A Review of Science Learning Game Environments

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Overview

This report provides a brief review of seven science learning games (SLGs) that have been or are being used to support science education primarily targeted to middle school student learners. SLGs games first and foremost. They are conceived, designed, played, and analyzed as computer games, rather than educational courseware, simulations, or interactive presentations of science concepts. As such, criteria such as intrinsic motivation, effective game play balance, and fun are among our requirements for a SLG like the SciThink environment that we are proposing to develop and deploy.

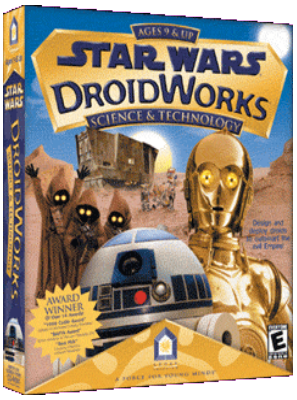
SLGs are a small and mostly marginalized genre of computer games when one looks at the international computer game industry. No companies appear to be making millions of dollars from their best-selling SLGs. In fact, most of the large, well-known computer game companies avoid developing games that are envisioned as "educational" and targeted to specific age-skill groups. Instead, they more often seek to develop games that are fun, entertaining, and engaging, as well as focused on fantasy worlds, rather than on education and academic subjects like physics or space science. Subsequently, there is comparatively little industry interest in developing and deploying educational games in general, and SLGs in particular. However, as some game scholars and educational theorists have observed, many computer games succeed because they are great learning environments that embody both classic and modern theories of constructivist learning, self-identity through role play, reflective thinking, domain-specific specialist language skills, and multi-player socialization. Thus, our choice is to develop and deploy SLGs that will be fun, collaborative, and oriented to science and engineering knowledge and practices associated with aerospace vehicle design, system modeling and simulation, systems integration, as well as network-centric activities and learning experiences. With this in mind, we can briefly review some recent SLGs to get a sense of what areas of science and engineering are being addressed, along with the relative level of investment required to support the development, deployment, and evaluation of such SLGs.

Seven SLGs are relevant to our review at this time: *Droidworks* from Lucas Arts; *KineticCity* from the American Association for the Advancement of Science; *Genius--Task Force Biologie* from Radon Labs (in Germany); *DinoQuest Online* from the Discovery Science Center and UCI GameLab; *Race to Mars* from the Discovery Channel (Canada), Quickplay Media Inc., and Virtual Heroes Inc.; *WolfQuest* from the Minnesota Zoo and Eduweb Inc.; and *Gamestar Mechanic* from the University of Wisconsin ADL

Co-Lab and Gamelab Inc. What will become clear from a review of these is that SLGs require development budgets in the $500K-$1.5M range, and these figures do not include deployment, support, or evaluation costs, whose total cost will be comparable or greater to SLG development. Furthermore, these costs are based on SLGs that do not specifically address the needs of students from communities that typically do not embrace science and engineering career paths, nor do they address the need to facilitate scientific reasoning through written materials or online communication. Thus, it appears that realistic costs for developing an SLG environment that supports student learners of different age, skill, and linguistic abilities with adult mentors and science educators represents a 3-5 year investment, approaching in the range of $3M-$5M in total.

Droidworks

(The following contains source material for a review of Droidworks by Anne J. Lombardi, http://www.macreactor.com/reviews/droidworks.shtml. Also see http://en.wikipedia.org/wiki/Star_Wars:_Droid_Works for additional details).



Droidworks was a PC-based computer game with 2D graphics developed and marketed in the mid-1990's by LucasArts Inc. It is no longer commercially marketed, though it would run on just about any of today's entry-level or low-cost PCs (i.e., it has minimal computer requirements). It's development cost is unknown, but relative to commercial computer games developed in the mid-1990's a low-to-mid six-figure development budget (e.g., $250K-$500K) seems plausible. For our purposes here, it can be considered as among the first computer games designed to support acquisition and practice of scientific knowledge and engineering systems design in the form of a commercially marketed, fun and entertaining computer game about science and technology targeted to learners in middle school grades or older.

