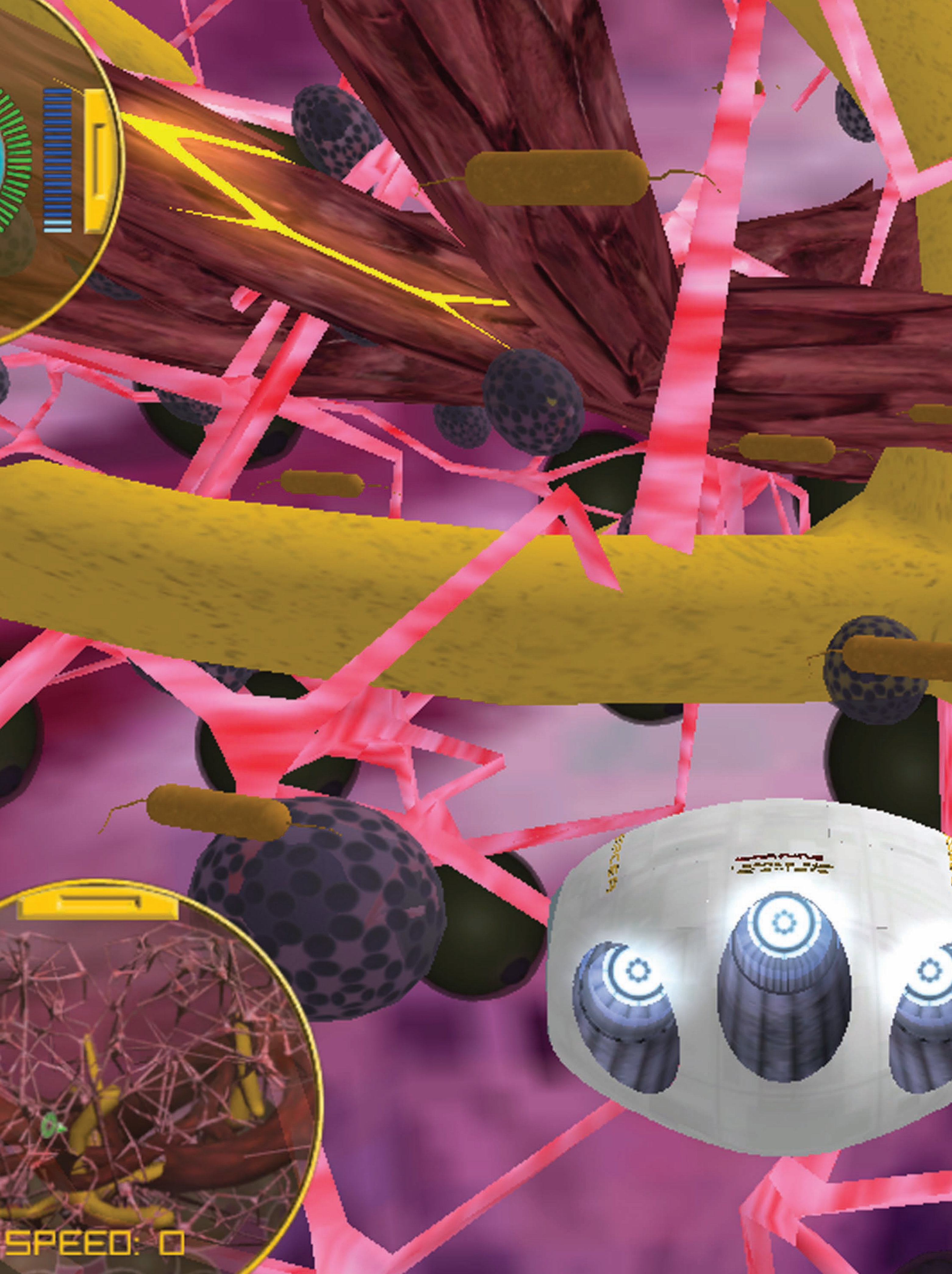
SPEED: 0

HOW TO BUILD SERIOUS GAMES

Like a discovery game that requires players to earn the right to take on new challenges, Immune Attack compels its players to learn the rules of the immune system before it reveals deeper biological insight.

