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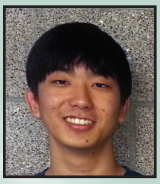
Making Learning Fun: An Analysis of Game Design in Science Learning Games



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Making Learning Fun:
An Analysis of Game Design in Science Learning Games*

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Abstract

This report describes and documents observational results that arise from the playtesting-based evaluation of twenty-six computer games focused on science learning or scientific research. We refer to this little studied genre of computer games as *science learning games* (SLGs). Our goal was to begin to identify a new set of criteria, play mechanics, and play experiences that give rise to play-based learning experiences in the realm of different scientific topics. More broadly, the games we examined may be viewed as demonstrating support for students/players to informally learn about different topics in science, technology, engineering, or mathematics (STEM), or to participate as citizen scientists in authentic research projects where games with a purpose may encourage broad participation in a scientific research study. We also include a comparative analysis of three non-STEM focused commercial games to three STEM games within our sample, just to see if we can similarly identify additional insights about SLG play mechanics and user experiences that can arise through non-SLG play. We then finish with a short description of a new science learning game, called *Beam*, that was designed and implemented to demonstrate some of the insights that were produced through this approach to the comparative playtesting and observational analysis of a sample of science learning games.

Introduction

As computer games became a staple in the world of entertainment with the rise of home console, innovators harnessed the capacity for these interactive and entertaining devices to become tools for learning. Along with the entire video game market, the selection of educational games grew, becoming large enough to be considered a genre in the world of games. Unfortunately, games in this genre, especially those that focus on topics in science, technology, engineering or mathematics (STEM) can sometimes have fun take a backseat when it comes to engaging the user, effectively eliminating a delivery mechanism that could make even the most mundane material interesting. The challenge comes in the form of finding the right balance of fun and learning through the introduction of proper and innovative game mechanics meant to immerse the player in the world of the games particular subject matter. In this paper, we aim to analyze a variety of educational STEM games and reveal to developers in this field good examples, and weak examples or ambiguities in gameplay, while trying to find the golden balance of fun and learning.

Over the course of studying our respective disciplines of game development, we've accumulated some informal principals of STEM game design, based on the sample of games playtested. Our goal here is therefore to explore how playtesting a sample of computer games within a common genre can be used to identify and rate salient features, capabilities, and experiences that in turn may influence the design of a new generation of games within the same genre. We offer an analysis of what makes a game fun and engaging to play from the player's standpoint, using what knowledge we have gained from first-person experience with playtesting these games in the course of analyzing what's been done and what could be improved.

Ready to Play Science Learning Games

The following is a list of currently available computer games whose content, play mechanics or play experience focus on different topics in a domain of scientific research or education. Some of these games are focused on engaging players in "citizen science" where one objective is for game players to help solve authentic problems that are of interest to scientists working on a complex problem that can be factored into pieces addressable through individual, repeated, collective (multi-player) or crowdsourced (multi-player with shared intermediate results/findings) game play sessions. Other games focus on providing some kind of formal or informal STEM education experience addressing one or more topics in science, technology, engineering, or mathematics (STEM) fields. We will refer to all the games listed below as examples of *science learning games* (SLG): games whose purpose is to help the player learn about problems, challenges, techniques, or concepts relevant to some science/STEM domain, or how to use them in solving provided problems/puzzles.

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 examine, compare, and ultimately identify SLG play mechanisms for reuse or repurposing that will be fun, collaborative, and oriented to STEM knowledge and practices, as well as network-centric activities and learning experiences.

Most/all of the SLGs we examine are likely to have associated game play videos or "machinima" associated with them, which can usually be found on *YouTube*. So feel free to search and view such videos to see what else you can learn about each such game. These games are also likely to have some description within *Wikipedia*, so consider reviewing that information as background. Some of the games also are themselves the subject of scientific research or technological innovation, as indicated by associated research papers or publications in research journals. Games of this kind may therefore have multiple or complex research objectives that span different STEM domains (e.g., protein science--for game content and challenge problems, and computer game science--for game design principles). You are encouraged but not required to locate and review such papers, but doing so may help you more deeply understand the potential of games in science/STEM may be. In contrast, STEM focused games are often targeted to audiences of students within specific K-12th grades (e.g., targeted to 5th grade life science students). So the subject/topic in such STEM games is generally not research oriented, but more often oriented to preparing students to fulfill National Science Education Standards for specified grade levels. Nonetheless, it is always useful to see if/how STEM learning games versus scientific research games compare in order to better understand which is more fun to play, what can be learned, how is player learning assessed (e.g, in-game question answering), and the like.

The list of games that follow is unordered, so the position in the list is not an indicator of importance or priority. However, we should expect that the quality or play experience of each will vary across a sample of games. Similarly, some games can be played directly online (are browser based), while must be downloaded onto a computer or mobile device (which means it may not be playable on every type of computer or operating system). So always be sure to check whether there are some sort of "system requirements" that must be satisfied in order to play the game (e.g., only runs on Microsoft Windows 8 with touch interface; or runs on PC/Mac but not Linux; or available for download from the Apple/Android App Store; or whatever).

1. *Algograph--Pebble It* (goal is to harness the intelligent, decision-making power of the human brain to solve mathematical graph pebbling problems) -- http://algoraph.cs.hope.edu/?page=pebble
2. *Cell Craft* (game that delves into the world of the cell, learning about how a cell functions while helping it survive in hostile environments) --

http://www.carolina.com/teacher-resources/Interactive/online-game-cell-structure-cellcraft-biology/tr11062.tr

3. *Cell Slider* (Spot real cancer cells through Cell Slider and help our scientists improve the diagnosis and treatment of cancer.) -- http://www.cellslider.net/
4. *Circuit Bot* (Link up a team of robots to carry out a mission) -- http://circuitbot.verigames.com/
5. *Eyewire* (mapping the tangle of nerves and ganglia behind the human eye) -- https://eyewire.org/
6. *Flow Jam* (your goal is to become increasingly adept at analyzing networks to see how you can maximize the flow) -- http://centerforgamescience.org/portfolio/flow-jam/
7. *FoldIt* (a citizen science game where players compete against one another to fold proteins into their most stable configurations) -- http://fold.it/portal/
8. *Gamestar Mechanic* (game-based quests and courses to help you learn game design and make your own video games) -- https://gamestarmechanic.com/
9. *Ghost Map* (Free your mind by finding a path through a brain network) -- http://xylem.verigames.com/
10. *Immune Attack* (navigate a *nanobot* through a 3D environment of blood vessels and connective tissue in an attempt to save an ailing patient by retraining her non-functional immune cells) -- http://immuneattack.org/
11. *Kinetic City* (a collection of science experiments, games, and projects) -- http://www.kineticcity.com/
12. *Life Preservers* (game that teaches National Science standards on evolution, adaptation, and the history of life on earth) -- http://lifepreservers.msu.edu/game/full/index.html
13. *Little Alchemy* (a non-scientific game for mixing and composing basic elements into more complex forms) -- http://littlealchemy.com/
14. *Nanocrafter* (focuses on synthetic biology problems) -- http://nanocrafter.org/
15. *Phylo* (an experimental video game about multiple sequence alignment optimisation) -- http://phylo.cs.mcgill.ca/
16. *Play to Cure: Genes in Space* (take the fight against cancer to space in this world-first mobile game that analyses cancer data and plots genetic faults as you play) -- http://www.cancerresearchuk.org/support-us/play-to-cure-genes-in-space
17. *Race to Mars: On Orbit* (Use the robotic ARM to build the ship that will take humans to Mars.) -- http://www.racetomars.ca/mars/game_onorbit.jsp
18. *Race to Mars: Rover XPL* (A game of strategy, puzzle and exploration on the surface of Mars) http://www.racetomars.ca/mars/game_xpl.jsp
19. *Radix Endeavor* (a massively multiplayer online game (MMOG) for STEM learning (science, technology, engineering and math) in middle and high school) -- https://www.radixendeavor.org/players

20. *Refraction* (lets you bend, split, and redirect lasers to power spaceships filled with lost animals! Help free as many animals as you can by expanding your knowledge of fractions) -- http://centerforgamescience.org/portfolio/refraction/
21. *Storm Bound* (Unweave the windstorm into patterns of streaming symbols) -- http://stormbound.verigames.com/play/
22. *Vampire Vision* (a game to measure and possibly improve players' visual perception) -- http://centerforgamescience.org/portfolio/vampire-vision/
23. *WolfQuest* (an immersive, 3D wildlife simulation game that challenges players to learn about wolf ecology by living the life of a wild wolf in Yellowstone National Park) -- http://www.wolfquest.org/downloads.php
24. *Xylem* (Catalog species of plants using mathematical formulas, but requires iPad for game installation and play) -- http://xylem.verigames.com/
25. *Circuits* (a puzzle game that requires putting together different parts of a song as circuits) -- http://store.steampowered.com/app/282760/
26. *Strata* (a puzzle game for strategically layer colored ribbons to match a pattern) -- http://www.desura.com/games/strata

Analysis Breakdown

The 26 games in our primary analysis can be separated into two categories: those that informally teach material on a scientific subject, and those that crowdsource public participation in finding solutions to scientific research problems. In the analysis, there will be a short descriptive summary of the game along with visual documentation. After that will be a quantitative analysis of several categories as well as reasoning for the given scores.

