Developing Games and Simulations for Today and Tomorrow's Tech Savvy Youth

By Eric Klopfer and Susan Yoon

Constructively promoting the educational development of today's young tech savvy students and fostering the productive technological facility of tomorrow's youth requires harnessing new technological tools creatively. The MIT Teacher Education Program (TEP) focuses on the research and development of educational computer-based simulations and games for K-12 students and teachers. This field grows out of the social constructivist basis of much of science and mathematics educational research where students are encouraged to learn through collaboration, conducting experiments and testing hypotheses. These new technologies engage students at a deeply meaningful level, and provide them with the tools and techniques that scientists, engineers and technology workers across a diversity of fields use every day. Also at the core of this program is the belief that we must build a bridge between students' experiences in and out of school by incorporating into school curricula the tools, technologies and experiences that students acquire outside of the classroom. The specific technologies that the TEP has created range from StarLogo TNG, a simulation environment that allows students and teachers to build their own 3D immersive simulations, to handheld Augmented Reality (AR) simulations that combine real surroundings with virtual simulated information to convey authenticity in large scale scientific investigations. This comprehensive program works with scientists and engineers to ensure that the tools accurately convey scientific practices. It involves multiple levels of teachers in a variety of subject domains as design and implementation partners, and engages researchers to better understand what and how students learn from these technologies. Our goal is to provide important links between school curricula and the tools and technologies students are either already experiencing or are likely to experience in real world events, with the notion that they will acquire the skills, knowledge and habits of mind to be successful participants in our increasingly technology-infused society, thereby "bridging" experiences between the classroom and the outside world.

Demand for new skills and ways of thinking

The shift from an industrial to a knowledge-based workplace has demanded that students acquire a new set of skills that include effective collaboration, working with incomplete information, adapting to changing conditions, managing complexity and creating and sharing knowledge (Dede, 2000; Peters, 1997). Murnane and Levy (1996) state that traditional curricula and activities are poorly adapted to helping students gain proficiency in this new set of skills and suggest that new educational experiences are required to meet this need. While technology has predominantly led to these new challenges, fortunately, it

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also presents itself as part of the solution in that these technologies can provide engaging and meaningful learning environments and educational opportunities (Dede, 2000).

Too often the call for an educational focus on preparing students to operate in a knowledge-based society has only resulted in attempts to improve surface-level computer literacy skills like word processing or internet use (National Academy of Sciences, 1999). To be really prepared for tomorrow's world and workplace, however, students must be technologically "fluent," not merely literate. In *Being Fluent with Information Technology*, The National Academy of Sciences (1999) defines such fluency in terms of three categories of "FITness": Contemporary Skills, Foundational Concepts and Intellectual Capabilities. While many programs address the first of these skills, far fewer address the second two, particularly the intellectual capabilities which include: engaging in sustained reasoning; managing complexity; testing solutions; organizing, navigating and evaluating information; collaborating; and communicating to other audiences.

As these intellectual capabilities indicate, the skills and understanding that we are trying to build in today's youth extend beyond "information management." They center on the idea that we must create a culture in which students can navigate novel problem spaces and gather and apply data to solutions collaboratively. In addition, Resnick (2002) suggests that an equally important goal for advancement and innovation is for educational programs to foster creativity and imagination. In other words, students should be acquiring habits of mind that will not only enable them to address today's problems and solutions, but also allow them to venture into previously unimagined territories. To achieve this, they should develop the capacity to use technological tools in order to create manifestations of their ideas and further, to test their ideas and convey them to others. Having ways for students to both learn and express themselves through new technologies is key to producing new innovations. Integrating these ideas into the essence of the "FITness" skills allows us to re-envision the proficiencies that our program seeks to promote in students, providing bridges between what is learned in classroom contexts and the learning needed to succeed in the broader knowledge-based workplace. These are:

- Work with local and remote peers to solve problems collaboratively (Collaboration)
- Identify pertinent data sources and then collect, analyze and apply (often incomplete or faulty) data (Data Navigation)
- Develop understanding of and manage solutions in complex systems (Complex Systems)
- Use creativity and imagination to provide innovative new ideas, technologies and solutions (Innovation)
- Construct and test ideas and technologies in meaningful ways (Construction)
- Communicate solutions, innovations and ideas to diverse audiences (Communication)