The premise of Droidworks is simple. The player is a member of the Rebel Alliance (in the days of the original *Star Wars* movies), and is on a mission to foil the Empire. Disguised as a Jawa on the planet Tattooine, users must design and build droids (i.e., futuristic robots) that can successfully complete a given mission in the game. On the way to attaining the rank of Master Droid Builder, players must ultimately find the Empire's hidden Assassin Droid Factory, and reprogram the Assassin Droids before they destroy the Rebellion.

However, not just any droid will do. Players must be able to construct a droid that meets certain mission requirements, resource constraints, and overcome certain obstacles. To do this, they must have knowledge of different concepts in the physical sciences concerning machines, light, energy, forces, and materials.

In the droid workshop, after viewing a brief tutorial on droid-building, players can start constructing droids to complete their mission. Droid-builders can choose from many of the eighty-seven unique parts to construct millions of different droids. Unique viewing features allow the droid to be seen from any possible angle and zoom. For added laughs, players can paint the droid for a personal touch or even turn on some disco tunes to watch their droid in Saturday Night Fever, Star Wars style. Droid building is great fun in itself, allowing users to be creative and marvel at the different contraptions they can invent.

Players get their first chance at seeing how form meets function in the Sandcrawler Training Facility. Here, droid builders can see how their creation operates before it meets

the dangers on its mission. The droid Holocam-E ("Cammy"), accompanies players throughout the Training Facility and the missions to point out different scientific obstacles. With some testing under their belts, users can learn to analyze their creations and modify them into a better product, which is a practical and useful skill in the game but even more valuable in the real world. The Training Facility also gives the added benefit of allowing players to learn how to control the droid so that nothing is left to guesswork once it is deployed on its mission.

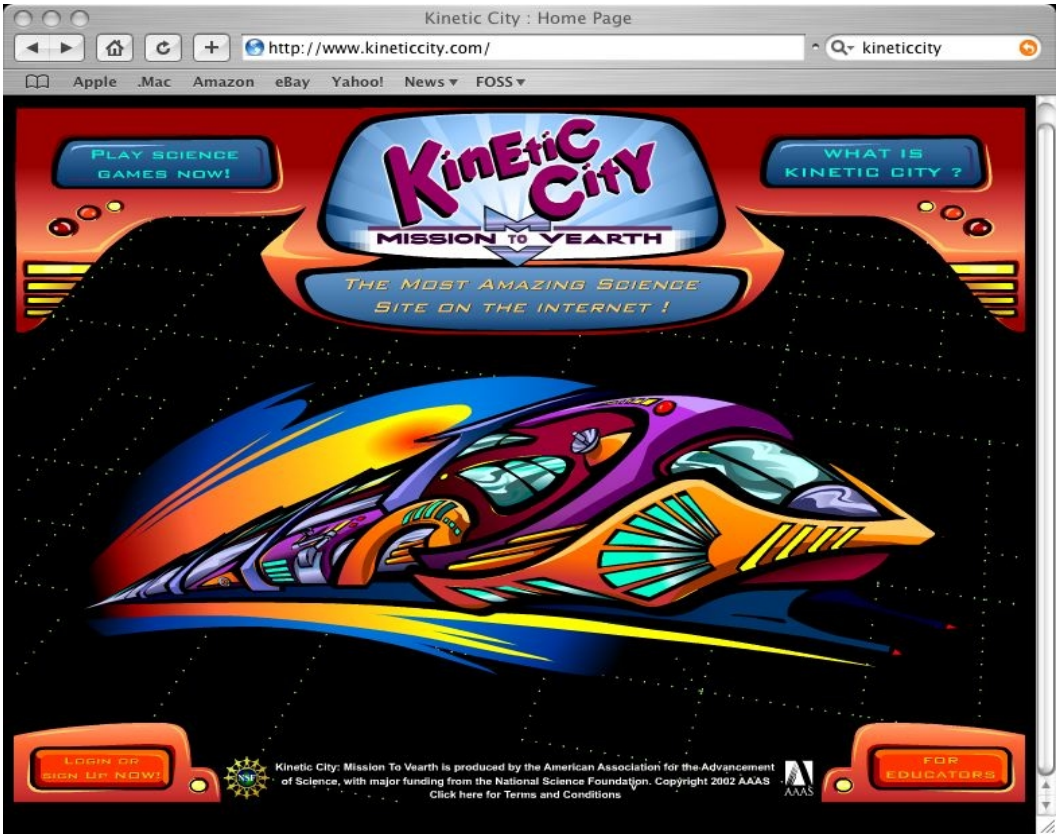
Once on the mission, the challenge begins. Players are given an objective and other basic information, but the rest is left up to their own analytical skills. Each mission highlights a different concept, such as energy, force and motion, simple machines, light, and magnetics. While maneuvering around other obstacles that demand pure gaming skill, players learn how to manipulate these concepts to their own advantage. With this virtual laboratory-style approach, players leave the mission with some knowledge of the subject they just utilized.