For the quantitative analysis, each game is rated on a 1-5 scale in the following categories: Overall User Experience, GUI Functionality, Gameplay Mechanics, Educational Value, and Entertainment Value. The categories were chosen for the following reasons:

- *UX (User Experience):* In any game, overall user experience is important in keeping the player immersed in the game. In educational games, further immersion results in greater educational value because the player remains playing the game longer. Some things that contribute to UX are continuity, lack of bugs, and cohesive gameplay. Testing for UX is often called, "playtesting."
- *GUI:* A properly functioning and attractive GUI not only pulls the player into the game, but also makes the game easy to use. In the case that the GUI is poorly done, it can become frustrating for the player to use and in turn result in the possible termination of a play session.
- *Gameplay Mechanics*: Gameplay forms the solid foundation of any game. They are especially important in educational games as they are meant to serve as a tool for delivering knowledge for the player. It becomes important for the mechanics used to actually incorporate knowledge into them, as well as avoid repetitive tasks.

- *Educational Value:* In an Educational game, educational value is obviously important, because if the game is not teaching the player about a specific subject matter, it isn't fulfilling its primary objective.
- *Entertainment Value*: The final goal for Educational games is to have a finely tuned balance of entertainment and education to immerse the player in the subject material and allow for the exploration of a certain topic in a fun fashion. An Educational game without any sort of entertainment value is much like a lecture.

To be clear, we make no claim that the scores assigned are definitive or un-biased. Instead, we note our purpose is to describe our reactions and subjective evaluations of different games through a systematic, comparative effort to playtest games within a sample population of a emerging game genre. Other evaluators may come up with different ratings, so we encourage others to repeat our observational study with this same sample of games, rate them on the same dimesions as done here, and then write up and share their findings. As before, our goal is to develop new knowledge about how to better design science learning games, and in our case, we choose to do so by starting with a systematic review of a significant sample of games within this genre. Our efforts to replicate this study will serve to help further broader development of game design and play experience heuristics that can further the science of SLGs. Similarly, identifying, playtesting, comparatively analyzing, documenting and sharing studies of other SLGs not included in our sample is also an valuable follow-on effort that we encourage.

With these items in mind, we can briefly review a set of recent SLGs to get a sense of what areas of science and engineering are being addressed, in order to better inform the choices we may recommend or elect to support through the development, deployment, and evaluation of one new SLG, called *Beam*, and described later.

Top Games List

In preview to the game playtest assessments that follow below, we first identify four games that stood out to us in this study, along with the core reason or characteristic for the selection, including our rating for each of the five dimensions used in our study.

Cell Craft – Most educational and engaging game

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	3	4	5	4

Things to pay attention to: Cell Craft was selected as the most educational and engaging SLG in our sample because it had high educational value, and because it took the already widely-used and successful RTS mechanic (inspired by *StarCraft* from Blizzard Entertainment) and developed modifications that repurpose this game play mechanic, creating an interesting twist in how the game was played (see Cell Craft Comparison for an in-depth look at these modifications). In addition, the implementation of a storyline gave justification for gameplay and encouraged the player to stick with the game.

Eyewire – Best GUI and UX design

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	4	2	5

Things to pay attention to: Eyewire, like several other games on this list, delivered the quality of a downloadable game with a web-based package. However, Eyewire set itself apart in that the GUI was not only intuitive, but it was designed so that even players with little knowledge of neurons could accurate solve the issues presented. (see Eye Wire Analysis for an in-depth look).

Wolfquest – Most well-rounded game

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	4	4

Things to pay attention to: While not being particularly amazing in any individual category, Wolfquest delivered an all-around game which performed well in each category. This is surely preferable to delivering a game which excels in one category but fails in another, which is generally the case in many of the games presented. In our introduction, our goal was to analyze games that found the right balance between education and entertainment, while still delivering an experience close to that of mainstream games, and we believe Wolfquest accomplished that.

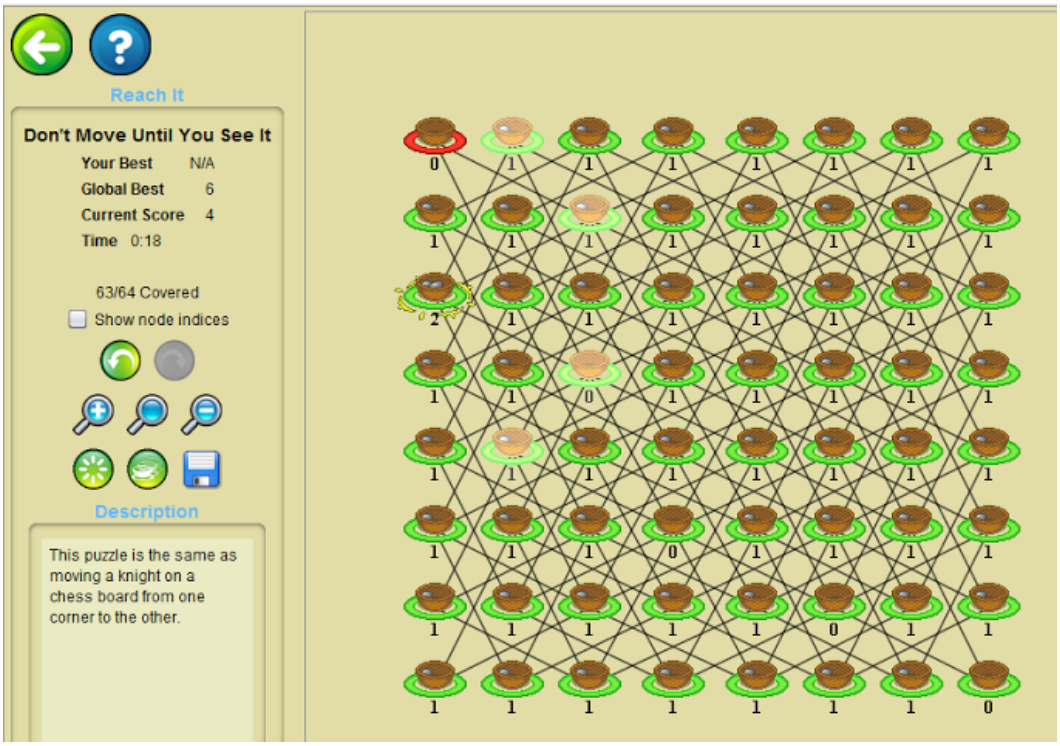
Strata – Best modern puzzle game

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	5	1	4

Things to pay attention to: Strata was given this category, because while not a game designed for educational purposes, delivered a package of beautiful UI design, great UX, and interesting game mechanics (see Strata Analysis for an in-depth look) that suggest its relevance as either a technology design or engineering learning game. Because of this, we believe that educational SLG game developers should pay attention to these elements so that they can combine these elements with a proper educational and entertainment experience.

At this point, we now turn to present the database of game playtesting assessments we produced for 26 games we included in our sample.