While these skills represent the purposes for the development and implementation of our new technologies, they are also guided by a set of design principles through which these goals are achieved. Following the above discussion points, the following design principles have been constructed to build bridges between:

- Class work and the rest of students lives — promote working across time and space inside and outside the classroom
- Students' interests and educators' learning objectives — harness today's students' skills and interests by understanding a diverse and changing youth population
- Popular, scientific and classroom cultures — create connections between students' experiences with their peers and through media, and corresponding places in academic, scientific and classroom cultures

- Where they are now as students and what they may become as professionals — engage students deeply in activities to allow them to see themselves as successful scientists, engineers and problem solvers
- Where schools are now and where they can go — start from where schools are now to work within current contexts and help lead them in new directions

Through the development of new technologies, supporting pedagogies and professional development strategies, the MIT Teacher Education Program has started to build components for these needed bridges. They stretch from one bank representing where students are now and span a river to the bank where schools, teachers and the culture of education exist.

Where students are (one bank of the river)

As we look to where students are now, the TEP has focused on three main technological innovations that have had a great deal of influence on students' lives and appear to be headed for even greater influence — social computing, mobile/ wireless computing and video games.

Social computing includes instant messaging (IM) via computer or cell phone and may also be extended to include sharing of information via Peer-to-Peer (P2P) networks. Students enjoy and potentially can benefit from this real time collaboration and information sharing, whether it is about where to gather for a meeting, or collecting and disseminating distributed resources. Finding ways to integrate this technology into effective learning activities can be a challenge, but the TEP has made this a core component of its handheld Participatory Simulations in which social interaction is key, as well as in its Augmented Reality (AR) simulations in which students must collect and analyze location-specific information over vast spaces.

Mobile and wireless computing overlaps with social computing to some degree in that one of the chief uses for mobile and wireless computing is IM. Students use IM through their cell phones to arrange meetings at the mall, but may also use it to exchange answers covertly on a test in a classroom. Similarly, students use Personal Digital Assistants (PDAs like the Palm or Pocket PC) to organize their lives, but also to store things like illicit copies of the periodic table for a test. Creating ways to use these capabilities effectively in the classroom and educating students on responsibility is the key to success. Both the MIT Participatory Simulations project and Augmented Reality (AR) project use these technologies at their core, employing the latest in wireless technologies to promote collaboration.

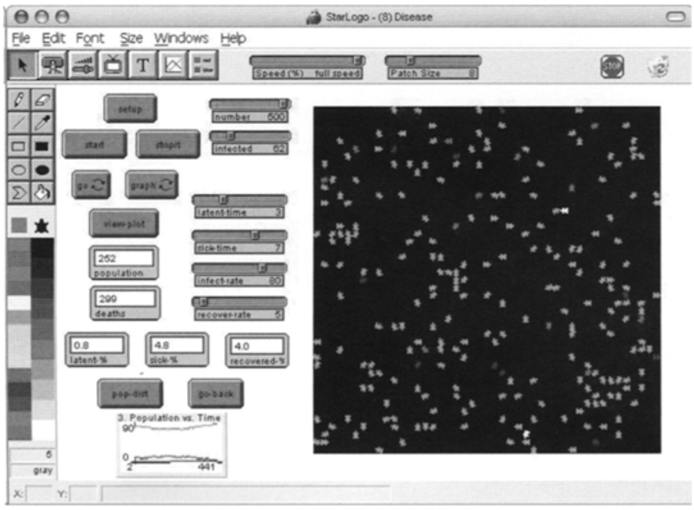
Video Games also overlap with the two previous domains since many students play video games on their phones or mobile Game Boys®. To date video games and learning have had a tumultuous relationship because many perceive video games as taking away time from productive learning activities. However, a resurgence of interest in the educational value of this medium, due to the overwhelming interest by today's youth, and evidence that game players may be learning important skills for the workplace (Beck & Wade, 2004) has shown that video game design has implicitly taken on many facets of good instructional design (Gee, 2003).

