Collins et al. (1991)'s definition of scaffolding which revolves around experts' support for novices to carry out tasks. The scaffolds will eventually be ***faded***, and learners could carry out similar tasks without them. Extending the notion of scaffolding to support from software, Jackson et al. (1998) discussed two strategies of technology-enabled scaffolds: ***learner-adaptive***, where the design will automatically change to respond to learners' needs; and ***learner-adaptable***, where the design enables learners to initiate the ***fading*** of scaffolds. The scaffolding analysis framework (Sherin et al., 2004) stresses the necessity to compare learning performance between unscaffolded and scaffolded situations. Scaffolds are also relative: while ABM & P are frequently regarded as an approach to scaffolding learning of domain knowledge (e.g., Basu et al., 2015), the learning of ABM & P needs its own scaffolds as well (Sengupta et al., 2013).

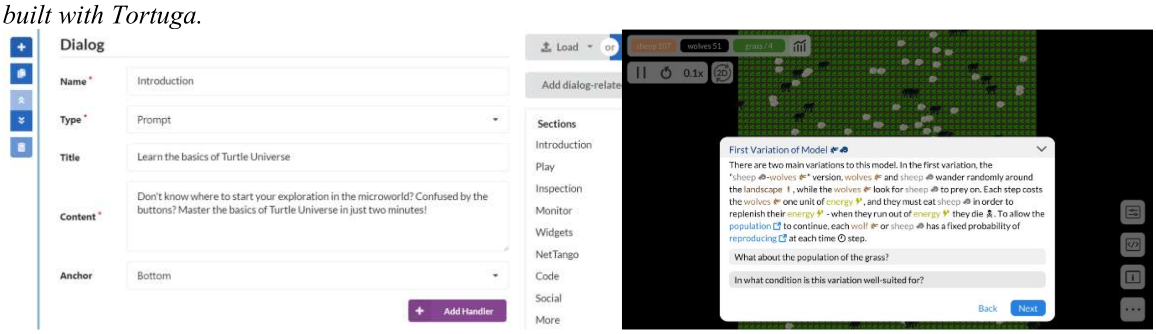
NetLogo provides several built-in features for designing scaffolds, but there are also tradeoffs in using them. For example, the scaffolding interfaces of BEAGLE curriculum (Novak & Wilensky, 2007) leads to much more complicated code, limiting learners' capability to understand or build on that model. Introducing the NetLogo language to novice learners is also difficult. Blocks-based interfaces for ABM & P, such as NetTango Web (Horn, Baker & Wilensky, 2021), or CTSiM (Sengupta et al., 2013) were launched to provide a "code-first" or "quickstart" environment to lower the threshold further. However, building those modeling interfaces requires significant technical expertise, and they often come with their own needs for scaffolding as well.

In this section, we briefly presented some related work that discusses the importance of ABM & P and the efforts to broaden its access; that defines the design goals and strategies of technology-enabled scaffolds; and that attempts to scaffold ABM & P through technology design. We believe it is necessary to further lower the threshold for designers to create technology scaffolds that are learner-adaptive and learner-adaptable.

Technological System Design

Figure 1

(a) The Visual Editor of the Tortuga System and (b) Screenshot of Wolf Sheep Predation's Interactive Tutorial, built with Tortuga.

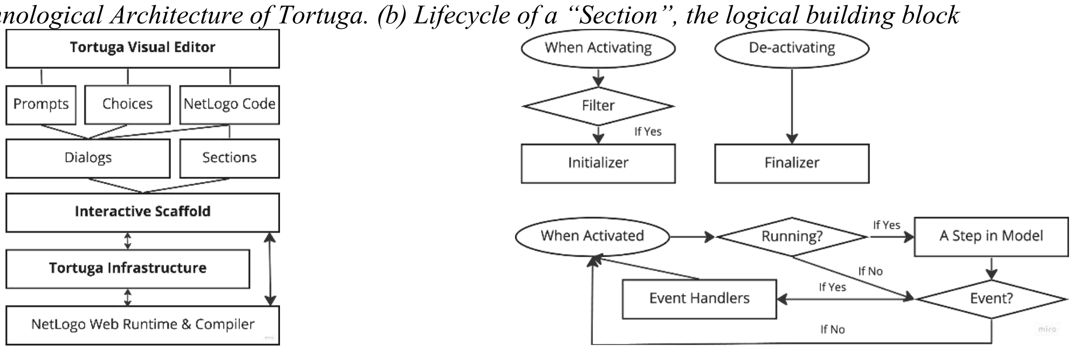


(a) (b)