Algograph – Pebble It



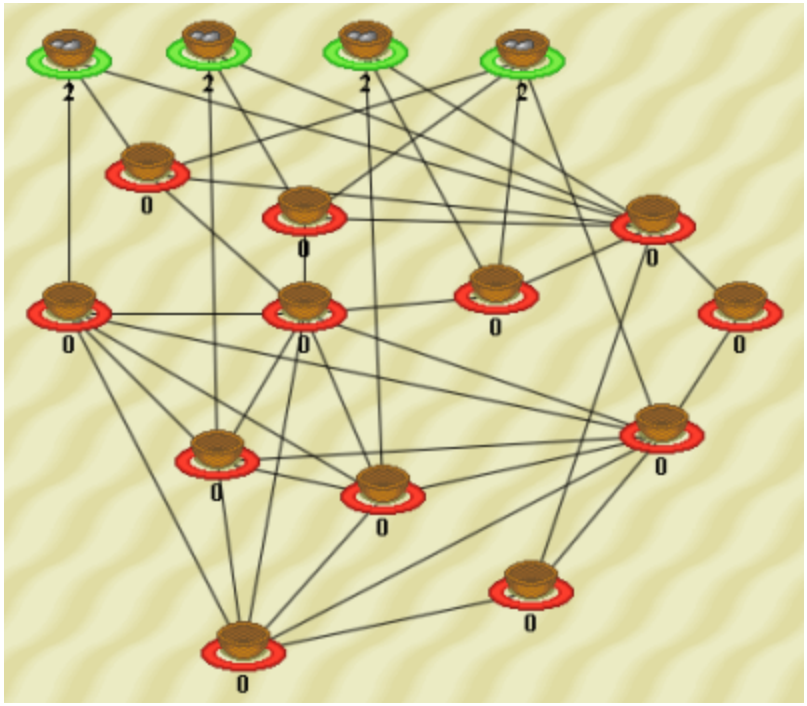


Figure 1: Game interface screenshots for *Pebble It*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
2	2	4	3	3

Game:

Pebble It is a human computing game based on graph pebbling that offers puzzles for users to solve with specific rules.

Analysis:

Pebble It is interesting in its focus on graph pebbling that make its unique among other games. However, the implementation could be improved with some difficulties with GUI. In addition, most of the problems presented do not seem resource intensive for a computer, and it is not obvious how a human playthrough would help with any computation or research. In addition, the number of puzzles is very lacking and could be more exciting with more puzzles.

The GUI as stated before is problematic in the selection of "baskets" are somewhat unreliable. In addition, the baskets can overlap and led to unwanted selections. If performing a wrong move, the user must exit and re-enter the puzzle to get the lowest score, which maybe become disruptive to the overall gameplay.

Gameplay is fairly unique in its puzzle concept, but more numerous and difficult challenge would greatly add to a more full experience.

Pebble It does feature a ranking system, but the game lacks in the competitive aspect. Replaying each level once and remembering the order is enough to get on the top of the small ranking list.

Cell Craft

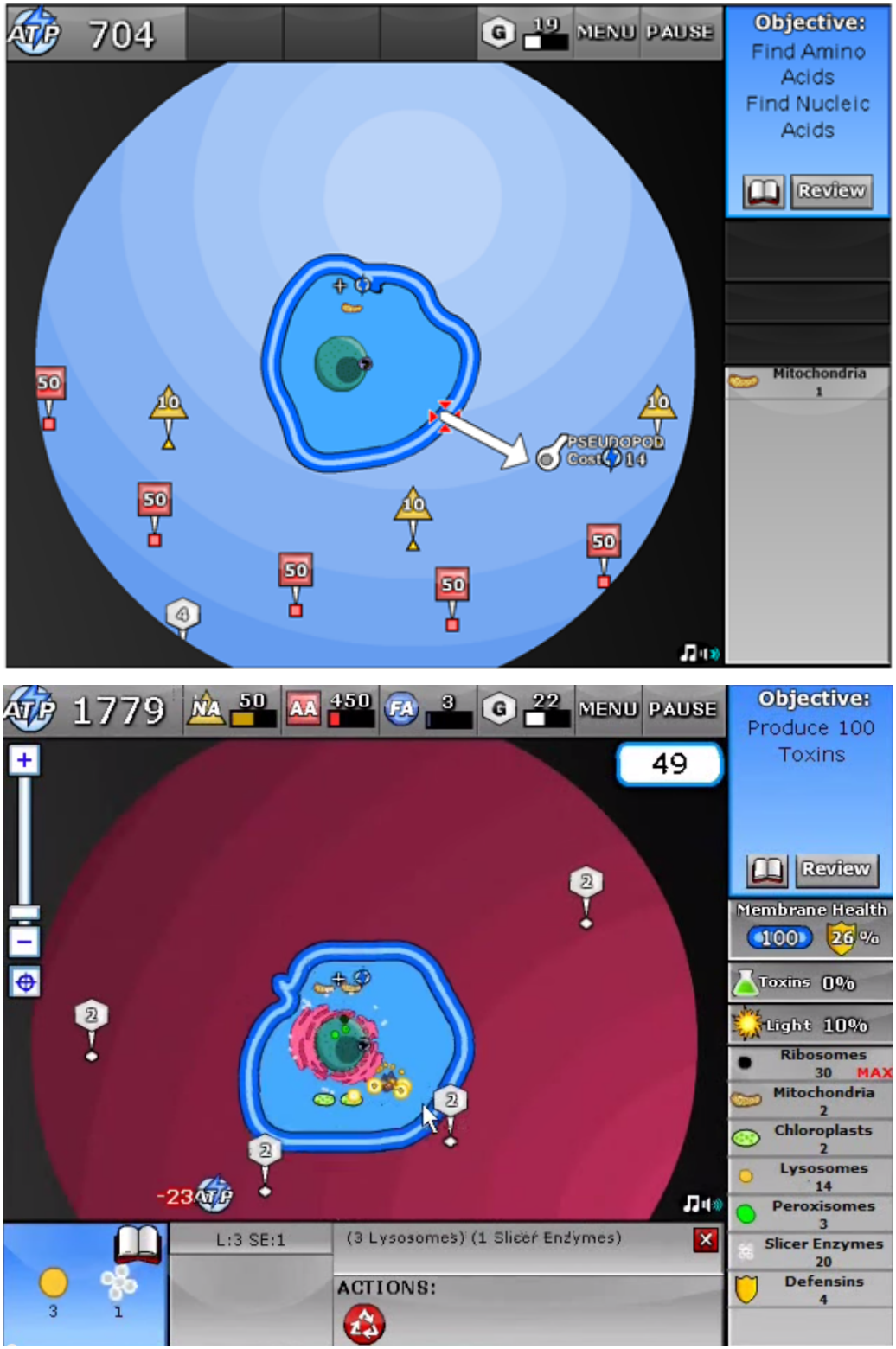


Figure 2: The game interface screenshots for *Cell Craft* during an earlier level.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	3	4	5	4

Game:

Cell Craft is a game built to teach middle school or high school kids about the structure and function of the cell. The game comes with a story about how two biologists are tasked with finding a way to save their species from a meteor impact. Game mechanics are similar to that of RTS games, in which you have to use limited resources to produce and fight off enemies.

Analysis:

The Overall User Experience was well done. There were no bugs apparent during the game playtesting period and the gameplay was cohesive with the narrative, and gently integrated new game mechanics while introducing new challenges.

The GUI was well designed, and allowed the player to access any information they needed throughout the course of the game. For instance, there was a current objective table which aided the player in instances where the objective took time to complete. The GUI also readily gave you prices (in terms of ATP, Amino Acids, and RNA) for objects your cell could create. The only reason the GUI was given a score of 8 instead of 9 is because sometimes clicking through the various arrows in the tutorials or cut-scenes would become tedious, and the game used several different icons for resources instead of a single icon per resource to ease use.

The Gameplay Mechanics were well done. Through the use of concepts such as Mitochondria, Ribosomes, and Viruses, the game integrated the knowledge that the player learned through the game into standard RTS game mechanics. For instance, moving the cell cost ATP, or energy, which in turn could be recovered by finding Glucose, or sugar, and then provide an energy boost by creating a Mitochondria, or powerhouse, within the cell. This balance of resources and scientific concept led to interesting game mechanics that worked to sustain immersion and player interest during game play.