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Computer and video games offer many options for communicating complex concepts in ways that reflect the wonder of discovery at the root of all good science. It is, however, extraordinarily difficult to implement a video game that accurately represents the underlying science and that is sufficiently engaging to hold a student's attention. With this in mind in 2004, we created an interdisciplinary team to build Immune Attack, a PC-based single-player video game that combines a realistic 3D depiction of biological structure and function with educational technologies for teaching immunology to high school students and college

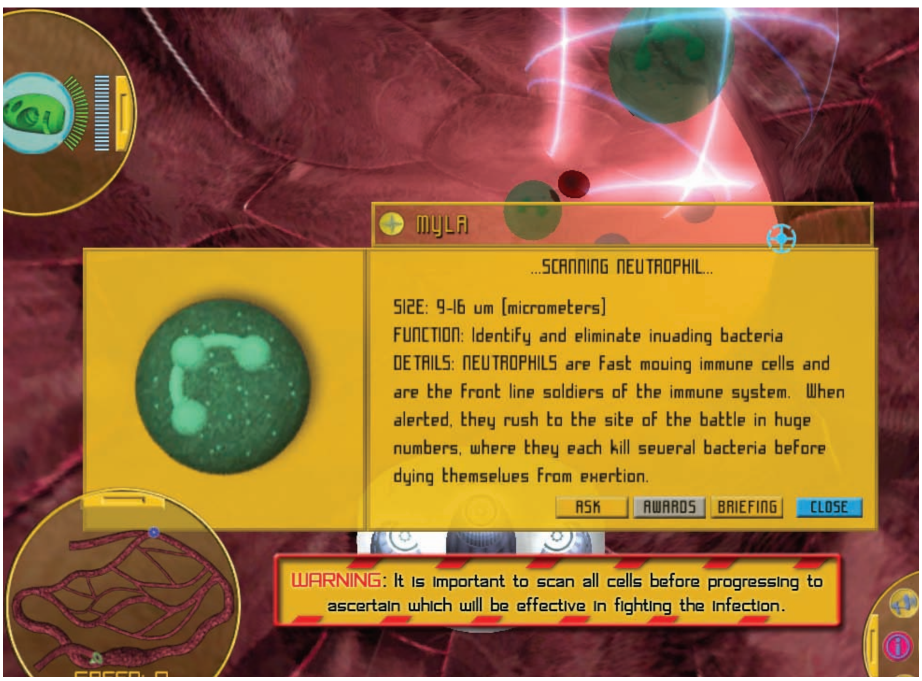
The nanobot Panacea navigates through the connective tissue of the body. (Excape Hatch Entertainment, Austin, TX, www.excapehatchentertainment.com/.)

freshmen. This National Science Foundation-sponsored game is designed to motivate students through a series of progressively more difficult challenges in a compelling game environment in which success depends on an increasingly sophisticated grasp of concepts in immunology.

During the design process, we identified three key research challenges:

Game design. Develop a strategy for gameplay that would be as engaging as the typical commercial entertainment games students play and that conveys valid educational content to the player;

Integration. Develop learning tools to generate and answer questions that guide the learner through the exploration and discovery of the required biology; and



Players who fail to heed the warning posted at the beginning of each action game risk not having enough information to win and continue.

Multiple scales. Build simulations and visualizations to display biological processes at multiple physical scales (from a whole-body lymphatic system to molecules on cell surfaces) and time scales (from reaction kinetics of protein interaction to disease dynamics over years). These research goals grew out of the detailed *Learning Science and Technology R&D Roadmap* released in 2003 by the Federation of American Scientists (FAS) with the participation of more than 100 experts in related fields [1].

Managing the development of a serious game requires the skills of many disciplines and a sometimes painful process that forces team members to learn from their specialized colleagues while reexamining cherished assumptions along the way. In this case, subject matter experts had to rethink traditional curricula. Artists and programmers had to confront a technical domain that lacks straight lines and where the key players are wobbling blobs. Game designers had to accept the odd rules of engagement in a battle where the player can't see the enemy, and friendly forces may appear to be far more evil than the invaders.