The Information and Data Expert (InDex) is one of the game's learning resources. At any point in the game, players can look to this built-in encyclopedia to learn the scientific concepts that they will face. Along with a brief explanation of the subject, video is also included to provide a better grasp of the concept. Users can even connect to the Internet to find additional information on the topic. InDex's value lies in its clarity of description and plain language. Concepts are explained in terms that many users or the least scientifically inclined can understand.

Overall, Droidworks reveals that it is possible to design a compelling and fun SLG, especially when it ties back to well-established cultural materials (like the Star Wars movies). Droidworks also shows that it is possible to develop a game that involves scientific thinking and engineering design practices in a form accessible by students of/near middle school age and beyond. However, it should also be clear that Droidworks makes no claims regarding its educational value or relevance to learners who may be at risk, nor to whether any of its content or subject matter clearly addresses topics found in the National Science Education Standards. Similarly, it makes little/no demand for players to demonstrate transfer of scientific knowledge or engineering design practice through written narratives or other form of online communication regarding their game play experiences.

KineticCity

Based on a popular radio show for young people broadcast across the U.S., KineticCity is a Web-based SLG environment focused on life science subjects relevant to 5th grade students and educators. KineticCity was developed by a team of science educators, game and web site developers brought together by the American Association for the Advancement of Science (AAAS) with a $1.2M grant from the National Science Foundation. The online game content was developed in ways that seek to embody, demonstrate, and engage 5th grade students with life science topics found in the National Science Education Standards.



KineticCity contains a collection of game modules, each of which is targeted to a specific set of topics or scientific concepts. However, it quickly becomes clear that the games are

modest relative to commercial computer game play experiences, and are better understood as "casual games" rather than sustained, immersive game play worlds. The game modules are designed for single players, and thus do not provide for multi-player game play or for game-related communication with other players, teachers, or mentors. Also, note that the game modules are narrowly focused on 5th grade science topics and science education standards. However, this does more readily facilitate systematic evaluation of the science knowledge or reasoning skills that student players may acquire as a result of their casual game play.

Genius—Task Force Biologie

GTFB is an SLG developed by the German game developer, Radon Labs and released to the German game market in 2005. The game is in German and there is no English version available, though it likely represents a development effort greater than $1M. It is similar to many "tycoon" style games available in the U.S. Such as *Zoo Tycoon* or *Roller Coaster Tycoon* where a central part of single player game play is design and interaction with respectively a zoological garden or roller coaster theme park. However, GTFB is focused on the theme of restoration of a remote ecological environment that has been decimated from an unknown source.

GTFB features a visual graphic style that mixes both high-realism game settings where information and tutorial help is provided to the player, along with stylized worlds/levels where the player can construct or interact with in-game resources like buildings, construction equipment, animals and plants. The game is highly regarded for its ability to provide situated game play that is tied to current concerns that link science to public interest (in environmental or "green" issues). Furthermore, the game includes five in-game "experts" or role-models who provide tutorial help or suggest lines of scientific reasoning for solving in-game problems, along with in-game tools/instruments for calculation and data collection, as suggested in the figures above.