The Educational Value of the game is very high (10) because not only did the game explain the various concepts of how the cell functioned in easy to understand language, but it also used these ideas in its own game mechanics. Because of this, the game made sure the player remembered what Amino Acids were, for instance, because they played a relevant role in the game for the creation of ribosomes and slicer enzymes to defend the cells from viruses.

The game has a fairly high Entertainment value as well, in part due to the narrative and the gameplay. The narrative was done so that the player would be met with challenges in the physical gameplay. The narrative, during cut-scenes, while a bit cliché, had its fair share of humor, from the sarcastic robot to the begging for grants by the academia. The gameplay was built so that challenges required active participation in the game.

Cell Slider

Figure 3: Screenshots of the game interface for *Cell Slider* displaying cell shape classification tools.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):

4	5	2	2	2

Game:

Cell Slider enables users to classify microscopic images and aims to use the collected data to aid cancer research. Users pick from categories with sample pictures for comparison.

Analysis:

Cell Slider succeeds in its main goal of making cell classification accessible to the general public and utilizing crowd-sourcing techniques to quickly and accurately organize large quantities of data. However, this game offers no other incentive for users to continue classifying these cells. In addition, it is difficult for users to see how their input makes an impact or if their classifications are accurate.

The GUI is very well-designed and intuitive. The ambient background colors and style avoid standing out or clashing with any of the other features. In addition, the pictures, symbols, and text are defined and visible, and the buttons are clearly visible and react intuitively. Smooth animations are also present and add to the design of this website without being intrusive. A flaw of this website however, is that certain links open a menu over the page that cannot be closed. The only way to go back to your previous page is to go back a page.

The gameplay is simple but is somewhat lacking. Because of the lack of incentive to continue classifying cell slides, users may find the game pointless to play despite the apparent benefit it would have to cancer research data. In addition, feedback to user inputs would help to let users know how that they are not making mistakes.

The game features a tutorial as well, that leads new users through the basics. It is also available to the public without logging in, but also gives logged-in users a profile and more access.

Circuit Bot

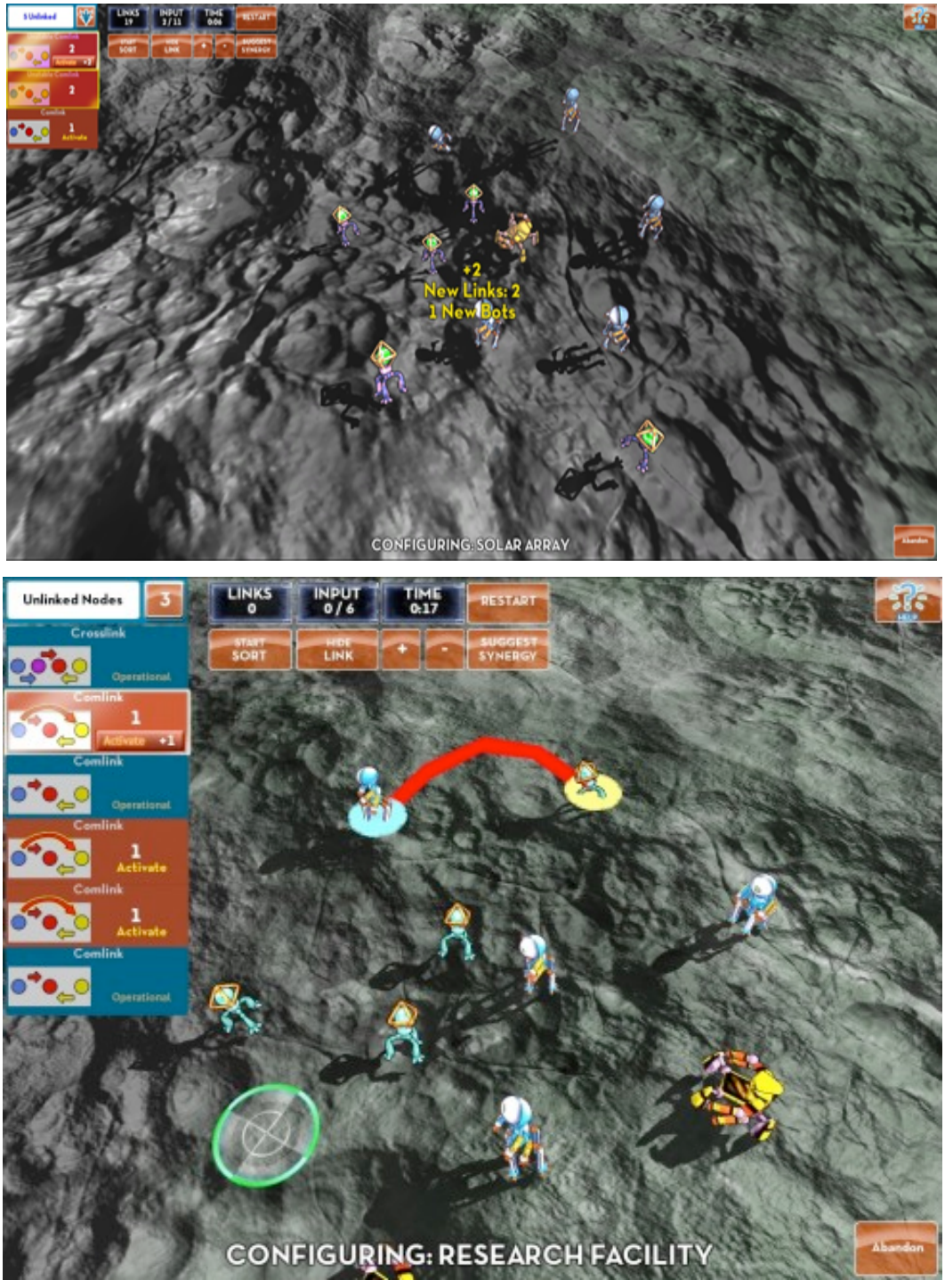


Figure 4: Screenshots of the interface of the first and later missions in *Circuit Bot.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
2	2	2	2	2

Game:

Circuit Bot is a game built around the idea of linking together robots to perform specific task, such as propelling an asteroid from Earth. The game is built in a 3D graphics engine and utilizes a simulation-type art style to depict its visuals.

Analysis:

While the overall user experience lacked any sort of bugs and the game is quite accessible, there doesn't seem to be any coherency between the educational value of the game and the gameplay, leaving the player confused as to how they are supposed to play the game.

The GUI is quite complex, with a fairly large amount of buttons, unlike other games, which gradually reveal the buttons as you play, Circuit Bot gives them all to you at once, and only explains what several do. The GUI at first was unresponsive and a bit confusing for how to progress, but later began working. Finally, several of the interfaces, especially the communication interfaces, were bordered with neon flashing lights which did not fit the color scheme of the game and seemed out of place.

Gameplay Mechanics, Educational Value, and Entertainment Value will be grouped into one analysis for this game, since their scores are the result of the same root issue. The problem with the game was is that it game you a number of robots and a series of buttons to press and never really explained what they did. The button would vary between Com Link, Unstable Comlink and have various point values, but never explained how the game was meant to be played or what it meant from an educational perspective. For the first couple of rounds, our solution was to click buttons and see what they did. We came to the conclusion that you lose points for unstable Com Links, but the game refused to explain why the Com Links became unstable and how to avoid them. Even then, the game stated that the operation was completed with upwards of 100% efficiency, which it once again refused to explain, but it can be assumed that was a good sign even after having at least a dozen unstable Com Links. The game mechanic of connecting com links through clicking buttons is never explained in terms of educational significance or how it actually works. Once the game introduced research tables and once again didn't say where resources for this system came from, we exited the game quite frustrated.

