

Guiding Without Feeling Guided: Implicit Scaffolding Through Interactive Simulation Design

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Abstract. While PhET interactive simulations (sims) were historically designed for college students, they are used at lower grade levels, and we are currently developing sims targeted at middle school (MS). In studying how MS students interact with and learn from these sims, we have been extracting insights about design for the middle-grade-levels and across K-16. This collection of work has highlighted the importance of implicit scaffolding, a design framework that reduces the amount of explicit instruction needed to facilitate learning. We present a case study of redesigning a sim – *Energy Skate Park (ESP)* – for effective use in MS. We conducted think-aloud interviews with MS students to identify successful features, sources of confusion or unproductive distraction, as well as features inconsistent with grade-appropriate learning goals. Drawing on these data and the principle of implicit scaffolding, we developed *Energy Skate Park Basics (ESPB)*. Interviews on ESPB demonstrate increased usability and learning for MS students.

Keywords: Computer simulations, tools, representations, scaffolding, physics education research

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INTRODUCTION

Often, the debate about the goals and methods of educating students has been framed as a choice between content delivery and student participation. A large volume of research can be identified that supports either side of the debate over the benefits of direct instruction and rote learning versus student-centered investigation and discovery [1,2]. In our view, the goals and methods of education are multifold. In this paper, we present a model toward simultaneously achieving the content goals of direct instruction and the participation goals of discovery.

A central idea in education is that building knowledge requires scaffolding to support student learning. In general, scaffolding tends to be explicit, such as direct instructions or guiding questions. Here we present a model of *implicit scaffolding*. In this model, scaffolding is built into the design elements and interactivity of the learning tool, as opposed to textual or oral guidance. In this way, we hope to achieve the process goals of discovery-based, student-directed learning, while also achieving the content goals of direct instruction.

THEORY

Our theoretical framework consists of two main components: a *model of learning*, and a *model of tools*. These components will lead to the central guiding

principle of our design philosophy, an approach which we call *implicit scaffolding*.

Model of Learning

The model we use is rooted in *constructivism*, which states that learners actively use prior ideas and experiences when building new knowledge [3]. In its original form, constructivism is powerful in its generality, but limited in its ability to embrace the material aspects of experience and learning. Vygotsky modified the theory to include *tools* that have a direct impact on the learning process. A further adaptation, *tool-mediated constructivism*, is shown schematically in Figure 1. In this model, the *learner* interacts with a *learning objective* (e.g., knowledge of conservation of energy), mediated by some tool (e.g., a book, or computer program).

We will make the case that interactive computer simulations can address multiple learning objectives beyond content. The model of mediated learning represented in Figure 1 leaves open a spectrum of pedagogical approaches. Approaches can vary in the degrees of guidance, from very explicit and directed to very open and student driven. Here we focus on a spectrum of inquiry methods. Though it may be beneficial in some cases, we do not consider *direct instruction* in the present analysis.

Table 1 describes the extremes of the inquiry spectrum. On one end of the inquiry spectrum we

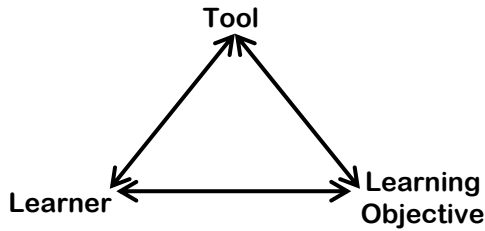


FIGURE 1. Tool-mediated constructivism.

place so-called *discovery* learning, characterized by minimal explicit guidance for students. On the other end of this spectrum, we place *heavily guided* learning, which is often characterized by specific procedural directions. Table 1 describes these extremes in terms of goals and roles for participants.

Our goal for student use of interactive simulations attempts to simultaneously achieve desirable characteristics of both discovery and heavily-guided inquiry. We would like students to engage actively with content in an individualized way and yet avoid pitfalls, such as unproductive learning trajectories and high variability of learning outcomes. Below, we will propose *implicit scaffolding*, a method that retains the most favorable aspects of discovery while using the tool to constrain, somewhat covertly, the variability of learning.

Model of Tools

A useful way of connecting tools to our model of learning is in terms of *affordances* and *constraints*. Affordances are features of a tool that allow certain actions [4]. For instance, the handle of a coffee cup affords *gripping*. According to Norman, for affordances to be used, they must be perceived [5]. The user must perceive that the handle affords gripping before gripping the cup by the handle. This example may seem trivial, but emphasizes our cultural knowledge of coffee cups. One could also use the handle for hanging the cup on the wall, but this affordance is less universally perceived. The key point here is that good design hinges on making affordances salient within the culture and context that they appear.

