WHAT DO GAME DESIGNERS KNOW ABOUT SCAFFOLDING? BORROWING SIMCITY DESIGN PRINCIPLES FOR EDUCATION

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ABSTRACT

What do game designers know about sustaining learner engagement? This paper analyzed the popular simulation game SimCity with the goal of identifying design principles that would be useful for educators. The term 'organic feedback' is used to describe how SimCity gradually increases the complexity of its simulations and gives players a constant, pleasing level of new stimulation with taking control away from the user. This model of organic feedback might be useful for designers of modern simulation environments that strive to give learners control of their learning, but also must meet the challenge of communicating complex content. The paper ends by describing how a game such as SimCity could be adapted to fit better into a school environment with new features such as better exporting of raw data, direct access to the simulation engine, and professional development support for teachers.

INTRODUCTION

A key challenge of using complex simulations for education is helping students move up the difficult learning curve of using these tools. Computer simulations such as Interactive Physics, StarLogo, and Stella have great potential as learning aids, but students must master a daunting set of skills and concepts before they can work effectively with them. Too often, a classroom teacher is forced to use these tools in a shallow or overly-structured way, not because the students cannot master the advanced concepts, but because students lack the motivation and self-direction to become experts with these tools without an unrealistic amount of personal help from the teacher. The result is that wonderful tools often get relegated to marginal roles within the curriculum, or are not used at all.

To address this problem, there is current research on methods of 'scaffolding' student learning in these environments. Some progress is being made on the cognitive side of this problem. For example, Model-It has been a successful implementation of a Stella-like dynamic modeling (Jackson, Stratford, Krajcik & Soloway, 1995), partly through clever interface design, and partly through attention to contextual variables such as curriculum design and teacher professional development.

There is now a need for research on scaffolding of engagement to supplement scaffolding of cognition. In order to master complex domains, students must stay engaged and motivated for extended periods of time, but the design features that promote extended engagement are not well understood. While there is a growing set of studies of developing learner understanding, there are few careful, detailed studies of students' engagement and attention-management processes while learning complex simulations.

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Happily, there exists a great untapped body of knowledge on this topic. The field of computer game design has been evolving for years, driven by the single-minded goal of creating software that can maintain people's attention and engagement over long periods of time. Some games, such as SimCity, require players to learn complex sets of rules and relationships, similar to the simulation environments built by educators. It is worth asking how games 'scaffold' students through the process of learning to operate in these systems, without having recourse to a curriculum, a classroom setting, or any motivators external to the game itself.

Game designers can also learn from educators, of course. Simulation game designers generally do not attempt to help players reflect on the embedded conceptual knowledge necessary for robust learning and transfer. Game designers also do not attempt to integrate games into a larger classroom context. This paper will develop some examples of how a SimCity-like game could be expanded with tools to support reflective learning and integrated classroom-friendly features.

ENGAGMENT AND THE 'FLOW' STATE

Most people have had the pleasant experience of becoming completely engaged in some goal-oriented task--perhaps a video game, a project, or a skilled performance. Perhaps the task is one that other people would consider to be unpleasant work, yet the person finds him/herself accomplishing a great deal with little conscious effort. The person loses track of the passage of time, and the work becomes a pleasant, highly productive, highly stimulating yet strangely relaxing experience. Many people have also wondered, why can't more of the things we do be accomplished with this degree of engagement and enjoyment?

Trying to answer this question, Csikszentmihalyi has researched the mental state which he calls 'flow'. Csikszentmihalyi's description of the resulting 'flow' state resonates with most people who have experienced, but perhaps not understood it. In flow-type engagement, the person finds that little energy or attention is siphoned off for self-monitoring; instead, all energy is directed into the task. The person often loses track of time, so completely is s/he engaged in the task. The challenge of completing the task, coupled with the feedback, provides a high level of stimulation, yet the person may also find him/herself strangely energized rather than tired.