EyeWire

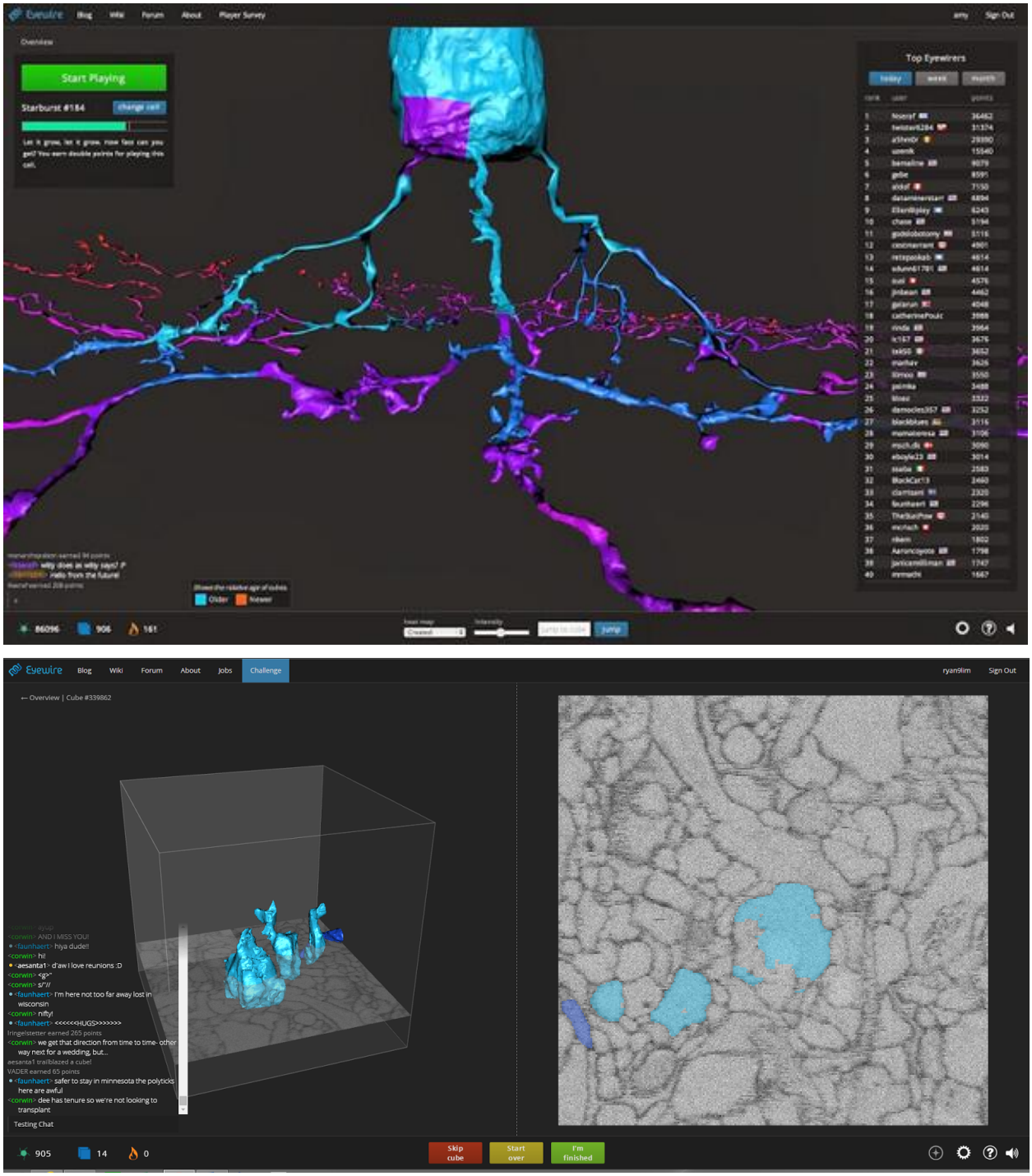


Figure 5: Screenshots of the game interface for *EyeWire* with user-selected areas.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	4	2	5

Game:

EyeWire presents a model of a specific area of brain to users who distinguish a single neuron using the 2D and 3D tools and views available. The game results from multiple users are compared and the crowd-sourced data is used to map out brain connections.

Analysis:

Overall, EyeWire is a superb game from the gameplay to its visuals and additional features. This game successfully crowd-sources neuron identification with a high degree of accuracy while maintaining an environment that keeps users engaged. In addition, the availability of this game as a website allows for easy accessibility and widespread availability.

The graphics and visuals are impressive, with the smoothness and functionality expected of downloaded application software, beyond typical website functionality. The 3D modeling and rendering work very precisely and present a visual model that is unique to the general audience. Navigation flows naturally, with added animations and minor user interactive additions to make the GUI intuitive to use. Important visual components are clearly defined and indicated with color to draw attention while the ambient gray areas avoid being a distraction to the game.

The game mechanics include basic identification, but include a variety of spatial and planar tools that give a puzzle-like quality. With the point system, accuracy becomes an important attribute to the game. Upon completion, a corrected model constructed with crowd-sourced identification is shown for comparison, to indicate missing or extra components. This process also allows users to learn from their previous mistakes and inaccuracies to continue to improve their performance.

One of the best features of this game is the ability to see how the user's contributions has influence on the entire project as a whole. Users also earn points depending on their accuracy and contribution, with profiles and game statistics. Points, accuracy scores, and a ranking system give enough incentive to make the game seem worthwhile to play while benefiting a good cause. Other minor features such as achievements also add to the interactivity of the game. A public chatroom also enables peer interaction, encouraged by a supportive online community.

Extra:

EyeWire has partnered with Korea Telecom (KT), the leading telecommunications company in South Korea, as a “Countdown to Neuropia.” EyeWire and KT plan to expand the scope of this game to Korea and the rest of the world.

Flow Jam

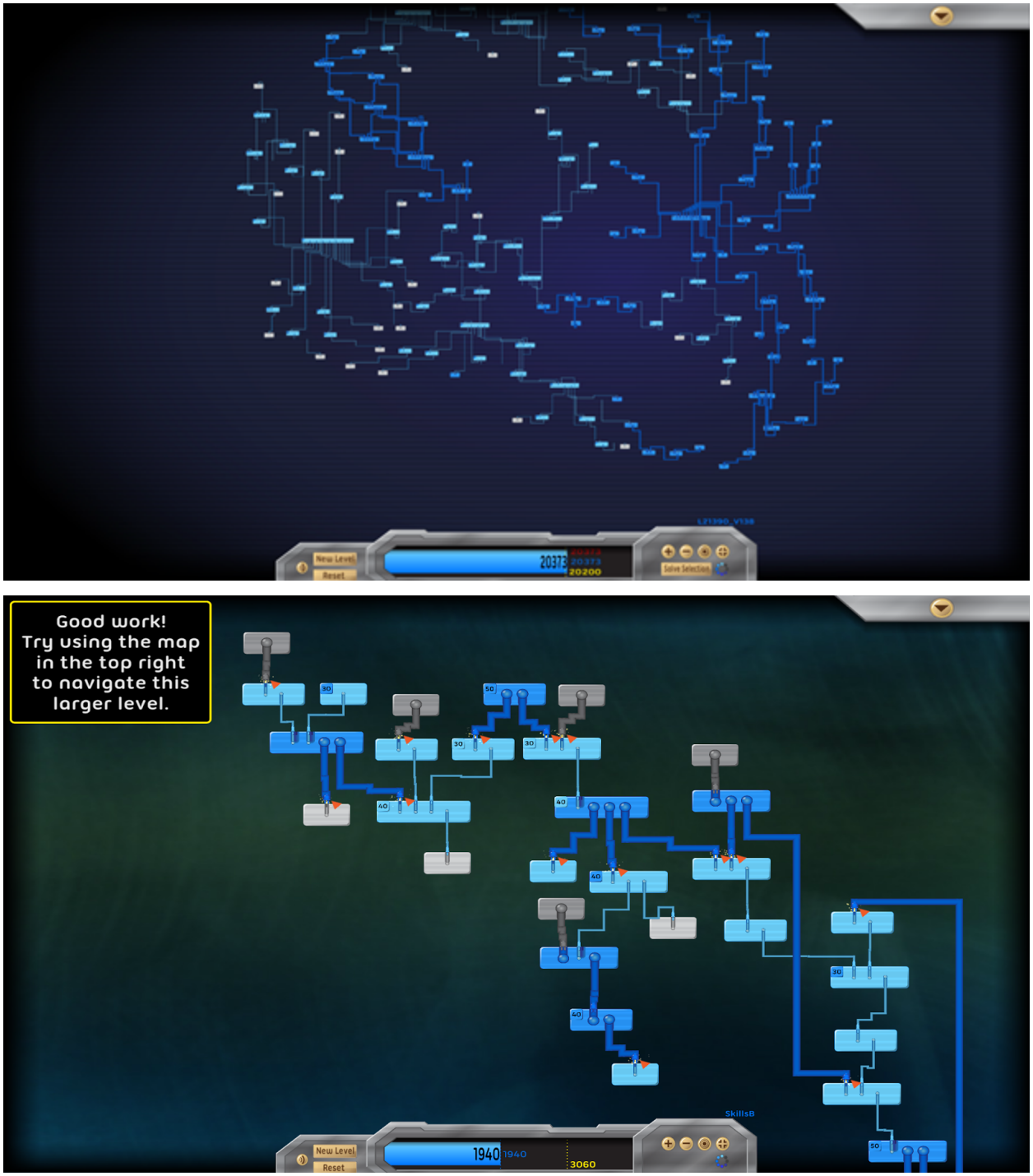


Figure 6: Screenshots of *Flow Jam*'s core interface for the tutorial and the puzzle for 7/13/14.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	4	4	3	4