Constraints are actions that cannot be taken with a tool, and are *productive* when the limitations they place lead to usage that was intended by the designer.

For instance, a coffee cup holds only so much liquid before spilling over. Proper filling of the coffee cup is fairly assured, the mark of a productive constraint.

Extending Norman’s approach to our interactive computer simulations, good design uses affordances and constraints to reduce impediments of the key learning goals. Effectively designed affordances and constraints also lead to productive exploration by students. Actions are afforded that encourage exploration and engagement, but actions are also constrained to minimize unproductive outcomes while highlighting important ideas and relationships.

Implicit Scaffolding

The above sections discuss a theoretical foundation for an approach to the design and use of learning tools we call *implicit scaffolding* [6]. Implicit scaffolding is meant to allow for student autonomy, the feeling that students have independent control over their experience, while both affording and constraining students to actions that are productive for learning. Students perceive the sims as engaging, open exploration spaces. Yet, the implicit scaffolding provides cuing and guidance so students are inclined to interact with the sims in productive ways; it guides without students feeling guided. A useful analogy to this form of guidance is a student working to solve a jigsaw puzzle without having access to the picture the puzzle will form. The shapes of the pieces and their individual patterns help to cue the boundaries of the puzzle, guiding the student to assemble a coherent (but previously unknown) picture.

A number of ways exist to design-in implicit scaffolding to our interactive simulations. Successful designs tend to leverage existing student resources and intuitions. For example, buckets hold objects, scissors cut, salt shakers shake, etc. Student attention can be cued to key parameters by using sliders. These designs tap into natural curiosities with minimal text (e.g. spark “what if?” or “why?” questions). We try to aid the parsing of information through thoughtful grouping of controls and displays. To support progressively increasing complexity, we use design elements such as tabs and “scenes”, and pay careful attention to the default starting conditions. When choosing constraints for actions, we strive to make them feel natural within the context of the sim.

TABLE 1. Characteristics of Inquiry Spectrum.

Characteristic	Discovery	Heavily Guided
Process of Learning	Engagement, messing about, question forming	Procedure following, question answering
Variability of Learning Process	High, individualized	Low, homogeneous
Role of Student	Creator, agent	Follower, (re-)constructor
Role of Teacher	Guide, co-participant	Provider, director
Source of Knowledge	Student, peers	Experts, teacher,
Nature of Knowledge	Evolving	Static, pre-determined

COLLEGE LEVEL SIMULATION

Energy Skate Park (ESP) is a college-level PhET interactive simulation that explores conservation of energy, as well as kinetic, potential, and thermal energy. The context of this sim involves a skater on a customizable track. Adjustable parameters include gravity, friction, mass, and starting height. The sim also includes options for displaying a dynamic bar or pie chart representation of energy, as well as energy vs. time and energy vs. position graphs.

ESP is one of the most popular PhET sims, currently used over 1.5 million times annually. Considering its extensive use and a content focus well aligned with MS learning goals, this sim seemed ideal for a redesign targeted at a younger audience.

Before any redesign decisions were made, we performed extensive interviews with MS students on college level sims, including ESP. During the ESP interviews, students were engaged with the simulation and enjoyed the context, but were overwhelmed by available features and many of the more advanced representations of energy (such as the Energy vs. Time graph). Students would find a feature or representation confusing, distracting, or even visually interfering with the sim action, but did not turn the feature off. The ability to customize the track without constraint or scaffolding seemed particularly inefficient for learning; we observed students spending significant time on the process of building exceptionally elaborate tracks as opposed to investigating the science ideas.

REDESIGN OF A SIMULATION

Based on interview findings, we modified many aspects of ESP to improve usability and learning for MS students. The redesigned sim, Energy Skate Park Basics (ESPB), exhibits an increased level of implicit scaffolding. First, features that did not align with grade-appropriate learning goals as defined by state and national standards were removed (such as the ability to change gravity), as well as representations that were confusing or overwhelming (such as the Energy vs. Time graph).

Since we found that MS students were overwhelmed with the number of ideas and features available at once in ESP, the first significant modification was to add “tabs” to the sim. Tabs allow us to separate sim features so that students only deal with a few key ideas at a time. The second significant change was to create pre-set tracks (or “scenes”) in the first two tabs, with custom track building reserved for the third tab. Fig. 2 shows the first tab of ESPB with the speed indicator, the bar graph, and the pie chart active.

Another major change involved constraining the ability to build custom tracks. In ESP, an unlimited number of track pieces were available and the track could be built off the screen. In ESPB’s third tab, only 4 pieces of track are available, the track cannot be built off screen, and the track cannot dip below ground level. These constraints allow students to build interesting tracks and test ideas (students almost universally try to build a vertical loop), but tend to keep them in a mode of exploration that remains productive. Such constraints do not determine when students can use any given feature – a student could change directly to the Track Playground (third) tab.