Csikszentmihalyi describes three conditions necessary for a flow state to occur: high challenge level, matching high skill level, and frequent informative feedback. The prototypical 'flow' experience is a musician performing a piece that is exactly at the limit of his/her skill. If the challenge level of the piece is too high, frustration may occur. If the challenge is too low, boredom creeps in. But when the match is at the right level, the musician may enter a flow state of enjoyable, high-challenge performance. The third requirement, for frequent feedback, comes from the music itself, which the musician experiences as it is played. These three conditions do not automatically produce flow, but they are the preconditions necessary for its occurrence.

Each of these three conditions presents particular challenges for learning. The first two, providing skill and matching challenge level, is more familiar problem, addressed by current research on scaffolding. This paper will focus mainly on the third challenge, providing frequent and informative feedback.

WHAT IS THE APPROPRIATE KIND OF FEEDBACK FOR LEARNING?

Structuring feedback is a delicate but crucial aspect of scaffolding engagement. Using feedback in the wrong way can 'hijack' students' self-directedness, and even kill motivation for tasks that students previously enjoyed.

FEEDBACK SHOULD BE INTRINSIC RATHER THAN EXTRINSIC.

Extrinsic feedback is a reward such as prizes, praise, grades, or even 'points' systems that is external to the task at hand. Motivation researchers warn that extrinsic feedback should be used very sparingly. A classic study in this area is from Lepper, Green and Nisbett (1973) who showed that extrinsic feedback can kill intrinsic motivation. In their study, Kindergarten students who had been observed to enjoy drawing were asked to draw for the researchers. Some of the students were rewarded at the end of the session with a participation award, while others were not. Later observation showed that those students who received the reward were less likely to spend free time drawing than those that had gone unrewarded! When students were extrinsically rewarded for a task, they changed their attitude toward that task, such that they were less likely to engage in it again without the promise of a reward.

Even verbal praise can have the same effect. Studies of expert tutors have shown that they use verbal praise very sparingly. Students who are engaged in an interesting task do not need to be told 'good job' repeatedly, and such praise can even be distracting or feel controlling. When students have a good relationship with a teacher or tutor they already know what actions tend to earn approval, so that during a task, all students need is information that lets them know they are performing correctly and making progress. This type of feedback is called intrinsic.

Intrinsic feedback is really just information about the task. In the example of an expert piano-player, the music itself provides the feedback. The performer gets immediate aural feedback if s/he hits a right or wrong note, or plays a passage well, because s/he hears it as it happens. The music may also be enjoyable, which helps sustain motivation, but the most important thing is that it is immediate and informative.

Many tasks, however, do not give the natural, immediate feedback that piano-playing provides. Consider a student working in a new computer modeling environment, who may need to spend a great deal of time reading an instruction manual, following a tutorial, or listening to instructions before the interactivity of the system begins to give stimulating feedback. Even when the student starts using the system, the feedback may be minimal and ambiguous until s/he has reached a more expert level. Initial student interactions with the system will often yield no feedback (because the student is doing something wrong) or will yield ambiguous feedback (perhaps an error message, or unexpected results) which the student does not know how to interpret. Only much later,when s/he has designed and run many models, compared results with normative data, or gotten extrinsic feedback from the teacher, will the now-expert student interact with the system in a skillful, feedback-rich way. Unfortunately, many students may never get that far along the path toward expertise, and many teachers may not have time and energy to support entire classes of students in this endeavor.

Analysis of computer game environments, in particular SimCity, will show how clever game designers have built in many kinds of intrinsic feedback to scaffold learners through initial stages of use. As compared to other complex simulation environments, SimCity will be shown to provide interesting feedback at many points along the learning curve.

AVOID CONTROLLING FEEDBACK.