DinoQuest Online

In 2005, effort began at Discovery Science Center (DSC) in Santa Ana, CA and its partners at the UCI Game Culture and Technology Laboratory to develop a new interactive game-based exhibit built on a theme of dinosaurs. This interactive hands-on exhibit would focus on introducing, demonstrating, and helping visitors to experience and learn about concepts from life science (e.g., skeletal systems, elements, and function; digestive system; prey-predator relationships). The life science concepts selected for presentation in the exhibit were those that correspond to curricular topics found in K-6 grade science education standards for California. This exhibit was designed to enable the development and deployment of both a physical game-based interactive exhibit at the DSC that would be linked and integrated with a Web-based online game environment. The physical exhibit called *DinoQuest* (DQ) became operational in mid 2006, while the online game environment called *DinoQuest Online (DQO)*, went into full-scale operation in 2007.

- Physical interaction quest game: *DinoQuest* at DSC
  - Life-size dinosaurs (e.g. Argentinosaursus, T-Rex)
  - Family-based problem-solving and collective learning in physical environment
  - Game progress tracked via user-controlled IR transmitters that activate embedded sensor net

- Web-based SLG: *DinoQuest Online*
  - Addresses CA science education standards for K-6 grades
  - Interoperates with *DinoQuest*
  - Designed for internationalization
  - Developed by UCI GameLab

DQ and DQO were conceived, designed, and deployed as collaborative, multi-player science learning game (SLG) environments, and were developed at a cost of more than $6M. Since DQ and DQO became operational respectively in 2006 and 2007, attendance at DSC has nearly doubled (from 275,000 in 2005 to 525,000 by end of 2007), with more than 85,000 K-8 grade students now experiencing DQ and DQO at the DSC per year, while another 150,000 K-8 students are exposed to DSC programming in their schools (including DQO) per year as well. Approximately 55% of the students engaged at DSC or through its outreach program are Hispanic, while another 10% are African American.

Both DQ and DQO embody a number of innovations and advanced concepts for SLGs as found in some of the other SLGs reviewed here. For example, the physical DQ environment is built around the use of an embedded infra-red (IR) sensor network with more than 120 sensor engagement points. DQ players (e.g., young learners and their parents) start from the DQ Field Station where they sign up to complete one of eight available DQ field research missions.

Go to Field Station and Select a Mission

8 Educational Missions:

- Aimed at California Science Education Standards for grades K-6
- Mission topics: Predator / Prey, Trace Fossils, Anatomy, Habitats, Identification
- Each mission focuses on a different collaboratory and field of science
- Missions selected, tracked, and completed at networked multi-media kiosks

Next, as part of their mission, players are tasked to find, locate, or discover specified objects or arrangements of dinosaurs that reveal anatomical features (e.g., the eye socket for a triceratops) or a predatory (meat-eating) raptors posed in opposition of plant-eating dinosaurs.

Embedded Sensors and Transmitter Activation

In the course of completing their research missions, players are provided multi-media guidance and feedback from online characters who act as roles models for different kinds of scientists. These role-models vary by age, gender, and ethnic background, much as the world of science has such variation. This is to help encourage players who may come from a background where people like them may not have thought about pursuing an educational path that could lead them to a career in some field of science or engineering.

DinoQuest Research Team and Collaboratories:
Diverse Science Role Models (ethnicity, age, gender)

DQO compliments the DQ experience with 13 online game modules that also build from the experience of field research and scientific methods for learning about dinosaurs and life science. DQO is a Web-based multi-media environment that can run on a PC with a Web browser and Flash plug-in (i.e., more than 98% of computers accessing the Web on a world-wide basis). DQO is structured as a multi-level game environment so that players must make progress and advance to ever more complex tasks in order to both gain "research points" and fossilized DNA samples that in turn will allow them to play the higher level game modules. Game modules exist for activities like re-assembling a collection of dinosaur bones into a skeleton, designing a dinosaur digestive system or understanding oxygen-CO2 gas exchange in a cardio-vascular system. The following figure shows a scene from the dinosaur reconstruction laboratory game module with embedded help/tutorial materials revealed.

DQO's final level, called DinoSphere, is a multi-player environment of four ecological niches (or microcosms) where player controlled dinosaurs of different types and capabilities (chosen by players using their research points and fossilized dinosaur DNA samples) are allowed to interact with one another so as to survive (when food sources may be scarce, or when to avoid being prey), form groups with similar dinosaurs (small predators need to group into a pack in order to take on large prey that might otherwise defeat them), and the like.