Game:

Flow Jam is a crowd-sourcing game built around puzzles where the player has to get rid of "jams," which are the result of an improper wire connection. These can be repaired by changing the type of wire by clicking on a widget. Point values are determined by matching widgets to specific colors and clearing as many jams as possible. Levels are often set up so that clearing jams often results in the creation of more jams and even the highest score in the level can still have a fair amount of jams within the puzzle.

Analysis:

The Overall User-Experience was well done and the developer pays attention to the community. For instance, many players suggested the implementation of a full-screen mode, which would ease visibility in the game, and the developers listened and implemented one. There was only one bug, which came in the form of GUI accessibility. The game doesn't allow you to play the full game unless you have an account, and the full screen mode button is only accessible through gameplay. After finishing the tutorial in full screen, we exited to the main menu, but the game insisted we log in on their website, which we couldn't access because the game was in full screen. While this was remedied with a quick alt-tab, it could be easily fixed with the presence of a full screen button on all menus.

The GUI is well done, and delivers the point score as well as the point amount for each individual action, which is useful in determining the weight of each decision, something useful in a puzzle game based on point value.

The gameplay mechanics are well done. Through the process of trying various combinations of "narrow" and "wide" connections, the player is tasked with finding the optimal setup with minimal jams. Sometimes these puzzles can be quite complex and finding the optimal setup of wires can be a daunting task, but the tutorial does a good job of explaining the variety of widgets and how they affect your point value so that the player isn't lost when faced with a difficult challenge.

The educational value was given a low score because, while the game can help to engage puzzle solving capabilities, as most puzzle games tend to do, there was never any explanation of what solving of these "jams" was supposed to teach or be learned. On another note, the entertainment value was high because the puzzled were quite entertaining and which can sustain determination to find the best solution.

Fold It

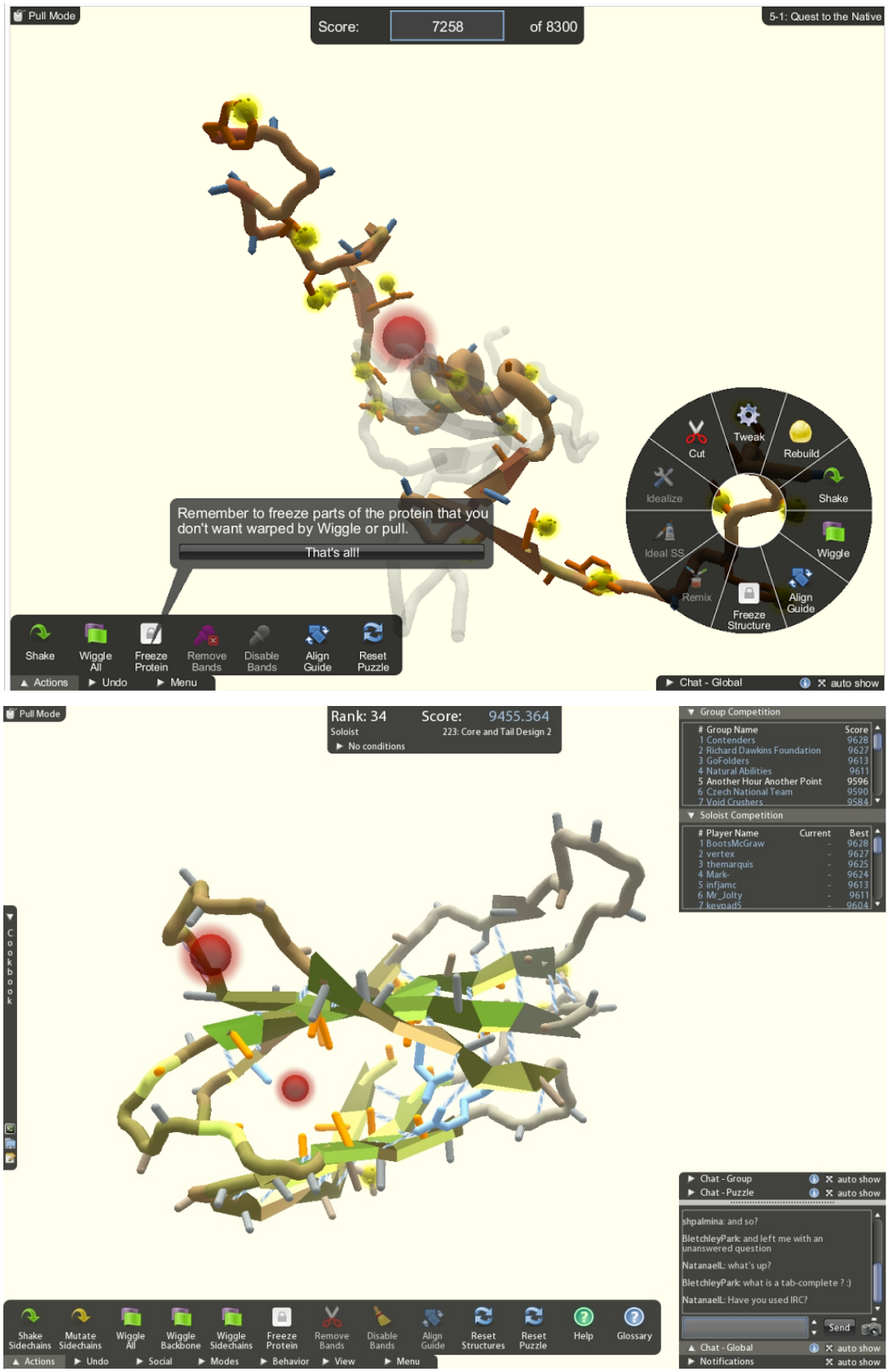


Figure 7: The game interface for *Fold It* in a tutorial level, and a challenge problem.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	3	4	2	3

Game:

Fold it is a game that converts optimizing protein structure into a crowd-sourced game for engaging citizen scientists in proteinomic research. Users must find the optimal positions of the protein strands (folds) to earn points.

Analysis:

Fold it succeeds in converting advanced protein structure restrictions into a game-like format, where the objective is to earn the most points. Results from each player help to optimize protein structure while giving players a competitive platform to design and use algorithms and reshape structures that represent proteins. However, the learning curve and the extent of options available may overwhelm new users.

This game features very simple and distinct shapes and colors that help distinguish different segments of the proteins as well as how optimal the configuration is. However, because of the sheer number of possibilities given to the player, the GUI risks being cluttered and overwhelming. 3D manipulation of the protein segments is very easy to use and takes advantage of larger capabilities of a standalone-application. Though some of its GUI elements seem outdated, nothing is visually obstructive to the user when playing.

Game mechanics include many commands that either allow you to manually manipulate different segments or contains an algorithm to help optimize the structure and earn the most points. However, the existence of these optimizing algorithms run the risk of making the player useless. The game features an extensive tutorial, yet new users may still rely on guessing the placements, something that a program could easily do with more speed and efficiency.

Fold It uses many incentives to draw players in, and maintain a competitive, significant experience. The game includes unique and frequently updated puzzles, an achievement system, rankings among other global users, and contests, where users can create their own puzzle to share with the rest of the community.

