37 Using Simulations as a Starting Point for Constructing Meaningful Learning Games

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Abstract For many school administrators and decision makers, the term "video games" holds numerous cultural associations which make their adoption in the education space challenging. Additionally, the term is so broad that it can sometimes be difficult to communicate explicitly a desire to build learning experiences that go beyond the Drill & Kill edutainment titles that currently dominate most people's perceptions of educational games. By contrast, the term "simulations" is often well respected among educators, particularly in the natural sciences. With "simulation" already being a full genre of video games, it would seem natural that researchers are beginning to explore the overlaps between simulation games and pedagogical goals that go beyond those found in Drill & Kill games. In this chapter, we survey some of the relevant research concerning both Simulations and Video Games, and outline practical pathways through which we can leverage the interest and frameworks designed for simulation construction, to facilitate the introduction of video game concepts and experiences into the classroom environment. In particularly, we report on the use of *Starlogo TNG*, a graphical programing environment in which kids themselves can create simulation-based video games, for deepening children's understanding of scientific concepts.

Keywords games, education, simulations, *StarlogoTNG*, video games, curriculum

Defining Good Learning Games

In 1965, The Nobel Prize Authority awarded eminent U.S. physicist Richard Feynman with that year's prize for his groundbreaking work in quantum electrodynamics. Often noted for his extraordinary ability to explain theoretical physics to students with engaging and lucid explanations, recordings and transcripts from

his lectures in the 1960's still form the basis of leading Physics education programs worldwide. Towards the end of his life, a B.B.C. interviewer asked Mr. Feynman where he himself had learned to think as a Physicist, and how he viewed his own education. He recalled a particular experience from his childhood in which he was playing in the fields with other children after their fathers had taken each of them for walks in the woods:

> "The next day, Monday, we were playing in the fields and this boy said to me, 'See that bird standing on the stump there? What's the name of it?'
>
> I said, 'I haven't got the slightest idea'.
>
> He said, 'It's a brown-throated thrush. Your father doesn't teach you much about science.'
>
> I smiled to myself, because my father had already taught me that [the name] doesn't tell me anything about the bird. He taught me 'See that bird? It's a brown-throated thrush, but in Germany it's called a Halsenflugel, and in Chinese they call it a chung ling and even if you know all those names for it, you still know nothing about the bird – you only know something about people; what they call that bird. Now that thrush sings, and teaches its young to fly, and flies so many miles away during the summer across the country, and nobody knows how it finds its way', and so forth. There is a difference between the name of the thing and what goes on" (Feynman 1999, pg 4).

Later in his life he was asked to serve on a textbook committee to determine which books were suitable for use in the greater Los Angeles school district:

> "What finally clinched it, and made me ultimately resign, was that the following year we were going to discuss science books. I thought maybe the science would be different, so I looked at a few of them. The same thing happened: something would look good at first and then turn out to be horrifying. For example, there was a book that started out with four pictures: first there was a windup toy; then there was an automobile; then there was a boy riding a bicycle; then there was something else. And underneath each picture it said, 'What makes it go?'
>
> I thought, 'I know what it is: They're going to talk about mechanics, how the springs work inside the toy; about chemistry, how the engine of the automobile works; and biology, about how the muscles work.' It was the kind of thing my father would have talked about: 'What makes it go? Everything goes because the sun is shining.' And then we would have fun discussing it:
>
> 'No, the toy goes because the spring is wound up,' I would say. 'How did the spring get wound up?' he would ask.
>
> 'I wound it up.'
>
> 'And how did you get moving?'
>
> 'From eating.'
>
> 'And food grows only because the sun is shining. So it's because the sun is shining that all these things are moving.' That would get the concept across that motion is simply the *transformation* of the sun's power.
>
> I turned the page. The answer was, for the wind-up toy, 'Energy makes it go.' And for the boy on the bicycle, 'Energy makes it go.' For everything, '*Energy* makes it go.' Now that doesn't *mean* anything. Suppose it's 'Wakalixes'. That's the general principle:

'Wakalixes makes it go.' There's no knowledge coming in. The child doesn't learn anything; it's just a *word*!