Even games that give only intrinsic feedback can have negative consequences, however, if they inhibit reflection, fail to allow learners to make decisions, or fail to scaffold independent learning. Arcade-style video games are a good example of controlling feedback. Traditional video games bombard users with challenges, such as aliens to blast, math problems to solve, or the like, and as soon as one alien is blasted, two more appear. While this rapid-fire feedback does maintain attention, and often even invokes a 'flow' state, it is less educationally valuable because the user's actions are entirely reactive rather than proactive. Modern constructivist education stresses that learners should develop decision making, self-monitoring, and self-regulation skills. In order to develop metacognitive skills, learners need to have time to reflect on ideas, and reflect on their own processes. Controlling feedback inhibits these skills from developing by setting the pace for the learners. Arcade-style games may sometimes be useful for or drill-and-practice skills training, but more complex and worthwhile educational goals require other kinds of feedback.

So, the ideal form of feedback is highly responsive, and helps maintain the engagement even when learners are confused or indecisive, but also does not prevent reflection or take over the task at hand. Is this possible? Perhaps it is, using a model of 'organic' feedback. This type of feedback is observed in games such as SimCity, and its imitators.

ANALYZING SIMCITY. WHY IS THIS GAME FUN?

SimCity has, from its introduction, been a surprising commercial success. The author of this paper first used SimCity for the purpose of reviewing its features for a doctoral seminar on educational technology. In this case, the 'extrinsic' goal of reviewing the software appeared to have no detrimental effects on intrinsic motivation. After finding myself awake two consecutive nights past 2AM, still telling myself I would go to bed after building 'just one more' neighborhood, I realized that this game had engaging features that went beyond the typical simulation tool.

As an exercise in borrowing game-design principles, the rest of this paper will be focused on the engagement-promoting features of Maxis' popular game SimCity original. For the (few) people who are unfamiliar with this game, a free version of SimCity original can be played online at http://simcity.com . Later version of the game, SimCity 2000 and 3000, incorporate much richer graphics and many advanced features, but the essential engaging qualities of the game are the same.

SimCity is striking, first of all, because of what it does not have. It is missing some of the elements that are thought to be most counter-productive by motivational theorists. First, there is no element of competition. It is not possible to play SimCity either against another person, or against the computer. Second, there is no externally-imposed goal structure. It is not possible to 'win' at SimCity, except in fulfilling self-chosen and self-defined goals. SimCity's designer, Will Wright, has claimed that its lack of goals makes SimCity not a game at all, but a 'toy'. Greg Cotziyan's useful correction is that SimCity serves as a setting for self-defined games: "Build the grandest possible megapolis; maximize how much your people love you; build a city that relies solely on mass transit. Whatever goal you've chosen, you've turned it into a game." Self-defined goals are, again, potentially superior from a motivational theorist's point of view;since they avoid the pitfall of killing intrinsic motivation with extrinsic goals, and they encourage players to develop habits of goal-setting and goal-monitoring. In a classroom setting, teachers would probably need to create goals for students using the simulation, or at least constrain students' possible self-chosen goals. But in any case, these goals would not have to be set against distracting external goals imposed by the game.

This leads to the really interesting question about SimCity: if there is no competition and no 'winning', what are the engaging qualities of this game? This review will focus on two qualities: the way it provides organic feedback, and the way the challenge level grows organically with the game. Both of these features have been copied by other game environments, notably the Civilization and Age of Empires conquest games, and should be borrowed by educators as well.

ORGANIC FEEDBACK.

The most interesting aspect of SimCity is the way that it provides constant visual feedback on the state of each section of the city. Each city starts as a blank terrain of water, trees, and empty land. Players choose a spot, build a power plant, and then begin 'planting' empty squares zoned as Residential, Commercial, or Industrial (Figure 1). Residences begin to appear almost immediately, followed by industrial and then commercial development. (Figure 2). These developments, once made, are not static. Buildings constantly appear or disappear, improve or degrade throughout the game depending on economic conditions in the city. Each block of the city develops differently, affected by both city-wide and local conditions.