DQ and DQO represent sophisticated, multi-player SLG environments that thousands of students and young learners can engage on an ongoing basis, whether in person at the DSC, or via remote access over the Web. However, neither DQ nor DQO provide support for encouraging players to engage in written narratives or online communications with others in way that demonstrate both their mastery of the life science subject matter, as well as their ability to demonstrate scientific thinking needed to articulate concepts or research methods through writing. However, as the target audience for DQ and DQO is learners in the K-6 grade (children of age 5-12), then it may be reasonable not to demand demonstration or mastery of scientific writing skills, which are more typically expected to develop during middle school and secondary/high school grades.

Race to Mars

Race to Mars is a television series produced by the Discovery Channel Canada for broadcast over cable/satellite television networks. It represents a science fiction series organized into 10 one-hour episodes that began broadcast in 2007, at a reported production cost of $20M. An unknown fraction of this cost was allocated to the development and operation of a corresponding Web site that features a set of six 2D or 3D interactive game modules that build on and go beyond the televised content in order to provide simulated science missions on a virtual Mars planet, exploration base and data collection equipment, along with land-based vehicles for traveling about the planet.

The game modules were developed by a variety of providers including Virtual Heroes Inc., which is a commercial game development studio specializing in the creation of advanced training simulation and game-based environments for customers like the U.S. Army. An example 3D game module is "Rover XPL" shown in the figure above. The year is 2028, and you are controlling one of the latest-generation Mars Rovers on a mission of science and inquiry. Among other things, users are tasked to navigate across *Dao Valles*, a ravine-strewn valley in the southern half of Mars. Alternatively, users can explore the *Valles Marineris*, a canyon that stretches more than 3,000 km in length. And race against other players to make the scientific discoveries that may change the landscape of human exploration.

This 3D multiplayer game provides a simulated experience of what it's like to explore Mars first-hand. This game module employs the top-rated, Unreal 3 game engine that supports multi-player game play across the Internet. The materials presented in the game for the most part are scientifically accurate (e.g., modeled from images captured by the Mars rovers) or plausible (suggested by NASA planetary exploration vehicles). However, mastery and complete engagement with the range and complexity of materials presented suggests that the target player audience for these games would be those with at least a secondary/high school education who can read somewhat technical articles (with space exploration terminology and scientific/engineering jargon), and who are also fluent in accessing, downloading, and playing multi-player computer games from the Internet. Such an audience is thus likely to be targeted to adults as learners, rather than to students in the middle school or high school grades.

As such, game modules associated with Race to Mars, like Rover XPL, may be considered a high quality, realistic game based on science and space exploration. However, these game modules are not clearly tied to K-12 science education standards except at the 11-12th grade level, nor targeted to students with middle school level knowledge, skill, or linguistic abilities.

WolfQuest

WolfQuest is a new multi-player SLGs focused on the subject of the ecology of wolf packs, and their quests for food and other collective activities in different ecological niches. As a multi-player game, each player acts to control/guide the actions of an individual wolf within a larger pack of other wolfs, each controlled by a different player. Such a SLG is effective in conveying to young learners concepts like collective action (e.g., hunting as a pack, surrounding and overcoming larger prey) as well as social bonding, and hierarchical social relationships (alpha wolves who lead the pack, mother wolves who care for the young, and others).

WolfQuest represents an innovative new project that brings the immersive, compelling drama and action of video games to informal science learning while creating a model for nationwide distribution. Designed for players age nine to adult, WolfQuest seeks to teach wolf behavior and ecology through its exciting gameplay and intense social interactions.

Development of WolfQuest (still in progress in 2008) has been funded by the National Science Foundation at $550K to the Minnesota Zoo (where a corresponding Wolf exhibit is featured) and EduWeb Inc, which is a developer of interactive materials for informal science education. Subject matter content for WolfQuest is provided by the International Wolf Center. WolfQuest is being developed using a low-cost, commercially available 3D game engine, called Torque, available from Garage Games.