What they should have done is to look at the wind-up toy, see that there are springs inside, learn about springs, learn about wheels, and never mind "energy". Later on, when the children know something about how the toy actually works, they can discuss the more general principles of energy. It's also not even true that "energy makes it go", because if it stops, you could say, "energy makes it stop" just as well. What they're talking about is concentrated energy being transformed into more dilute forms, which is a very subtle aspect of energy. Energy is neither increased nor decreased in these examples; it's just changed from one form to another. And when the things stop, the energy is changed into heat, into general chaos. But that's the way all the books were: They said things that were useless, mixed-up, ambiguous, confusing, and partially incorrect. How anybody can learn science from these books, I don't know, because it's not science" (Feynman 1985., pg 297-298).

Education today is under attack from many directions. In one thread, critics similar to what Feynman argued in the past, say that we teach only superficial elements, failing to present the true complexities necessary for a rich understanding of any subject matter: Science needs to explain how things work, not just their labels. History needs to teach students how to analyze causal relations, not just names and dates. Foreign language students need to be able to communicate comfortably and naturally in a foreign culture, not simply describe grammar rules. All disciplines need to teach how to work as teams and to create new solutions, not how to regurgitate answers.

In another thread, observers lament how poorly engaged students today are with learning materials. Many blame the rise of video games and other digital media that youth today are engulfed in for making it impossible to design educational materials that can 'compete' for students attention (see Hartman 1999). In the early 90s, many curricular designers saw an opportunity to migrate textbook exercises to a video game format in a series of "edutainment" titles in order to recapture attention among youth. These poorly conceived games, however, failed to increase youth engagement, and the "edutainment" software market on the whole is largely struggling except for games targeting the youngest audiences (Harvey 1995).

It is only by meaningfully considering these two threads together that we can address either concern. We could easily imagine an edutainment title designed to drill children on the names of different species of birds, then play an animation sequence as a reward for correct answers; this would undoubtedly suffer the same fate as earlier edutainment titles of combining the educational value of a bad video game with the entertainment value of a bad lecture (Jenkins 2002). Instead, we should not begin by either viewing games as entertaining, but lacking any cognitive merit, or acquiring knowledge as being an inherently unpleasant experience that requires a superficial delivery mechanism to make it palatable. Rather, we should look closely at the ways in which games can already naturally facilitate problem solving and deep-thinking, and the ways in which acquiring new knowledge can be stimulating and enjoyable. As starting points, we feel some of the most promising work to date has been in the field of using simulations in classrooms. While, strictly speaking, simulations are not always inherently games,

they often share many commonalities, and there are often numerous ways in which simulations can be developed into full-fledged games. Furthermore, there is already a rich tradition and body of literature supporting the use of simulations and modeling for educational purposes. By extending these, we find the harmony between learning and enjoyment often comes naturally.

When looking at the full possibilities for learning games, it is critical that we first put aside certain non-games: virtual worlds (e.g. *Second Life*) are not games, as there are no explicit goals or feedback – though virtual worlds may be used to create games by adding those elements. Virtual worlds may also be simulations (e.g. a virtual world in which you are given different items to determine the speed at which they fall), but they are not inherently simulations or games and need to be approached with caution when using them to evaluate the use of Learning Games in Education. Besides virtual worlds, we must also be careful to distinguish between many educational "games" found on the Internet that more closely resemble multiple-choice tests with rewards than a commercial video game. Games like *Biology Jeopardy* come to mind. In order to differentiate these entities from bona fide Learning Games, we need to make one clear distinction: Learning Games are educational games in which the content/learning objectives are inextricably linked to the game play. That is, it is not possible to replace the content in the game with another content area, or doing so would entirely destroy the game. So, *Biology Jeopardy* is not a Learning Game, in that you can just as easily swap in another set of questions in some other content area. Similarly many edutainment titles (e.g. where you shoot the equation with the right sum out of the sky) are not Learning Games. That doesn't mean that these games can't be useful for teaching, they just aren't a very interesting research topic. The only learning leverage that this form of games (sometimes referred to as "chocolate covered broccoli", because it involves merely coating the unpalatable content with a tasty coating) offers is motivation. It may indeed be more motivating to shoot math problems out of the sky than to do them on paper, but that doesn't offer much new to the realm of learning theory. Increased motivation yields more time on task and better scores (at least in the short term – long term learning implications are less clear).