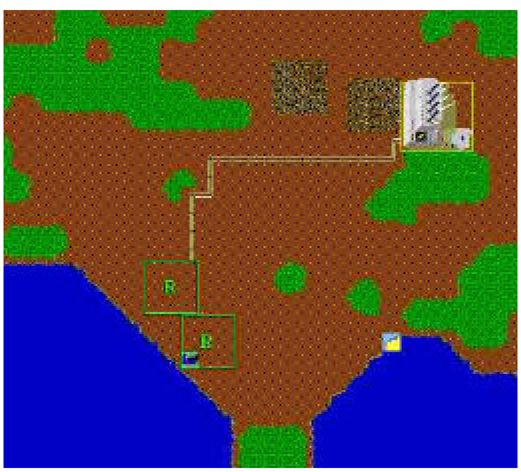


Figure 1. The beginnings of a Sim City, with a power plant and two residential zones.

Figure 2. Residents begin to move into the city (bottom) and factories appear.

This constantly growing city provides an interesting and very engaging kind of feedback. Feedback from the game does not take over control, as in an arcade-style game, but neither does it allow for extended dead time when a player is indecisive or puzzled. Organic-style feedback can provide an engaging give-and-take that is still directed by the user.

I call this organic feedback because the nearest comparison to playing SimCity is planting and managing a garden. As with a garden, there is a balance between planning, acting, and responding. Interacting with a Sim city feels much like interacting with a growing organism, which is in some ways malleable, but also has a personality that are revealed only over time, and much of the pleasure derives from discovering this personality through interaction.

ORGANIC SCAFFOLDING.

SimCity also has an 'organic' style of increasing its challenge level. In the early stages of SimCity, players can ignore all but a few aspects of the simulation, and their city will still grow. But progressively, as their city gets larger, players must learn to manage tax rates, property values, crime, pollution, mass transit, waste removal, and other factors. None of these factors must be dealt with at a particular time, but each must be taken on in some fashion for a city to continue growth. This is a very clever and natural way to introduce complexity. And this organic scaffolding again compares well to arcade-style games, which artificially inflate difficulty (e.g. aliens fly faster and faster), and complex learning environments which present a tool in its full complexity from the outset. Organic scaffolding gives players a degree of control over how fast they take on new challenges, but also gives an actively responsive system to keep players engaged.

As good a game as SimCity is, it is no small challenge to implement organic feedback and scaffolding in other domains. It interesting to note that Maxis itself has not identified the crucial dimensions of SimCity. There are a slew of follow-up Sim games, most of which were market failures, and many of which do not successfully replicate SimCity's organic character. I hope that by identifying and describing the powerful aspects of SimCity, it will be easier for educational designers to borrow these ideas and implement them in many other games directly targeted at education.

ADAPTING SIMCITY-LIKE GAMES FOR THE CLASSROOM

Before SimCity, or any imitators could be completely successful in a K-12 environment, there is a need for numerous adaptations. These are not to accommodate the unique needs of learners—SimCity already does that quite well--but to accommodate the unique needs of the K-12 classroom setting. Most attempts to design educational games have failed, or failed to reach their potential because they do not understand how to design for this context. Even the games that do sell well to schools such as Oregon Trail or, for that matter, SimCity, are usually relegated to 'filler' time or enrichment, because they are not well-integrated with other educational activites, and are not fully compatible with classroom practices.

I will describe four adaptations in detail, and four miscellaneous other extensions of SimCity that would make it a more usable and useful tool for K-12. While illustrated here with the example of SimCity, each of these is intended to be generally useful for any similar application.

1. Data reporting, graphing, and exporting
2. Teacher's assessment tools
3. Experimental design features
4. Direct access and modification of the simulation engine
5. Allowing debate on simulation assumptions
6. Integration with larger curriculums
7. Integration with tools to support group work
8. Professional development and support opportunities for teachers

DATA REPORTING, GRAPHING, AND EXPORTING

Underlying SimCity's rich visual garden is a large amount of quantitative data. For classroom use, students need to be able to access this data.

Prop type	Yr 1	Yr 50	Yr 100
Residential	$30	$50	$150
Industrial	$50	$75	$105
Commercial	$20	$60	$120

Figure 3.