WolfQuest is also supported by a Web site where information about the game and access to the game itself, for download on to a networked PC, is available. WolfQuest players can learn about the game and download the latest version, as well as post tips and strategies, ask questions of wolf experts, share personal wolf artwork and stories, test their wolf knowledge with online polls and quizzes, compete for prizes, and participate in partner promotions. Also on the site will be background information about wolf ecology and conservation and educational materials for classroom use.

WolfQuest's impact has the potential to be greatly expanded by a national network of Informal Science Education (ISE) institutions. Each institution will publicize the project to current and expanded audiences in its region. Versions of the WolfQuest Web site

customized for each network member will promote the institution's wolf-related programs, foster regional social interaction online, and provide data for evaluation.

Gamestar Mechanic

(There are no available images or screenshots for Gamestar Mechanic as of this writing. However, the description that follows is based on a presentation on Gamestar Mechanic at the *2008 Serious Games Summit* at the Game Developers Conference, San Francisco, CA 18 Feb 08 by its lead developers at Gamelab Inc. and Parsons School of Design).

Funded through two grants from the MacArthur Foundation totaling $3M, the University of Wisconsin-Madison, Advanced Distributed Learning Co-Lab; the Games, Learning, and Society research group in the UW School of Education; Gamelab Inc.; and the Parsons School of Design are developing a Web-based 2D game environment for middle and high school age learners for the domain of "game development." The funds are broken down to allocate $1.2M for game development (by the GameLab and Parsons School of Design), while $1.8M is allocated for deployment, evaluation, theory development, and dissemination of educational and research results.

What makes Gamestar Mechanic a SLG? Simply put, Gamestar Mechanic focuses on helping 12-18 year old students learn about concepts, techniques, and tools from computer science and information system design, including interactive system prototyping, user testing and feedback, and rule-based systems. Game development can be viewed as a part of computer science where scientific thinking and engineering design are required in the course of designing, implementing, diagnosing, and play testing an interactive information system (i.e., a computer game). Beyond this, game players take on the role of a game developer or "game mechanic" who can customize or repair games that others have developed, much like an automobile mechanic might do with someone's automobile. As such, Gamestar Mechanic is more of a meta-game, in that the primary way to play the game is to learn how to create or "mod" (modify) 2D computer games. Many universities (e.g., Carnegie-Mellon University) employ similar methods using concepts or methods found in computer games (or virtual worlds) for teaching introductory Computer Science courses.

Summary capabilities for a Science Learning Game Environment

Based on the preceding review of seven SLG environments, the following requirements begin to appear.

First, development of an SLG environment (including game modules, game Web site, and game network for at least one physical host site) is in the range of $500K-$2M. Adding support in the environment for writing and online communications by students assisted by local/remote mentors may be of comparable cost, and thus add a minimum of $500K. SLG environment development cost should be estimated at $1M-$2.5M, and anticipate a two year development schedule.

Second, development costs do not include deployment, evaluation, theory development (i.e., how to build new SLGs based on the lessons from this effort), and dissemination of technical, educational, and research results. These costs can be estimated at $500K-$1.5M. Thus, developing and deploying a SLG environment that can lead to demonstrable science education results, that engage K-12 grade students working individually, or collectively with one another, and with adult mentors, should be estimated at $1.5M to $4M level, where the range represents narrowing/broadening the scope of academic subjects, number of game modules included, and diversity of student audience. Thus, if the target audience is expected to include students with varying verbal and linguistic skills, then the costs will be at the high end, compared to an audience of high achievement students who made already be pre-disposed to scientific thinking and mastery of written communications.

Third, from a subject matter standpoint, it appears that an SLG environment can be designed to address topics spanning scientific disciplines and systems engineering practices. For example, topics drawn from aerospace science and systems engineering are addressed in SLGs like *Droidworks* and *Race to Mars*. In contrast, SLGs like *DinoQuest Online* can work with young learners when supported by their parents or other adult supervisors. Thus, it may be best to consider targeting new SLGs to middle/high school grades where more scientific thinking and engineering concepts may be required. However, in any situation, it should be clear that any science content for student learners can be framed to be in alignment with national or California science education standards.