Components such as maintaining player interest, devising ways of gauging proficiency and advancing to the next level, teaching essential skills and weaving interesting problems to solve have been mastered by many of today's game designers. Figuring out ways to both use existing games that do this well (e.g., *Civilization III, Sim City 4*), and creating educational games explicitly for this purpose is what started The Education Arcade (TEA) at MIT. The mission of TEA, a partnership of programs in education and media studies in collaboration with other scholars and developers, is to demonstrate the social, cultural and educational potentials of games by initiating new game development projects, coordinating interdisciplinary research efforts and informing public conversations about the broader and sometimes unexpected uses of this emerging educational form in K-

```
turtles-own [age infecttime fertrate

to go
  infect
  recover
  check-health
  setage age + time-step
  if (health = sick) or (health = le
    [setinfecttime infecttime + 1]
  batch-babies
  die?
end
```

Figure 1. A simple epidemic model in the current version of StarLogo. A section of code for the model is seen on the left, while the run time view is seen below.



number 500
infected 62
latent-time 3
sick-time 7
infect-rate 80
recover-rate 5
population 252
deaths 299
latent-% 0.8
sick-% 4.8
recovered-% 4.0

12 classrooms. TEA works with the Entertainment Software Association to hold an annual video games in education conference in conjunction with E3. Currently TEA is working on new game development projects in history, environmental and health sciences, as well as a large media literacy effort. A partner project, The Learning Arcade, is collecting, developing, and distributing curriculum for commercial "edutainment" games.

From the perspective of where students are now in terms of social computing, mobile/wireless technologies and computing and video gaming experiences, there are exciting opportunities to build bridges into classrooms and curricular contexts. These bridges are the subject of the section that follows.

Technologies and pedagogies: The bridges

Bridge #1: Understanding complex systems using *StarLogo* and *Adventures in Modeling*

The role of complex systems in authentic scientific practice and the recognized place of modeling in the curriculum (AAAS, 1993) indicate that improving student understanding of complex systems and conveying more authentic scientific methodologies ought to be a significant component of science education reform. Yet, research (cf. Resnick, 1996; Penner, 2001) has shown that students struggle with understanding the dynamics of complex systems despite the importance of this conceptual domain in high school science (Jacobson, 2001). In order to help students understand complex systems better a computer-modeling environment called *StarLogo* was created for students and teachers (Resnick, 1994). In *StarLogo*, one writes simple rules for individual behaviors of agents that "live" and move in a two-dimensional environment. For instance, a student might create a model of an epidemic by defining rules for healthy and sick people that describe how they should move, how they interact and how they become healthy or sick (Figure 1). Similarly, one might define rules for how a bird flock forms through a set of simple rules that each bird follows about where it should fly with respect to its neighbors, not by following a "lead bird" as one might expect. Because *StarLogo* makes use of graphical outputs, when students watch many people simultaneously following those rules, they can observe how patterns in the system, like the spread of a disease, arise out of individual behaviors. Building models from the individual, e.g., "bird" level enables people to develop a better understanding of the system, or "flocking" level behaviors.

To make this software more accessible and effective in the classroom we developed a curriculum, *Adventures in Modeling* (Colella et al., 2001) that challenges the traditional scientific method approach in science classrooms while building understanding of complex systems. The curriculum strikes a balance between structure and exploration by organizing activities around a set of open-ended *StarLogo* design Challenges on the computer and a series of off-computer Activities, in which participants enact and analyze a simulation.

Though on-screen computer modeling is one focus of our teacher professional development workshops, off-screen Activities provide another way to connect abstract notions of scientific systems to personal experience (Colella, 2001). These Activities allow participants to think about concepts like exponential growth, local versus global information and group decision-making from a personal perspective. Another set of "Participatory Simulation" activities developed and distributed through MIT, use handheld Palm computers to engage participants in simulations. These simulations might be thought of as computer-facilitated activities in which the students act out the simulation themselves. Research has found that these simulations, which range from simulating epidemics to genetics to market economies, successfully build student understanding of complex systems, as well as their interests in new technologies (Colella, 2001; Klopfer et al., 2004; Klopfer & Woodruff, 2002). These activities have also been found to engage a diversity of learners, even those with little to no technological interest. The personal and collaborative nature requires everyone to be engaged yet allows each person to play a unique role.

Bridge #2: Constructing new worlds and understanding with *StarLogo TNG*

Currently, we are in the midst of a three year NSF-funded project to work with middle and high school students and teachers to integrate computer modeling into the curriculum, raise both science and math content knowledge and improve technological proficiencies. The program has met with a great deal of success in the classroom and has made strong links with other educational organizations focused on improving technological knowledge, skills and career awareness.