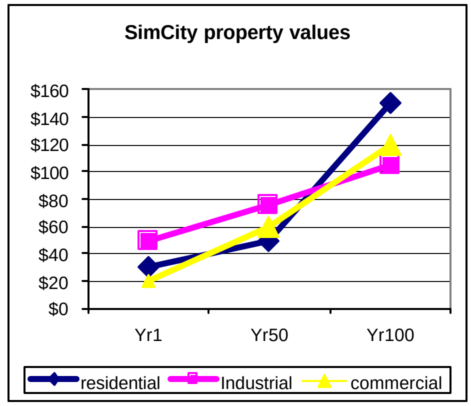


Figure 4.

SimCity should have flexible data reporting tools that can export various data from the city as data charts (Figure 3), or as standard graph types (Figure 4). Or, if students prefer to work with other tools such as Microsoft Excel, it should be possible to export data in a standard format.

Since much of SimCity's data is very localized to particular blocks of the city, it would be useful to have 'inspection' tools to get at this data. This might be accessible through a mouse action, such as a right-click or double-click, or through a separate 'inspection' tools. As with other data, it should be possible to log, graph, and export this data.

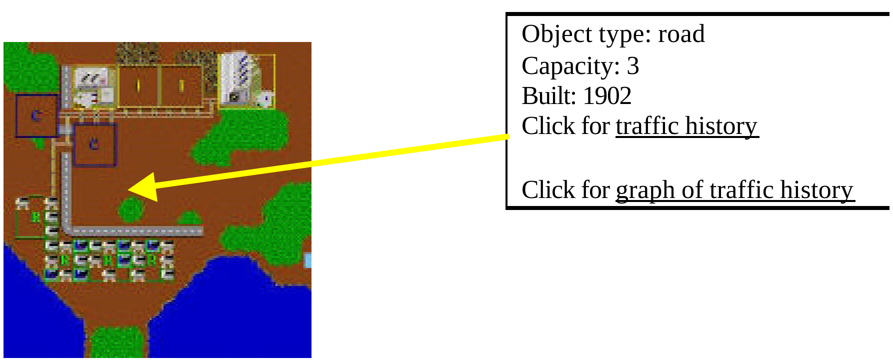


Figure 5. Mockup of an inspection tool report on a section of SimCity road.

TEACHER'S ASSESSMENT TOOLS

Designers must not underestimate what a challenge it is for teachers to monitor and respond to classes of 20-30 students undertaking individual investigations. Walking around the computer lab is an important, but by itself inadequate method of monitoring student work. Most games lack tools to support teachers gathering and analyzing student outcomes, and this is one factor that relegates computer game use to enrichment or time-filling roles within the classroom.

Software should be designed with group data reporting tools that can be assembled by teachers into a single class report. (This useful design feature was discovered by the author after building such a tool for research purposes, and being surprised by its immediate and enthusiastic adoption by teachers!) The ideal system would allow a great deal of customization, and would be available in an online format so teachers could access it from any location. Such a system should also store teachers' notes, and should allow exporting into another tool such as Excel.

This system should also support both passive and active data entry by students. Passive data, similar to log files, would simply monitor and report student work. An active system would prompt students to describe their goals, actions, and observations and perhaps allow students to save visual or numeric data. Active entry supports learning by prompting reflection on action, and rewarding student planning even when results are unexpected or negative. It also helps teachers make more informed assessments, by revealing student intentions. The Project Portfolio software (Loh, 1998) is an example of active entry being implemented in tools designed for both student and teacher use.