Since we were operating with a limited budget and the primary goal was to incorporate science research in a number of areas, we chose to work with a research team rather than a commercial developer. The team had expertise in such areas as biology, immunology, pedagogy, game design, and learning science. We drew on their knowledge of: the complexities of the underlying biology; information technologies needed to build complex simulations and visualizations; instructional objectives and strategies best suited for the target audience; application of the software tools to build games the targeted audience would find engaging and motivating; programming and scripting languages necessary for Q&A tool integration; and evaluating the effect of game/exploration-based instruction.

Collaborating institutions included FAS, Brown University, and the University of Southern California. FAS had overall project management responsibility, including learning content, development of learning tools, and the project evaluation plan. Brown University led the game programming effort, provided expertise regarding scientific visualization, and assisted with art design. The USC team was responsible for game design, user interface, artwork, 3D models, cinematics, and sound. Several members of the team had prior experience in commercial game design.

Battlefield Metaphor

The immune system of living organisms is inherently fascinating but can be extremely difficult to understand. Its operation involves complex interactions among a large number of cell types, antigens, and intercellular processes. Members of the game design team were immediately intrigued by the fact that the immune system is based on rules that lend themselves to translating key concepts into software. The idea of immune cells combating bacteria naturally lends itself to battlefield metaphors. Invading bacteria and viruses breach natural defenses and unless stopped by friendly forces will continue to conquer new territory. However, the immunologists in the group vetoed the idea of using anything resembling a first-person-shooter game where the immune cells would locate and blast invaders into oblivion with weaponry, which is simply not how the immune system works.

Following contentious scientifically deep discussions and frequent reviews of the background immunology, the gamers began to realize that the strategies used by the immune system, the defensive maneuvers used by invaders, and the field of battle where the engagement plays out are more fascinating and bizarre than anything experienced in any commercial first-person-shooter game. The approach we ultimately chose is a variant on discovery games (such as Descent and Freelancer) where the player explores strange territory, earns the right to use advanced equipment by demonstrating competence, and moves on to new challenges.

The game-prototyping process began with crude interface sketches and playable paper prototypes. We assembled these materials to pursue the key question posed by all original game-design problems: What does the player do? After a slow nine-month start, the team switched to an iterative design process that stressed rapid prototyping, play testing, and revision. During the final stages of development, we tested and revised game usability on a weekly basis. This testing showed precisely where users had problems understanding the controls, pedagogy, object of the game, and user interface.

Learning Content and Gameplay

We formed an educational advisory board that included immunologists, instructional designers, game developers, and experts in educational technology. The immunologists and instructional designers initially sought to define the learning objectives. They worked with the game designers to devise a gameplay strategy that would support the learning objectives, meaning that previous knowledge would be needed to succeed at each increasingly sophisticated gameplay level. Together, we decided it would be far more interesting for the player to be involved in the details of how real biological battles are fought—details typically reviewed only in advanced university textbooks. These texts are challenging for most students due to their extremely complex vocabulary, but we felt that clever visual tools and clear English explanations would make these fascinating biological systems lucid to all players.

Learning Objectives	Game Design/Play
General	
The student will be able to comprehend the basic strategies of major pathogens.	Stylized, but accurate, behaviors of a variety of bacteria, viruses, and toxins; simple rules govern their behavior.
The student will be able to identify and understand the role of key components of the immune system, including innate responses, inflammatory responses, and secondary response systems, including antibody response.	Stylized, but accurate, behaviors of macrophages, neutrophils, mast cells, NK cells, and T and B cells, together with key signaling proteins; simple rules govern their behavior.
Innate Immunity	
The student will be able to analyze the concept of how immune cells recognize "self" peptides vs. "non-self" peptides.	The challenge is to train macrophages by selecting receptors that identify pathogens and functions that help destroy the pathogens. The player must train the macrophage to recognize and kill pathogens in a timely manner.
The student will comprehend the various stages of cell development (such as maturation and activation). The student will learn to identify and apply the chemical compounds used to detect certain pathogens.	Monocytes entering tissues develop into macrophages. As phagocytic cells encounter pathogens, immune cells, or relevant proteins, the player utilizes functions available only to the cells in their activated state. Cells "trained" by players can operate autonomously.
The student will be able to identify, understand, and synthesize mechanisms of cell migration and extravasation.	The player can take control of specific characters (such as macrophage cells) that follow/leave protein trails and learn to navigate from the blood vessel through the tissue to the site of infection. Additional play levels permit the player to learn to navigate from the site of infection to the lymph nodes, moving in and out of tissue.