Viewed in this light, we can begin to see the discrepancies between the promises of Learning Games espoused by theorists, versus the lackluster results seen in educational gaming deployments to-date. While theorists point to the potential for bona-fide Learning Games to convey deep principles of subject matter in the way Feynman describes, extremely few bona-fide Learning Games actually exist. Instead, much of the evaluation of the field centers on non-games promoting exactly the form of education Feynman despised and students find dull. The simple solution to this would be to say "Learning Game designers are just lazy and need to build better games". The truth of the matter, however, is that designing meaningful learning games is an extremely difficult task. While we are beginning to see the emergence of high quality learning games and slowly coming to an understanding of the principles necessary to build them (Klopfer et al. 2009), this is still largely uncharted territory with many challenges and often requiring considerable budgets to tackle correctly.

Rather than looking for how we can extend previous efforts at Edutainment to address their shortcomings, we advocate that one approach is building upon the rich tradition of using simulation games in schools. As simulations model domain specific concepts, they naturally exclude superficial educational approaches that reward memorization of factual concepts with play. While researchers and educators have already demonstrated rich and powerful learning within games such as *Sim City* (Star 1994), *Civilization* (Squire et al. in-press) and *The Sims* (Sanford et al. 2006), we believe that explicit focus on aligning the strengths of simulation games with educational structures can yield even deeper learning experiences across a wider range of disciplines. At the end of the chapter we introduce *Star-Logo TNG*, a free, ready-to-use simulation construction environment with curriculum plans suitable for Ecology, Biology, Physics, Computer Programing, Math and other subjects.

The Role of Simulations in the Curriculum

The first question to ask when thinking through the possibilities for games in education is "what do we actually want to teach?" Edutainment and Drill & Kill titles generally focused on memorizing facts or more simple curricular goals, as this allowed a simple recycling of the same game system across numerous disciplines with simple content changes. However, it did not lead to rich learning in any particular subject. In thinking about the influence of games and simulations on science learning, I [Dr. Klopfer] reflected on my own experience and training as a graduate student in a biology program. Often when I speak with science teachers they are shocked to learn that my work was almost entirely theoretical with little bearing on what is taught at the high school level. But in fact, while there are supporting references to "real" biological systems, most of the work is entirely theoretical and primarily derived from computer simulations. The fact that simulations have revolutionized modern science (Nature 2006) and support not only confirmatory explanations, but also predictions and new discoveries, is not a part of the experience of most science teachers or their students. So perhaps first and foremost, simulations are critical for the science curriculum because simulations are critical to science. Teaching science without simulations is perhaps more fundamentally unsound than teaching biology without microscopes or chemistry without chemicals. Teachers and students must understand the science of simulations to have an understanding of the modern nature of science, whether that be for practicing science or simply making good decisions about science-based issues on a daily basis.

For researchers and practitioners finding themselves fighting an uphill battle with skeptic school administrators to bring video games into the classroom, beginning with simulations can provide a clear and relatively undisputed argument for their incorporation into the curriculum. At the same time, the jump from simulation to creating true learning game experiences is relatively small and can be made

with little challenge either within the simulation itself or through classroom games constructed around the simulation. In particular, we look at three pedagogical goals served by simulations applicable to a wide range of disciplines: process learning, complex systems and simulation construction.

Process Learning

In education, computational modeling software and associated curricula including *StarLogo*, *NetLogo*, *Connected Chemistry*, *Biologica*, and handheld Participatory Simulations (Colella et al. 2001; Gobert 2005; Klopfer et al. 2005; Stieff and Wilensky 2003; Soloway and Pryor 1997; Resnick 1994; Wilensky and Reisman 2006) have been created for school age students to learn about and visualize systems. Agent-based programs like *StarLogo* and *NetLogo* reveal how simple rules for interaction ascribed to individual agents with varying traits can produce emergent population scale patterns such as flocking behavior in birds, slime mold aggregation, or ant colony organization. Wilensky and Reisman (2006) discuss how the graphical output of the dynamic predator-prey system being modeled enabled the student to not only visualize population patterns but also to hypothesize about the mechanisms giving rise to those patterns (e.g. environmental constraints on population growth). The authors point out that these mechanisms tend not to be well understood by students. In fact such mechanisms are typically ignored in traditional school curricula that treat individual and system scale processes entirely discretely, without providing an opportunity to connect them.