Class data report First hour Government

Show: **Teacher notes** | Student notes | new zoning | **property values** | tax rates and budget | disasters |transportation | crime | fire | major construction

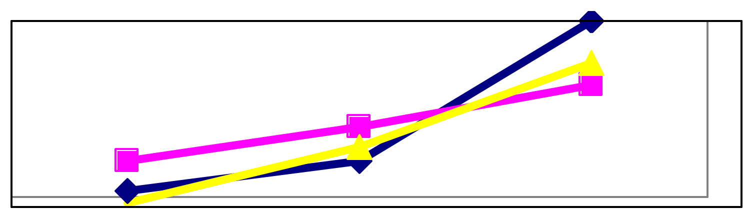
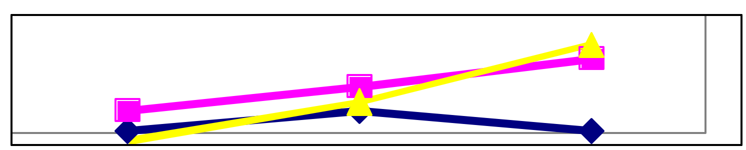
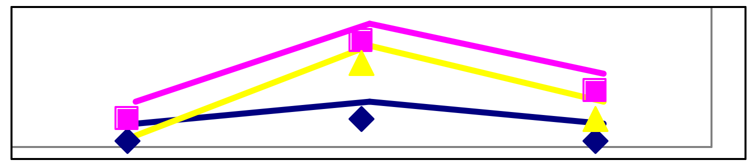
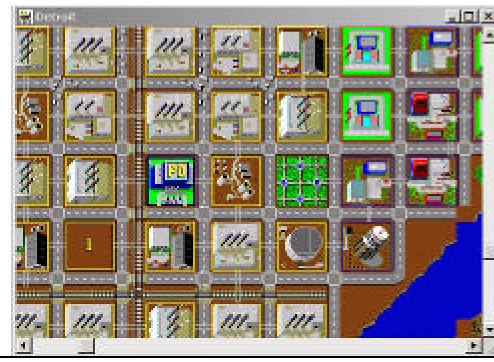
Baraka, Kelly **<u>Tchr notes</u>** -Working with Eve -Trying to max. res value, likes the fancy houses	
Brady, Tom **<u>Tchr notes</u>** -Working with David - missed class Tuesday, didn't understand market graph	
June, Cato **<u>Tchr notes</u>** -Working with Jeff -Market 'crash' due to overbuilding	

Figure 6. Mockup of the teacher view of class assessment

EXPERIMENTAL DESIGN

Students should be able to perform controlled experiments in a SimCity-like environment. Not only would this be an excellent way for students to learn about the simulation, but it would also give useful practice in experimental design and reporting.

Students could set up and run two or more experimental conditions side-by-side, allowing direct comparison. In an experiment, students might change only one small parameter, such as building a police station in one crime-ridden neighborhood versus another, and observe the short-term affects. Any subsequent changes made to one version of the model (e.g. fixing a road, adding a zone) would be immediately mirrored in other experimental conditions. After running this experiment for a few years, students could summarize results in reports that would be published to the class.

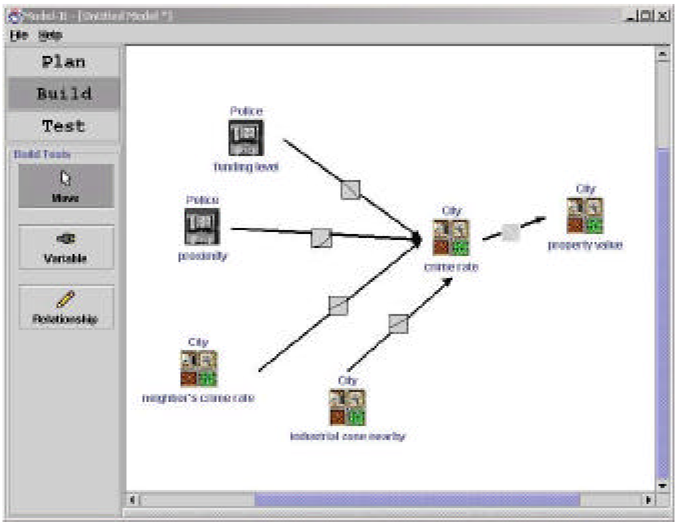
Condition 1 Detroit south side with no police station 1973	**Condition 2 Detroit south side with Police station 1973**
	

The software might also support design experiments comparing different intervention strategies implemented over time. For example, students might load one of the problem scenarios that is distributed with SimCity, such as Detroit, 1972, and try out different approaches to solving this troubled city's crime problem. Students could compare strategies of lowering taxes, increasing police protection, and urban renewal, to see which approach leads to a healthier city over a longer time period.