Gamestar Mechanic

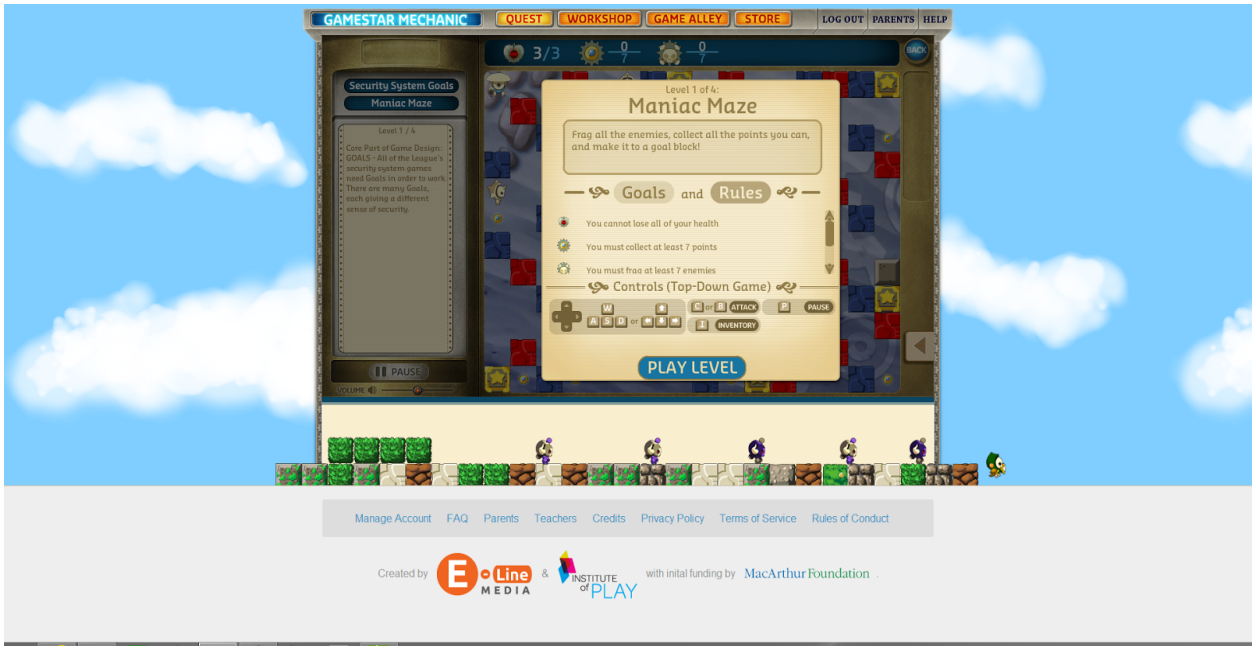


Figure 8: The game interface for *Game Mechanic* and mini-game instructions and sample game.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	4	4	5	4

Game:

Gamestar Mechanic is a role-playing game that takes the player through a series of mini-games. The game is quest-based and mostly linear, taking the user through a comic-like narrative. This game focuses on entertaining young players but also features resources to create their own mini-games.

Analysis:

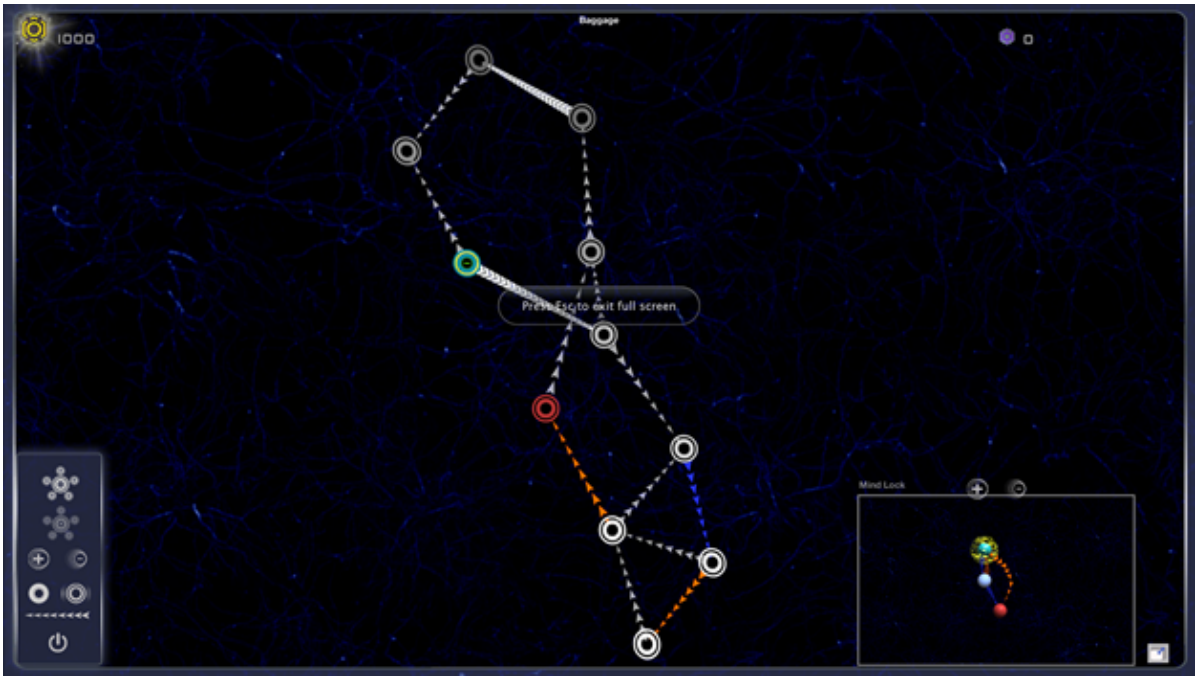
Overall, Gamestar Mechanic includes many features that would make this useful and entertaining to a target audience of elementary students. With everything from video tutorials to an online community, the game-making process is encouraging and simple for young children.

The GUI is fully functional and intuitive and includes comic-like visuals to support the narrative. The game uses a grid-like system to make the games more accessible to young children and easier to handle sprites. Though this restricts the mechanics for the games, it matches the target audience yet still allows for creativity and a basic level design.

Each mini-game has its own instructions to play, shown at the start, but most have simple movement, jumping, and or shooting. The level editor given in Gamestar Mechanic presents a drag and drop environment with adjustable features.

Gamestar Mechanic encourages users to play through the main story with the incentive unlocking new content for the editor. The accompanying storyline and natural progression of the game feel interactive and engaging to continue playing.