There are a number of studies that show specific science learning results from simulations. For example Meir et al. (2005) showed that a simulation about osmosis and diffusion was effective in teaching certain aspects of this concept when compared to a control. Similarly, another study (Perry et al. 2008) by the same group (with which we are affiliated) showed that an evolution simulation was more effective than text at remediating particular misconceptions, but notably not better than a video of an expert lecturer. The *Modeling Across the Curriculum* (MAC) project has done research on learning through simulations in several domains. The *Biologica* project (Buckley et al. 2006) showed significant gains in learning by most students through their genetics software. Notably, some classes actually declined in performance, indicating that the way that the teacher used the software, not just whether it is used or not, was an important influence on learning. Similarly *Connected Chemistry* (Levy and Wilensky 2009) showed increased understanding, particularly of the connections across scale from micro to macro, through simulations in another MAC project. This connection from micro to macro shares some similarity with the osmosis simulations mentioned previously. Levy and Wilensky point to inspiration from other studies (e.g. Ardac and Akaygun 2004; Kozma 2000) that showed increased learning associated with simulations that explicitly make connections between different representations of the same system.

With respect to adoption by teachers, we know that the incorporation of technologically advanced curricular material into classrooms are met with many well documented challenges, including teacher time constraints, teachers' understanding of technology, teacher confidence levels in terms of computer programming, access to technology, and the lack of supporting curricular materials (Fishman 2004; Yoon and Klopfer 2006).

Complex Systems

Knowledge of how students develop an understanding of complex systems has recently gained momentum in learning science research (Hmelo et al. 2000; Jacobson and Wilensky 2006; Wilensky and Reisman, 2006; Yoon 2008). A complex system can be defined as a system of interconnected parts that as a whole exhibits one or more properties not obvious from the properties of the individual parts (agents). Complex systems scientists and educational researchers speculate that students have a hard time understanding the mechanisms that drive the emergence of large scale global phenomena from smaller scales of interacting agents (Chi 2000). The confusion about causality across scales is thought to be a primary source of misconceptions not only in the formal study of science, but also in everyday life experiences (Wilensky and Resnick 1999). Explanations for how patterns emerge require integrating and matching explanations across scales. That is, patterns at certain scales are intentional, while those at other scales represent self-organization from the interactions of agents at smaller scales. The way in which schools of fish move through the water and herds of ungulates roam across the savannah provide some of the most vivid examples of how individual actions lead to grand large scale patterns. While local environmental conditions can impose hard limits on where species can live and thereby impose large distribution patterns, the interactions of individuals within and between species contributes substantially to pattern development, influencing biodiversity and even evolution (Levin 1999). While a coherent understanding of complex systems presently eludes most students (Jacobson 2001), the need for learning about complex systems is real, and the tools are available. Classroom friendly agent based modeling tools are readily available and have been tested in a number of disciplines, including Biology (Klopfer 2003; Klopfer et al. 2009), Chemistry (Levy and Wilensky 2009) and Physics (Scheintaub and Klopfer 2008).

In a recent paper, Goldstone and Wilensky (2008) argue that using simulations of complex systems can promote far transfer across systems of disparate subjects that share common complex systems principles. Students learning from simulations of complex systems "actively interpret" the simulation, and learn to understand systems by identifying these common principles. Transfer occurs not because students remember abstract formalisms, but rather because they can apply methods of interpreting events. They note that the transfer of understanding across systems can occur even when students don't explicitly note the underlying similar-

ities between the systems. This is a compelling argument with large potential for transforming the way that science is taught and learned.