DIRECT ACCESS AND MODIFICATION OF THE SIMULATION ENGINE

An educational simulation should also allow students to 'open up the hood' of the simulation, to examine, modify, or add to the existing simulation engine. This could support a variety of new types of inquiry, such as trying to improve the model, examining effects of different causal models, and critiquing the assumptions of the original designers.

How should these complex simulation engines be represented for students? The most precise and detailed view would be to show computer code or pseudocode describing the algorithms. Most classroom users would probably want some less daunting visual representation of the engine. One possibility would be to allow students to query the engine, for example asking for information on what affects a local area's crime rate, and getting a flow diagrams as a result. This might appear similar to a Model-It model, as shown here.



This representation is good for showing the causal links between variables. Other representation might better capture the geographical nature of these calculations. Examples of simulations software with good visual representations of intracting spatially-grounded data are AgentSheets and StarLogo.

There are an additional set of educational adaptations that are not features of the game itself, but are desirable contextual features.

ALLOWING DEBATE ON SIMULATION ASSUMPTIONS

Classroom use of a SimCity-type of game should also encourage students to challenge the assumptions built into the game. As at least one author has pointed out, (Starr, 1994) simulations sometimes embody controversial or politically loaded ideas. For example, SimCity has a strong built-in bias in favor of public transportation rather than car traffic. Any American big-city mayor who tried to replace highways with railways as often as SimCity mayors can would be quickly voted out of office. Students should learn that games necessarily have hidden assumptions, and get practice in examining these assumptions. Questioning and critique does not necessarily need to be built into the game itself, but should be part of a curriculum surrounding the game.

SUPPORT COLLABORATIVE LEARNING.

Simulations can be effective prompts for discussion between small groups, or entire classes of students. It is a tempting, yet probably not a very good idea to build collaborative software features directly into a simulation environment. A better model would be to use simulations in conjunction with a collaborative environment. An example of such an environment is Knowledge Forum, which supports classes of students engaging in collaborative knowledge building. KF encourages classes of students to become scientific communities by asking questions, exchanging ideas, and posting research reports online. Cohen and Scardamalia (1991) is an example of Knowledge Forum being used in conjunction with the simulation environment, Interactive Physics. In this model, students collaborated on several levels: within small groups, across the classroom, and with their teacher. One could also imagine collaborative investigation of SimCity being done between two or more classrooms, or between students and outside mentors. Real-time tools such as chat, application sharing, or videoconferencing might also enter the mix as student research groups mimic the work of professional scientific collaboratories.

CURRICULUM SUPPORT.

This is a humbling, but crucial idea for software designers to understand: even the best software environments can comprise only one part of an effective curriculum. The best simulation experiences are embedded within well-designed curriculums that bring together readings, discussion, and a variety of offline activities. SimCity does publish a good teacher's guide that begins this process (Kuntz). A higher level of support would include well-developed curriculum units at various age levels mapped to national curriculum objectives, and an online digital library of readings and associated resources.

PROFESSIONAL DEVELOPMENT.

Teachers need a great deal of hands-on support, both technical and pedagogical. Successful educational reform projects often use summer workshops to bring teachers together to introduce innovations, share techniques, and give teachers the personal support they need to continue challenging innovations. Summer workshops can be followed up with online support throughout the school year, including opportunities for consultation and online libraries of support software and curriculum units. Even though it is mentioned last in this list, professional development may be the most important factor in determining the long-term success of an educational intervention.

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