The technical design of Tortuga aims to bring a low-threshold, high-flexibility way of designing, developing, and implementing technology-enabled interactive scaffolds for ABM & P. Using the NetLogo language and a visual editor (Fig 1a), Tortuga eliminates the need for designers to learn complicated web-based technology for creating scaffolds. The deep integration between Tortuga and NetLogo allows designers to build scaffolds that could capture learners' emergent interactions and the models' emergent behaviors (see the example in Fig 1b). Tortuga is built on the infrastructure of NetLogo Web and works in parallel with NetTango Web (Horn, Baker & Wilensky, 2021), the domain-specific block-based programming interface maintained by the NetLogo team.

Figure 2

(a) The Technological Architecture of Tortuga. (b) Lifecycle of a "Section", the logical building block



Interactive scaffolds built with Tortuga are capable of interacting with both its own infrastructure and NetLogo Web's runtime and compiler (Fig 2a). By keeping the interactive scaffolds separate from, but running in the same context as the model code, the designers gain access to 1) new customizable and programmable interface widgets such as dialogs and stencils (Kelleher & Pausch, 2005); 2) new capabilities to operate on and take input from most of NetLogo's interface widgets; and 3) new affordances to react to the learner interaction (e.g. changing a certain parameter, or clicking somewhere) and the modeling space (e.g. when the status of agents changes). Fig 2a and 2b demonstrate its main building blocks: 1) Section, similar to a unit or sub-unit in a curriculum; and 2) Dialog, similar to a page or paragraph. The main difference between a traditional curriculum and Tortuga Interactive Scaffolds (TIS) is that while the former is designed linearly, the latter can be designed with a network of triggers.

Sample Learning Design

We designed and implemented 9 sets of TIS. One of them is a content-agnostic interface tutorial. The other 8 sets cover diverse scientific topics, such as biology (Wolf Sheep Predation) or physics and chemistry (GasLab Gas in a Box). Finally, we created a new model (Pocketworld Playground) to introduce ABP through a block-based programming space. All the scaffolds and the Tortuga system are open-sourced.

Figure 3
(a) Screenshot of the content-agnostic tutorial. (b) Screenshot of the programming tutorial.