One interesting related note that Goldstone and Wilensky point out (citing Goldstone and Sakamoto 2003 and Scheiter et al. 2006) is that despite the intuitions of some designers, models of complex systems that are abstract and idealized promote learning better than models that are detailed and realistic. Work on simulations of complex systems has not been restricted to desktop computers, Participatory Simulations (e.g. Wilensky and Stroup 1999; Klopfer et al. 2005), the C5 architecture (Repenning and Ioannidou 2005), and Ubiquitous Games all use distributed architectures and mobile devices to engage students in social simulations, maximizing the benefit of social collaboration and adapting more flexibly to classroom realities.

Simulation Construction

From the student learning perspective, researchers suggest that construction, in addition to manipulation of simulations, may lead to more optimal learning outcomes (Papert 1980; Resnick 2002; Sherell et al. 2005). For example, Kuch (2007) found that by providing students with a tool to create their own simulations and the skills to design models, students were able to augment their intuitions to develop testable hypothesis and scientific models. This is particularly relevant in the domain of complex systems, where programming activities that focus on simple behaviors can help students connect those behaviors to emergent system scale outcomes (Goldstone and Wilensky 2008). Recent calls by national organizations indicate that efforts should be made to improve capacities in computer programming including algorithmic thinking (ACM 2004) and model-based reasoning (NRC 2006), and acquiring, manipulating and representing data as well as the engineering of computational tools that support those activities (NSF 2006).

From Theory to Practice: *StarLogo TNG*

In order to facilitate the process of students creating their own complex systems simulations and creating games that incorporate complex systems simulations, we designed a program called *StarLogo TNG*. This offers a framework for thinking about the combination of simulation development (engineering design) with simulation use (scientific method). The two cycles of design and investigation are connected by an intermediate area of "Test, Tinker and Play". One might design and build a simulation and then start to test it. As one tests the simulation they enter a cycle of observation and data collection, followed by generation of questions. This in turn comes back to more testing or tinkering. These linked processes model the way that many simulations are developed, tested and used, while promoting skills

in both scientific methodology and engineering design. Other work on student created models of complex systems have employed *NetLogo* and *AgentSheets*.

While one could simply use *StarLogo TNG* to recreate and visualize different simulations, its real power comes in its ability to naturally blur the lines between simulations and games. Besides all the components needed to build complex simulations, *Starlogo TNG* also includes a suite of tools for attaching different input controls, scoring mechanisms, objectives, and feedback to create game experiences out of simulations. By exploiting the many connections between Simulations and Games, we hope school activities constructed around *Starlogo TNG* can achieve many of the goals set out by learning game theorists, while simultaneously building upon the clear pedagogical rational from using simulations to understand a given discipline, as well as the constructionist pedagogy advocating by Seymour Papert and others. By including game elements, however, kids are given freedom to experiment in ways not normally encouraged in a simulation, and challenged to understand the depth and manipulability of a system well enough to accomplish their goals. As an example, Klopfer et al. (2009) outline an example classroom in which two teams of students are each working on designing their own virtual worlds. Both of them are researching the nature of fluid dynamics, tide flow, buoyancy and other ocean concepts, then prioritizing which aspects should be modeled and which are superfluous. Both are researching weather systems to understand which variables to incorporate and how they will impact the overall system dynamics. But one is designing a simulation of warming seas to understand the impact on endangered animals, whereas the other is constructing a jet-ski racing game to entertain their friends. While the former would have a much easier time gaining acceptance in a curriculum review committee, as some other chapters in this book demonstrate, the latter has its own set of advantages for student engagement, imagination and depth of exploration. By using environments that can fluidly move between these two worlds, we hope we can provide a more natural entry path for learning game adoption by schools and create more meaningful connections and transfer between game worlds and formal learning.