Immune Attack learning objectives and game design and play.

Our first step was to program play levels built on basic biological concepts and a repertoire of playable immunology characters. The first play level—in which the player learns to train a macrophage—presents the central challenge of the immune system—telling friend from foe—while introducing the most versatile and basic immune cell, the macrophage. It begins with the player navigating a blood vessel, knowing an infection is nearby but not how to find or defeat it. With help from built-in hints, players learn they must train a macrophage to accomplish three tasks: find the part of the blood vessel closest to the infection and exit the vessel; follow a chemical trail leading to the bacteria creating the infection; and attack and kill only the bacteria, not the many types of friendly "self" cells in the region. In each more challenging game level the invaders become increasingly sophisticated in their method of attack, as well as in their evasive maneuvers. Countering increasingly capable enemies requires that players train more highly specialized immune cells (such as neutrophil suicide squads and natural killer cells). Resource limitations restricted the first release of the game to two play levels—training macrophages and training neutrophils—but we developed plans for additional levels (see the table here).

We next had to decide how the player would train the immune cells. After rejecting plans to write short logic programs for the immune cells to execute (deemed boring by the game designers) and plans to allow the cells to have behaviors that were biologically impossible (unacceptable to the immunologists), a compromise emerged in which players begin by exploring a rich 3D world where they gather information needed to train their agents—the immune cells. When players feel they have gathered enough information, they attempt to train the immune cells using small "action games" (such as finding and following the right chemical trail). The subject-matter experts were willing to tolerate biologically impossible behavior in these 2D training games since they were clearly artificial. If the player wins the action games, the cells in the full 3D model begin to demonstrate behaviors that implement the training lesson(s) (such as follow the correct chemical trail). Players who fail at the action games are given hints with regard to what information must be learned and encouraged to learn it, then try the action game again until they master the learning objective.

Integrating Educational Content

Players usually skip introductory text—educational and otherwise—going immediately to gameplay. We designed Immune Attack so the basic rules of the game—the powers given to each character, clues to following trails, signaling, and telling friend from foe—closely follow the rules of the immune system itself. We made every effort to let players gather information through clear visual and auditory media that provides information while allowing their eyes to stay fixed on the action; for example, players learn about macrophages by interacting with behaviorally realistic macrophages, rather than by reading about macrophages, even though the game provides some material in the form of text and photographs. A warning is posted before each action game (see the figure here) to alert players that previously available information is required to win the game and that it is up to the player to seek it out. Players who fail to read the information have difficulty winning action games and is itself another important lesson.

The FAS Learning Science and Technology R&D Roadmap project [1] highlighted the importance of stimulating learners to ask questions and provide context-sensitive, timely, accurate answers. Immune Attack incorporates a generic inquiry management tool called My Learning Assistant, or MyLA, developed at FAS to be compatible with many different types of instructional games, not just Immune Attack. We felt it was important to minimize both the amount of text players must read and the interruptions in gameplay. The instructional designers made the case that while this may be true for entertainment games, it might not be the correct approach to accomplish the desired educational goals of Immune Attack. The final version of MyLA, now incorporated into Immune Attack, allows users to ask questions, view images and video, and look at animations and photos that relate to the answer. All this data is stored in an integrated database. To access MyLA, players pause the game, but despite this interruption they (and their teachers in the schools where we tested the system) were enthusiastic about using the Q&A tool during evaluation of the game prototype. The game required models of blood cells, including: several types of immune system cells; models of the interior of blood vessels; and the tissue outside the blood vessels. The tissue environment proved the most difficult to model realistically because it involved developing a model of a bewildering array of cells and connective tissue and because few 3D examples were available for guidance.