While many teachers we work with are successful at developing their own models and using them in the classroom, we have had relatively less success getting teachers to facilitate model construction with their students. Yet teachers and researchers alike recognize the importance of this kind of programming activity in that students build up the necessary skills for computer science. This alone opens up new realms of possibilities. Wolfram (2002) has described how very simple computer programs can be used to explore vast new domains of science. Learning to develop algorithms requires students to solve problems systematically. Many problems require students to develop and apply mathematical skills and analysis to develop their programs and interpret the output. Together these skills comprise a suite of desirable learning outcomes for students, many of which are difficult to engender through traditional curriculum activities. Teachers, however, have been limited by the time, expertise and comfort it takes to introduce their own students to programming. Additionally, students have conveyed that while they find the experience rewarding once it has begun, it does not have the polish and visual appeal of many of the graphical tools and games to which they have become accustomed.

Enter *StarLogo TNG* (TNG was originally used to designate "The Next Generation"), a new tool in which models can be developed using a graphical programming language built of "blocks." In this redesign process we carefully considered our audience — primarily middle school through high school and college students — and the context in which these tools might be used. This has brought about the development of a broadly applicable tool, one in which, for example, a biology teacher might encourage students to build simulations of a biome, or students might choose to develop a 3D adventure game. With regard to this latter application, today's tech savvy youth have grown up with video games as a part of their culture. For many, games are what entice them to use technology. While boys still currently invest more time in game playing than girls, the gap is rapidly closing and both boys and girls have become avid gamers. Through this familiarity with games, students have begun to develop one half of video game literacy (Gee, 2003) — they have learned to "read." But they have not yet developed the other half of that literacy — learning to write. In order to achieve full video game literacy, we can use the existing half to lead them into writing, thereby connecting their interest and knowledge of games to the practice of programming. Using *StarLogo TNG* students and teachers can rapidly develop and understand new programs and create their own 3D worlds in which to run them. *StarLogo TNG* incorporates two major changes from previous versions of *StarLogo* — StarLogoBlocks, which provides a graphical interface for building models (Figure 2a), and Spaceland (Figures 2a and 2b), which provides a 3D perspective of the model in action.

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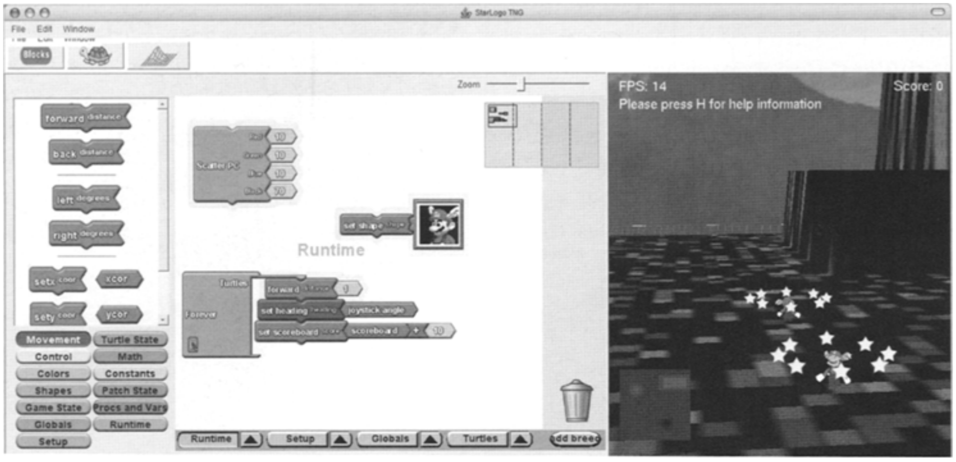

Spaceland is a three dimensional view of the world which can be navigated via keyboard controls (and soon an on-screen navigator). The default view is similar to the old *StarLogo* view, being a top down representation (Figure 2a). From this view, the user can now zoom in on any portion of the world for a closer look and view the 3D landscape as they fly by. The other available view is the first person view or "Turtle's Eye" view. In this representation, the user sees out of the "eyes" of one of the turtles in the system (Figure 2b). In the proper context, a more realistic looking world can be used to convey useful representations of scale and context, e.g., conveying the sense of a landscape or the changing of seasons.