While the call for the usefulness of introducing simulations in schools is hardly new, or even of constructing video games for that matter, the technical proficiency required to do so has largely limited the possibilities to simplistic simulations that fail to captivate and excite students. Mostly this challenge comes simply from how difficult it can be for non-programmers to learn how to create complex programs. In order to make even a simple program, beginners need to learn the precise usage, syntax and ordering for a myriad of commands and control structures. Forgetting even a single semicolon could mean learners would never see their program succeed. In order to make programming more accessible to early learners, Seymour Papert and his colleagues created the *Logo* programming language. In *Logo*, learners were given a specialized learner language with an extremely simplified set of commands and syntax. For example, programming simple behavior for a game character could look like this (Begel and Klopfer 2004):

```
to run
```

```
if pc = red
    [ rt 180 ]
setenergy energy – 1
eat
ifelse (random 100) < 10
    [ die ]
    [ move ]
end
```

Yet, even this simplified language proved intimidating for novice learners. Some would simply write "if red", without realizing that a conditional requires properties on either side of the equals sign (Begel and Klopfer 2004). Some would forget which commands needed to be bracketed, and which ones didn't. Others would simply forget the names of different commands needed to accomplish particular tasks. Any one of these possibilities or others would result in a complete failure of the program to run, rapidly frustrating students.

In StarLogo TNG, we instead give students an entirely new graphical mechanism for entering commands.

Fig. 37.1. Graphical Programming with *StarLogo TNG*
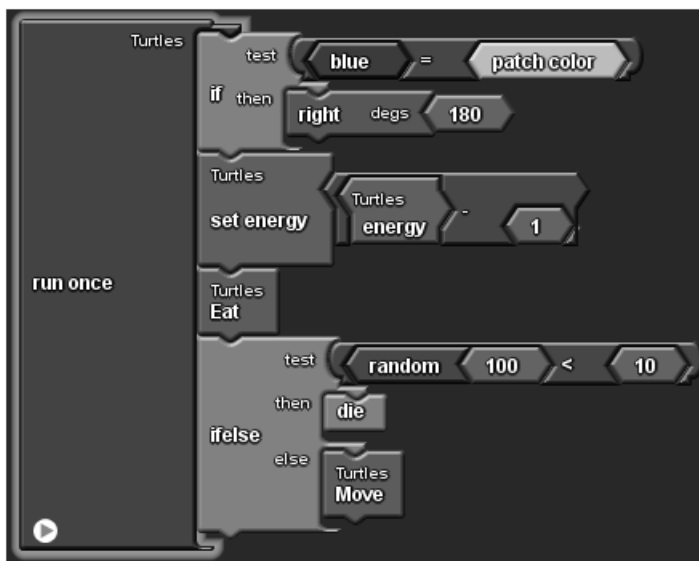
As illustrated (fig. 37.1.), students are given a series of puzzle pieces, each representing a particular programming command or property. Students construct the program by snapping together puzzle pieces. Anytime they forget the programming language, the system provides them with visual support. If students were to try to connect the "if" block to the "blue" block, they would observe that the triangle edged "blue" piece does not fit into the crescent shaped "if" hole, a fact which visually confirms that the two word types are incompatible. Similarly, if they tried to say "if = blue", they would see the empty hole for "patch color", requiring them to specify what needs to be compare with "blue". If a student forgets which words are available to them, they can simply browse through catalogs of shapes filled with the specific connectors that they might need. In this way, what to an outside observer might look like nothing more than colorful animated bricks turns out to provide crucial feedback for users learning the system. The interface still allows the rapid construction of statements but also forces learners to think through all of the steps in that construction.

Using this, students can not only play games/watch simulation systems, but understand and make changes to elements of a system, or program their own complex creations from scratch. Figure 37.2. shows an extract from an Ecology unit where students learn about the nature of forest fires. Here they play the role of Homer Simpson, trying to make informed decisions about which trees to cut down in order to best control a fire through their understanding of the simulation. Figure 37.3. shows *Runaway Bunny*, an action game in which players take the role of a rabbit trying to escape an oncoming forest fire based on their analysis and modifications of a fire simulation system.
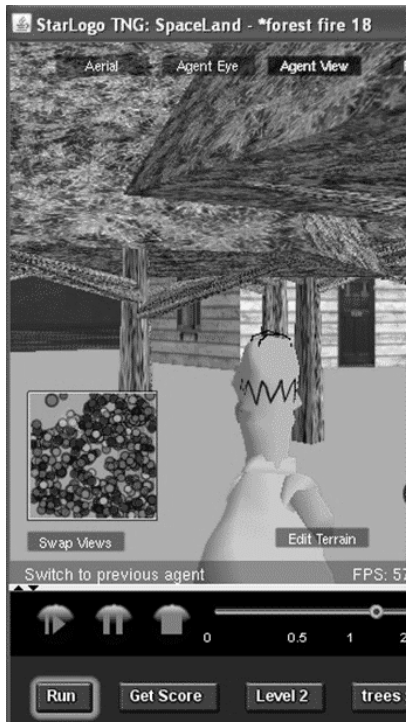
Fig. 37.2. Extract from an Ecology Unit