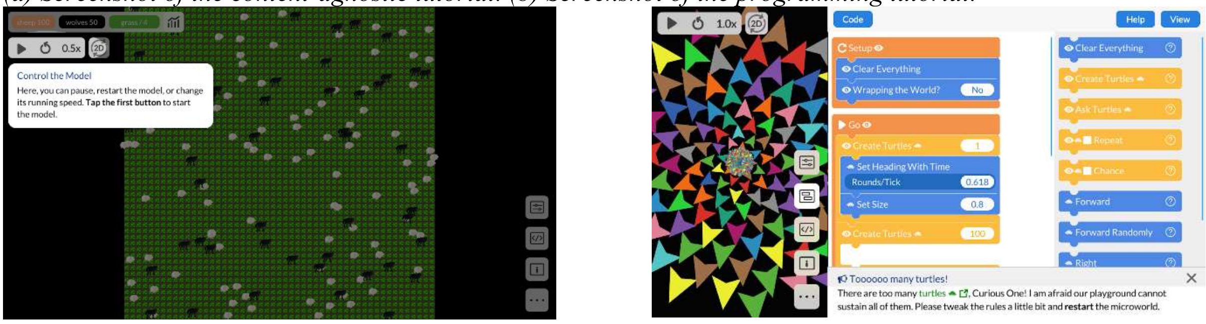


Fig 3a demonstrates the first paradigm of sample learning design that is **content-agnostic**, mainly to introduce the usage of the software. Here, the stencil-based design asks learners to carry out a specific task and is conceptually similar to Kelleher and Pausch's (2005). The second **content-specific** paradigm comprises 7 tutorials that aim to support first-time learners' exploration at their own pace. Designed with existing learning materials accompanying the models with slight changes of texts, we conducted another embedded experiment: for learners to opt out of the scaffolds, similar texts are still available. Fig 3b shows some design highlights: 1) learners can choose to "learn more" of concepts; 2) learners can choose to "ask questions"; 3) learners can choose to interact with the world instead. In addition, each interface widget receives a question mark that will trigger more information. The third paradigm, the **programming-oriented** tutorial, extends the previous one with several major differences. As the introductory model for ABP, the Pocketworld Playground is designed for learners to explore the space of creativity through programming. Instead of a mostly linear task structure, this tutorial was designed as a network, with 6 major pathways and many branches that fit different levels of prior knowledge and types of personal interest. It also comes with learner-adaptive scaffolds that react to learners' modeling decisions, such as when a learner creates too many turtles in the modeling world (Fig 3b).

Preliminary Study

We implemented all scaffolds in Turtle Universe since early 2021. Then, we collected and analyzed anonymized log data from consented learners during a 14-month period. The timing of user interaction suggests that most were K-12 age learners in out-of-school contexts. Our observation and informal conversations show that most learners had little knowledge of ABM & P before. By filtering the dataset to only include first-time users' first visit to any project, we excluded the effect of learners' prior exposure to Turtle Universe. Learners who spent less than 10 seconds in any model are also excluded. A total of 7,256 learners were left in our study.

Three quasi-experimental conditions were created through TU's design, each with two groups. Each first-time user is presented with two options: "*Free Exploration*", leading to the content-agnostic scaffolds for all but one model; and "*Guided Intro*", leading to the model-specific scaffolds. Learners were free to decide whether and when to stop using the scaffolds. Depending on learners' reaction to the scaffolds, two groups are created out of this situation: learners who engaged with the scaffolds (quasi-experimental); learners who opted out of the scaffolds (quasi-control). Then, we used regressions to compare the effectiveness of each condition on learners' engagement, with fixed effects to control the differences between models. Building on existing studies (Dewan et al., 2019), we used the following metrics from the log data to measure learning engagement:

1. **Time spent in the model (and excluding on Tortuga interfaces)**, to understand learners' engagement and if learners' engagement did increase other than simply reading the prompts;

2. **Total time spent in 8 scaffolded models within the 14-month period**, to reflect the extent of voluntary engagement with ABM & P, which suggests individual interests of learners (Michaelis & Weintrop, 2022);
3. **Number of exploration or tinkering events** (e.g. changed the value of a widget in ABM; added, changed, or removed programming blocks in ABP), to measure learners' deeper engagement with ABM & P.

We found that: 1) While all types of scaffolds improved learners' total time spent in the model, the **programming-oriented** condition performed the best (+223%), followed by **content-specific** (+57%) and **content-agnostic** (+31%). 2) **Content-agnostic** increased engagement mostly through reading prompts (no significant change), while other 2 conditions successfully improved engagement beyond them (+257%/+24%); 3) the **programming-oriented** condition performed the best in helping learners explore or tinker with the model (+666% in event occurences), followed by **content-specific** (+66%), while the **content-agnostic** condition saw a decline (-20%). 4) Learners in **programming-oriented** (+71%) condition engaged more with those models in the long run. All findings are statistically significant ($p < 0.05$).

Discussion

Tortuga is designed as a flexible technology system for developing interactive scaffolds for ABM & P learning activities while lowering the threshold. It could be used to design scaffolds as simple as two-screen prompts, or as complicated as a network. *What could be the cause of the different learning impacts between the conditions?* While the content-agnostic scaffold increased learners' engagement, it likely does that by requiring learners to follow steps. On the other hand, simply turning existing learning materials into interactive scaffolds, with a little bit of story-like framing, could produce significant gains in engagement. The scaffold's understanding of the modeling space, as well as its ability to support open-ended programming activities, could also be powerful, as shown in the programming-oriented scaffold. That being said, our study is limited by a certain learning context (online, out-of-school, informal). To better support learning designers and learners of ABM & P, it remains on us to conduct further studies with learning designers and learners in more diverse learning contexts.

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