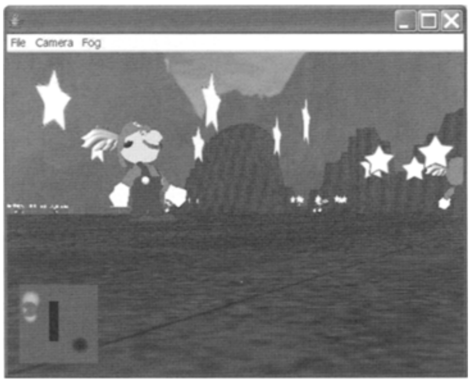

Figure 2. The current development version of StarLogo TNG. *The main view of* StarLogo TNG *includes panels for the programming blocks and 3D Spaceland views (above). The 3D view can also be selected to be seen from the Turtle's Eye perspective (below).*

Accompanying Spaceland is StarLogoBlocks, a visual programming language based on LogoBlocks (Begel, 1996). This uses pieces of code to represent puzzle pieces on the screen. The "blocks" metaphor provides several affordances to the novice programmer including quick and easy access to the entire vocabulary, and freedom from worrying about syntax since the shape of the blocks is designed so that only commands that make syntactic sense will actually fit together.

Bridge #3: Bridging time and space in and out of the classroom with Augmented Reality (AR)

The growing sophistication of mobile technologies brings with it the power to introduce new learning environments and experiences. The most powerful uses of handheld technologies require working with their limitations and affordances. The PDA is best used to present an extra layer of data to supplement information that users receive from their real world context such as readings from simulated instruments, interviews from virtual occupants of nearby buildings, or real life interactions with their classmates. The MIT TEP has been building simulations on handheld computers that involve K-12 students in authentic activities such as large scale environmental engineering investigations, genetic data collection and analysis and epidemiological studies that track the progression of disease through populations.

Studying realistic complex situations requires technologies that can make students feel as if the problem is authentic, while scaffolding the learning process and providing sophisticated investigative tools. Augmented Reality (AR) devices superimpose a virtual overlay of data and experiences onto a real world context. We use what we describe as a "light" form of AR, in which a real world context is supplemented by virtual information supplied via a location aware PDA. Others have described this approach as "hybrid reality" or "pervasive gaming," but we interpret AR to encompass a broad spectrum of technologies and approaches, from "light" versions that use much of the real world context and a simple small display like the location aware PDA to much "heavier" versions that provide more virtual information using head mounted displays. Early work on AR indicates these immersive interactive experiences are promising for learning (Falk et al., 2001; Klopfer et al., 2002; Klopfer & Squire, 2003; Klopfer & Squire, 2004; Walz, 2002). AR simulations can be designed not only to support learning disciplinary content knowledge, but also provide opportunities for students to develop critical 21st century IT skills including computer-mediated collaboration and information sharing, managing uncertainty and analyzing complex systems.

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For example, our first AR simulation, *Environmental Detectives* (Klopfer et al., 2002), engaged students from middle school through college in a real world environmental consulting scenario, a situation that most students are unlikely to experience. Students role-play environmental scientists investigating a rash of health concerns on campus linked to the release of toxins in the water supply. Working in teams (Figure 3a), players attempt to identify the contaminant, chart its path through the environment and devise possible plans for remediation if necessary. As students physically move about campus, their handheld devices (Figure 3b) respond to their location allowing them to collect simulated field data from the water and soil, interview virtual characters and perform desktop research using mini-webs of data. At the end of the exercise, teams compile their data using peer-to-peer communication and synthesize their findings. Indoors at the Boston Museum of Science, we created a second generation AR simulation that integrated the physical and intellectual space of the museum with the virtual space of the handheld computer. This simulation engages teams of parents and children in solving a scientifically based "who done it" by collecting virtual forensic evidence (Figure 3c) and interviews from virtual characters. Feedback from pilot runs of this simulation included comments from museum educators who found the technology to be uniquely effective for engaging visitors in museum exhibits, and from female players who discovered that the technology was very empowering.

Figure 3. Students viewing some virtual environmental samples as they play the outdoor Environmental Detectives *(above). In these outdoor games, the map view (center) is the main screen that players use. In the indoor game, (below)* Mystery at the Museum, *players collect virtual forensic evidence.*

AR games currently under development address the domains of infectious diseases and forensics. These domains incorporate many aspects of science and technology, and also provide engaging scenarios that are of public interest. While the initial games using this technology had the ability to span over large geographic areas, a new innovation in this next generation will be the ability to play over large periods of time (days or weeks). This innovation is designed to allow students to play in small amounts of time outside of class and then integrate their findings in course work within their classes.