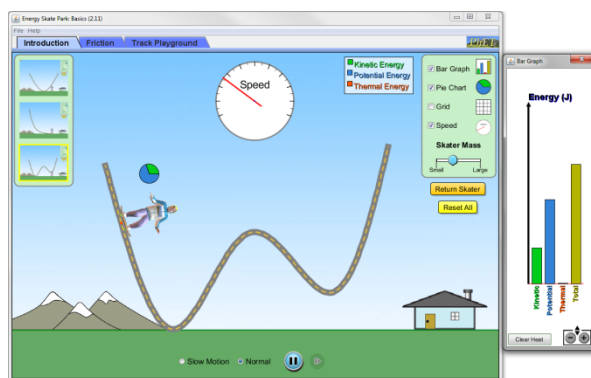


FIGURE 2. Energy Skate Park Basics: first tab.

EMPIRICAL SUPPORT

Methods

A total of 9 MS students (4 in 5th grade, 2 in 6th, 2 in 7th, 1 in 8th) were interviewed during the final stages of the redesign process. These students had not been previously interviewed on ESP. Interviews were video recorded and sim usage was captured using Camtasia software. During these interviews, students were asked to think aloud as they freely explored the sim. The interviewer made clear to the students that he was not judging them on the correctness of their thoughts or exploration strategies.

In the final four interviews, students were asked questions – before and after the free exploration – to gauge the effectiveness of the sim. The pre and post questions were identical and included the following:

1. What can you tell me about energy?
2. Have you heard of kinetic and potential energy?
3. (If “yes” to question 2): Can you tell me what you think about kinetic and potential energy?
4. Describe energy in the following three situations:
 - Ball held high by interviewer
 - Ball rolled on the floor by interviewer

- Ball falling in midair (if total energy was not offered, the student was asked specifically to compare total energy to the ball held high)

These questions were asked verbally, and the interviewer emphasized that the student would not be judged on correctness. A prop was used by the interviewer (a tennis ball or orange) to illustrate the situations in question four.

Results

Video data was analyzed by a team of two researchers who each made inferences about student actions and statements, discussing these inferences until agreement was reached on their meaning. As with the interviews on ESP, video analysis showed students were visibly engaged during the interviews, but they no longer displayed signs of being overwhelmed. Students easily manipulated the sim features, and expressed sense-making of the various dynamic representations of energy. In addition, we observed signs and articulations of enjoyment from the students while they were building custom tracks, such as smiling, laughing, and saying “cool”. Qualitative video analysis showed that these expressions were more common for students using ESPB.

During the pre-questions, all students talked about energy sources when asked to describe energy. Strikingly, all the students remarked that they had heard the terms kinetic and potential energy, but they could not describe these concepts in any detail. Overall, the students answered the questions regarding a ball’s energy poorly. Two students noted the ball having energy of motion while rolling on the floor and one noted it having energy while falling, but otherwise the answers were incorrect. Additionally, none of the students could discuss total energy.

During the post-questions, all students demonstrated new insights into energy, kinetic energy and potential energy that were not apparent during the pre-questions. Answers to general questions about energy were varied, but answers about the ball were fairly unambiguous and showed clear learning gains. Two of the students gave correct and complete answers, and the other two gave improved, but not perfect responses. We note that one of the students modified her answers to correct and complete after using the sim to double check her thinking. All students answered the question about total energy.

As evidenced by post-test performance, students were actively gaining or reinforcing knowledge with the sim, specifically from interpretations of the bar and pie graphs during the exploration time. As further evidence of facility and comfort with the sim, 3 of 4

students referred to the sim or used it to communicate ideas during the post-questions. It was clear that some of the students were referencing the bar graph during questioning, and it should be noted that the term “total energy” only appears on this representation, so increased comfort with that line of questioning appears to have come from interaction with the bar graph.

CONCLUSION

Computer simulations offer the significant advantage that the detailed design of the learning environment is highly customizable and can be specified and fine-tuned by the developers. We leverage this benefit to design-in features that implicitly scaffold students to explore along pedagogically useful paths without explicitly directing them. In this way, implicit scaffolding allows students to take more control over their learning path and engage in authentic science process skills, while simultaneously supporting productive content learning.

The experience of redesigning our interactive simulations for MS level students has highlighted the importance of implicit scaffolding as a guiding principle. Moreover, the lessons from this effort have “filtered up” to our newest college level sims. Even though college students can often accommodate a sim with less scaffolding, MS students have offered us valuable insights to improving the quality and effectiveness of our sims.

ACKNOWLEDGMENTS

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