Fig. 37.3. *Runaway Bunny* – an Action Game Created in the Ecology Unit

Other example curriculum includes an epidemiology unit in which children construct their own games in the process of developing their understandings of how diseases spread.[1] Most participants in this unit tend to create games in which players have to avoid different diseases by understanding the different spreading mechanics and strategically avoiding contact. However, the system provides total programming flexibility for students to introduce any creative elements they imagine, such as zombies. In Physics classes, students can easily construct games involving advanced simulations of how a projectile travels to a given target.[2] Interestingly, students appear readily able to transfer knowledge between their traditional coursework and their virtual worlds (Klopfer and Scheintaub 2008).

In a junior physics class students built swimmer-in-river simulations as part of a unit on vectors. The model has a swimmer with velocity, s, swimming at a given heading across a river of given width with current velocity, r. After building and playing with the simulation, students were assigned two-dimensional motion problems for homework. During a class discussion over the answer to a contested problem, one student went, unprompted, to the computer and opened his swimmer model. He plugged the variables of the problem into the code of the model and ran the model. As the swimmer reached the opposite shore he exclaimed, "I told you I was right!" When asked in an interview why he chose to use the computer rather than mathematical analysis to prove his point, he said. "This way you could *see* I was right". While we don't have comparative data, in another physics class that used *StarLogo TNG*, 75% of the surveyed students agreed with the statement that the *StarLogo* unit was more difficult than other units, while 100% of the students felt the unit was more rewarding; demonstrating the motivating potential of programming through game design/development in the context of a physics class.

While examples like the one above are encouraging for underscoring the educational value of working with Simulations, we should now be exploring all the ways in which we can further build upon such efforts to achieve the various promises of game-based learning. Within *StarLogo TNG* we could easily modify such a simulation to give players different control of the swimmer, calculate scores based off different trajectories, include different bonuses and power ups that change the river conditions, challenge obstacles to work around, etc. This, in turn, allows a much wider range of students to enter the games as players and become familiar with the basic physics principles. It also provides an opportunity for the students themselves to start working with physics, programming and design as they themselves may add these components. Over time, these players have the option to then go even deeper into the underlying mechanics by creating new games themselves based on their own understanding of systems – giving them an in depth understanding of the concepts from every angle. In this way learning games become not just a mechanism for funneling discrete content into kids minds, but rather a suite of experiences that can bring even students with zero exposure into the subject

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1 http://education.mit.edu/drupal/starlogo-tng/epidemic-tutorial, accessed 27 September 2010.

2 http://education.mit.edu/drupal/starlogo-tng/physicscurriculum, accessed 27 September 2010.

area and give them opportunities to work with all the concepts involved in recreating that phenomenon themselves.

To use Feynman's example, students in this case are no longer just memorizing that "energy makes it go" or how to define energy or even where it's used. Rather, in a sense, they themselves are writing the textbook, authoring their representations of how energy operates and putting it out there for the world to experience and provide peer-feedback. Additionally, as students get used to authoring, distributing and receiving feedback on their creations, we provide students with all the tools needed to continue their learning and exploration well beyond the duration of the class or the assigned content area, setting the stage for continued rich learning. In the same way in which we wish for students to reach a level of understanding deeper than "energy makes it go", we ourselves need to dig beyond understandings such as "games make it fun but less educational". Rather, we should look at "games" as a constellation of components (goals, feedback mechanisms, narratives, etc) and social practices (experimentation, problem solving, etc). By finding where each of these components already exist or are desired in our curricula, we can find opportunities to create learning games that are practical to build, rich in their learning and accessible to classrooms.

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