To facilitate more rapid deployment of new AR games to new locations, a significant part of our recent efforts has been devoted to developing AR authoring environments that would allow anyone to author their own games. These tools are designed for novices and structure the development process so that teachers and/or students anywhere can both play and author these games.

Professional development: Another important bridge

In the current educational climate of high stakes accountability, it is critical that teachers and administrators are able to understand the uses and acquire the ability to integrate new technological innovations with existing curricula. Another important bridge that must be built deals with the real-world dilemmas of practical applications within schools and the need to fulfill the edicts of federal reform policies like *No Child Left Behind.* In order to build this bridge, effective professional development programs need to accompany the development and implementation efforts of these new technological tools. Consistently, one of our central development goals has been to harness both complex systems conceptual understanding and skills to navigate within complex systems. Similarly, we take a complex systems approach to the design and implementation of professional development programs. Our professional development model is based on four foundational design principles of complex systems (FANS): Feedback — continuously monitoring the affordances and barriers to implementation; Adaptation — using the information obtained from the various feedback sources to modify and improve professional development activities as well as encouraging teachers to reflect and act on their own adaptation processes; Network Capacity Building — working toward scaling the technological innovations by building partnerships among program schools and external organizations and coordinating operations at the district and state levels; Self-organization — moving toward creating the conditions for autonomous, self-sustained program activities. We have used this model to understand how the various pre-service and in-service teacher populations we work with use our handheld Participatory Simulations (Klopfer, 2004). In our NSF-funded project working with middle and high school teachers in 20 schools across New Mexico, we have identified critical implementation variables hinging on a meta-theme of structure vs. agency (Yoon et al., 2004): a) centralization of resources: innovators vs. status quo; b) organizing for self-organization; c) harnessing individual network capacities; d) authentic use of communication tools; e) transforming self-efficacy beliefs; and f) working within pre-existing systems. Information garnered from this professional development approach has been extremely useful in coordinating efforts amongst researchers, facilitators and evaluators on our projects to address program needs as the new technologies are deployed in real-world classrooms and schools.

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Assessment: Understanding under what conditions the bridges hold up

Much of the thinking in science education focuses on the need to make the learning of science more like the practice of science. Calls for inquiry-based learning, developing skills for systems thinking, harnessing the tools and technologies of scientific practice and creating scientific investigations that reflect current understanding, are all components of this focus (National Committee on Science Education Standards and Assessment, 1996; AAAS, 1993). At the same time, studies in cognitive science over the last few decades have argued that students think and learn more effectively in an environment that is constructive, collaborative, interactive and contextualized than in a more traditional teacher-centered classroom (Bransford et al., 1999; Roschelle et al., 2000). Research on the topic of games and learning (supported by the experiences of teachers) has shown that constructing playful learning experiences can aid in building understanding (Malone & Lepper, 1987; Rieber, 1996; Rieber et al., 1998). Furthermore, the shift from an industrial-based economy to a knowledge-based economy has created a demand for students with a new set of skills.

In order to assess these new technologies adequately, we must do so in the context of these questions. We must think beyond whether these tools can engender better arithmetic skills and devise ways to assess whether we can meet our goals of fostering collaboration, innovation, construction, communication, the ability to navigate data and the understanding of complex systems. Traditional assessments are unable to measure these facets of learning and achievement. As we bring these technologies to young people in and out of the classroom we must begin to assess how well these goals are being met. The TEP has recently embarked upon efforts to assess what students are learning through our handheld projects via new instruments designed with these new learning goals in mind. For example, we are currently investigating how multiple uses of Participatory Simulations across high school biology curricula influence both students' content knowledge and more general problem solving and data analysis abilities. We are using a combination of standard science assessments (*Iowa Tests of Educational Development*) and custom designed assessment protocols that measure understanding of the biology concepts that are represented in the particular Participatory Simulation (e.g. genetics, which is covered in the game "Live Long and Prosper"). We are working with 10 teachers and 20 classes around the Boston Metro area. While student data analysis is forthcoming, preliminary results indicate improvements in data management and problem solving skills, increases in engagement levels, communication and collaboration capacities and greater in-depth conceptual understanding including remediation of previously held misconceptions.

But this is just one effort amongst many. We will continue to advance what students are learning through technologies in order to better gauge how our goals are being met.

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