Deciding what to leave out was also difficult. In a real blood vessel, for example, blood cells are packed in so densely that a viewer inside the vessel would see only blood cells; we thus had to reduce the number of cells in the blood. Similar trade-offs were needed in the tissue area outside the blood vessel. In real tissue, immune system cells squeeze between tightly packed layers of tissue cells. This would have made it difficult for players to understand the structures and impossible for them to navigate. The solution was to leave out 90% of the tissue cells, creating artificial open spaces. Each compromise involved contentious conversations among the gamers, game testers, and immunology experts. The immunologists were eventually satisfied that the importance of understanding the overall flow of cells and cell events outweighed the need to be completely accurate about cell density and relative size.

The range of physical scales presented another set of problems. The immune system operates at many physical scales—ranging from blood and lymph circulation, which operates at the scale of the entire body (m-scale), small-scale structures (such as lymph nodes) (mm-scale), immune cells (μm-scale), and cell surface proteins and receptors (nm-scale). The team found it made the most sense for most gameplay to take place on the μm-scale, with larger- and smaller-scale systems (such as the map of the tissue and close-ups of cell surfaces) displayed in a smaller, secondary window.

Unfortunately, the biological aspects and nature of Immune Attack prevented us from taking advantage of much of the functionality in existing game engines. Game engines are usually optimized for common game environments (such as indoor rectilinear and outdoor terrain environments). The biological environments that appeared in the early prototypes of Immune Attack did not easily map to these traditional surfaces. Similarly, the typical game behaviors supported by game engines were not easily transferred. This meant we had to create functionality that in other situations could have been reused from existing game engines. Moreover, the complex set of motions in the body would have been extremely difficult to simulate. We made a series of creative compromises, ultimately blessed by the immunologists, to create a plausible approximate simulation. These fixes included developing simple animations of most immune cell behavior and avoiding collisions by simply putting cells on preprogrammed tracks.

As the project progressed and our deadline (April 2006) for the first field test approached, we had to make a number of difficult decisions, since it was apparent it would be impossible to fully implement our original design. Many of the cherished goals of the immunologists (such as full 3D views of cell surfaces) and of the game designers (such as soft body physics) had to be sacrificed. The deadline did, however, force us all to focus on the essential elements of the game. The immunologists had to identify which concepts went to the core of the learning objectives and which ones were interesting but not essential. Gamers and game testers were forced to select the elements of the interface and gameplay that were critical to the "fun" of the game and which were in the "wouldn't it be neat if" category.

The game went through a series of alpha tests involving five high schools and about 220 students. The schools were in many parts of the country, including Rochester, NY, Washington D.C., San Jose, CA, and La Center, WA, ranging from those in less affluent areas to magnet schools. Students found the game accessible compared to traditional textbooks. Teachers were strong supporters, as they actively seek new ways to reach out to their students. Advice from the students and teachers was extraordinarily helpful and led to major changes in the design of both the gameplay and the interface. We are now completing a beta version of the game that will be evaluated by a wider group of high schools and a larger group of students across the U.S. The data will be analyzed by an independent evaluator at the conclusion of this phase of the project.

Conclusion

This development process gave us invaluable experience in understanding the perspectives and expertise of multiple game players, game designers, programmers, artists, subject matter experts, instructional designers, and others, all contributing to developing an educational game. Developing a serious science-based game is a challenging endeavor due to its having to satisfy experts and novices alike while addressing deeply held pedagogical assumptions, highly specialized nomenclatures, distinct expert viewpoints, visualization trade-offs, and the integration of gameplay and learning content. The cross-profession collaboration led to project prioritization that ultimately enhanced the game's core concept and usability and leveraged the team's diverse expertise. C

Reference

1. Federation of American Scientists. *Learning Science and Technology R&D Roadmap.* Tech. Rep., Washington D.C., Oct. 2003; www.fas.org/learningfederation.

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