Ghost Map



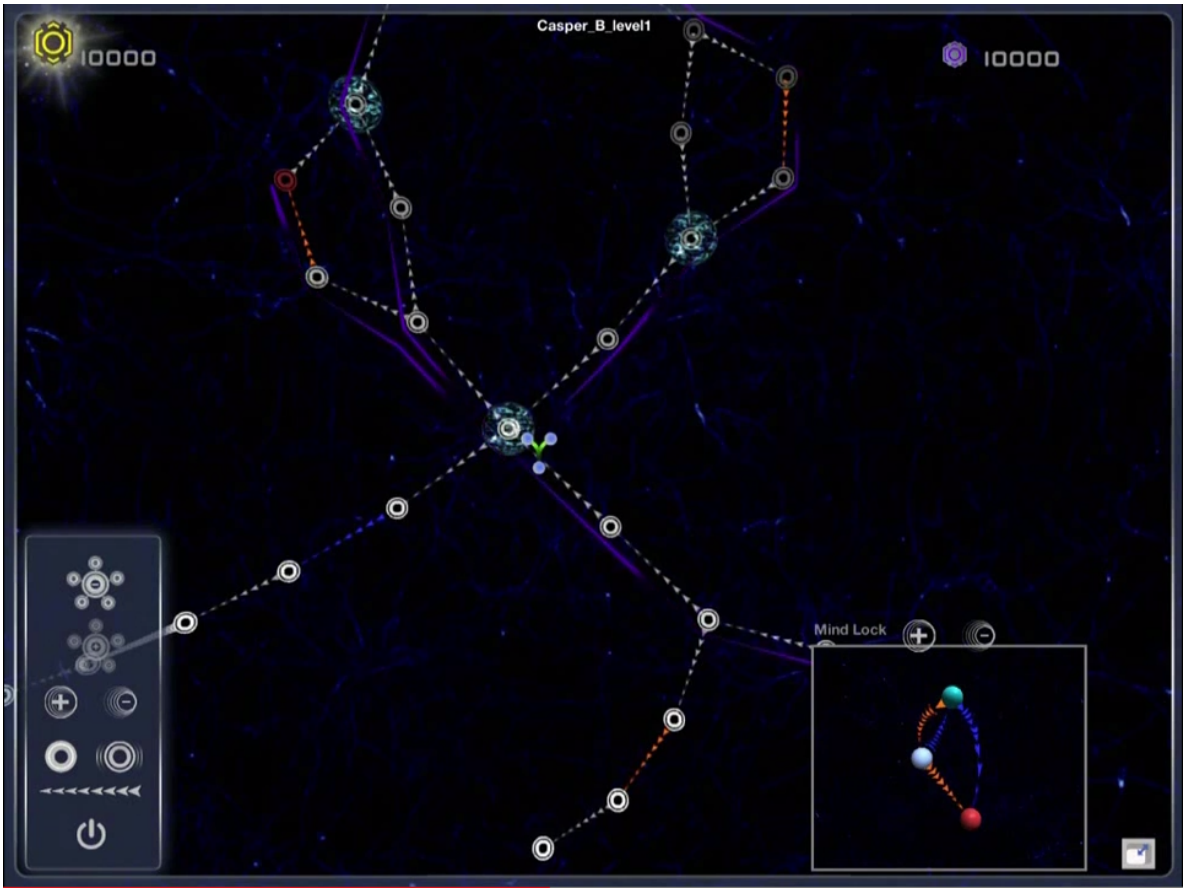


Figure 9: Screenshots of the *Ghost Map* Puzzle Interface.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	4	3	2	3

Game:

Ghost Map is a puzzle game meant to show players how the mind functions by depicting the thought map as a puzzle consisting of links that must be navigated to deactivate a "mind lock."

Analysis:

The Overall User Experience was accented by the futuristic design of the game, but there were several issues where the buttons were unresponsive for several attempts. The art style was consistently done with the exception of several effects that felt out of place and were only there for the purpose of bringing attention to the text, which could have been done in a much more subtle and sleek fashion.

The GUI was well built and delivered the information needed to solve the puzzle in a clean manner. The scroll wheel could have been implemented to allow for zoom and that would have eased navigation through the puzzle. Also, the incoming message prompts could have been placed less centrally so that they did not block parts of the puzzle itself.

The gameplay mechanics were unique and felt like an innovative way of looking at a maze, where finding the best route using specific pathways was the goal. However, there was a gameplay element where pathways could be disconnected for a price, although this seemed random and how it worked was never fully explained during the game playtesting period.

While the game was entertaining, primarily due to its maze-like puzzle structure and art style, the game did little to explain, in the duration the game was played, how these "paths of thought" actually worked in a physical brain. Although we were able to discern that these links function like neurons, the game never explicitly explains that and didn't teach very much about brain pathways.

Immune Attack

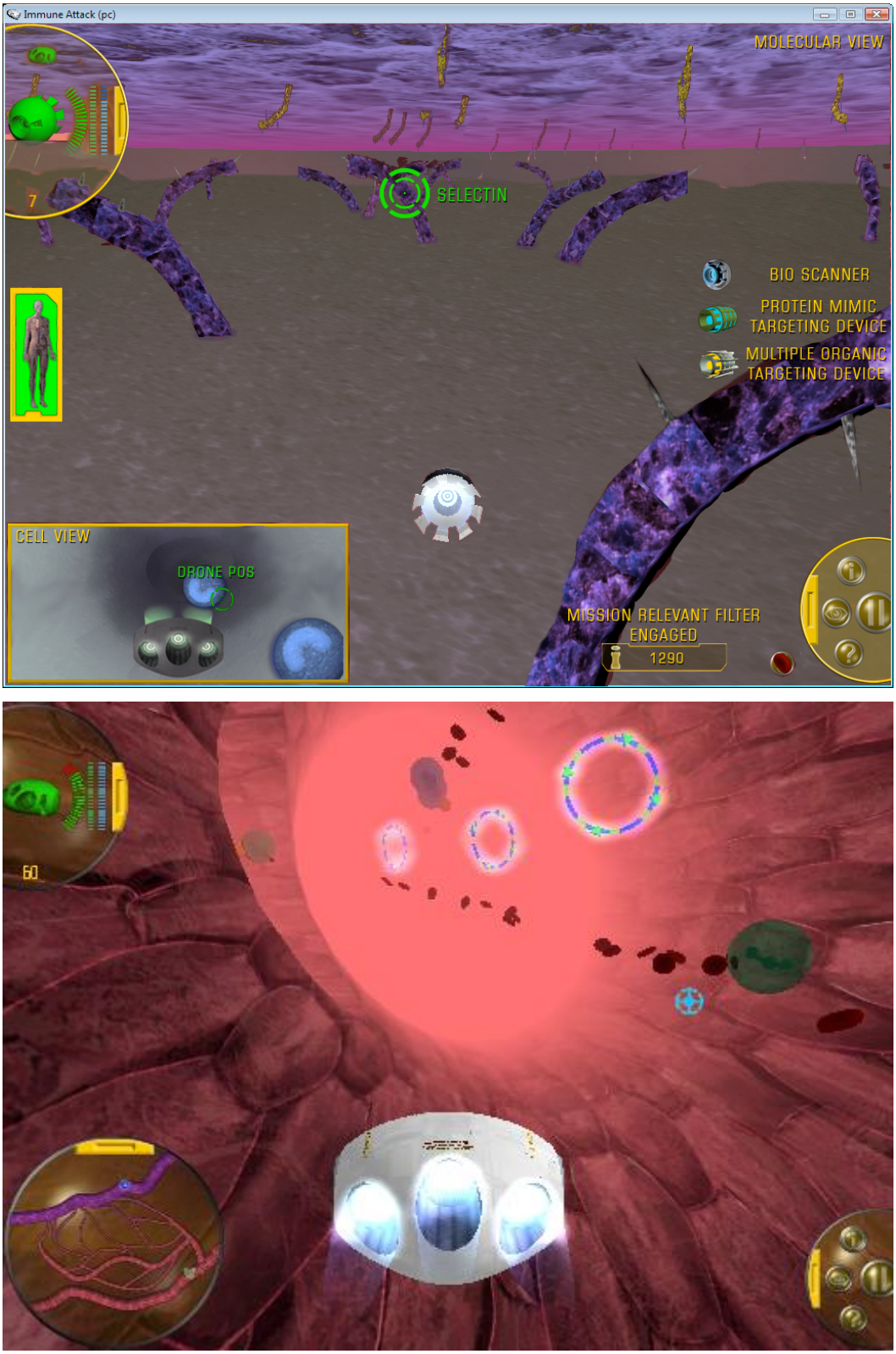


Figure 10: Screenshots of *Immune Attack* in a molecular view and blood vessel environment.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	3	3	5	3

Game:

Immune Attack focuses educating players about the body, cells, tissues, and organs in an interactive game environment. Immune Attack allows the player to navigate through the human body in first person view through a 3 dimensional environment.

Analysis:

Immune Attack tries to merge game mechanics with teachings about the body, but falls short in blending both together seamlessly. The two sections are nearly always distinct and those who care only about the gaming experience may find the educational cut-scenes as skip-able and unentertaining. However, the game does show a depiction of some biological processes and relative microscopic parts that are useful for visualization.

The GUI has relatively simple controls, but gets very unstable when setting speeds too high. A variety of GUI buttons are always available for easy help and menu selection. Overall, the controls require some patience to avoid collisions but does perform as expected. The visuals however, are low by today's standards and may disappoint those used to higher end visual quality, especially on the cells and tissues that they show.

The gameplay is simple overall, mouse controls for direction, adjustable speed, and basic shooting mechanics. As the game progresses, these may become repetitive and simple, but may satisfy a younger audience.

Immune Attack also offers information on nearly everything that is presented in the game that is available on a button click.

Kinetic City

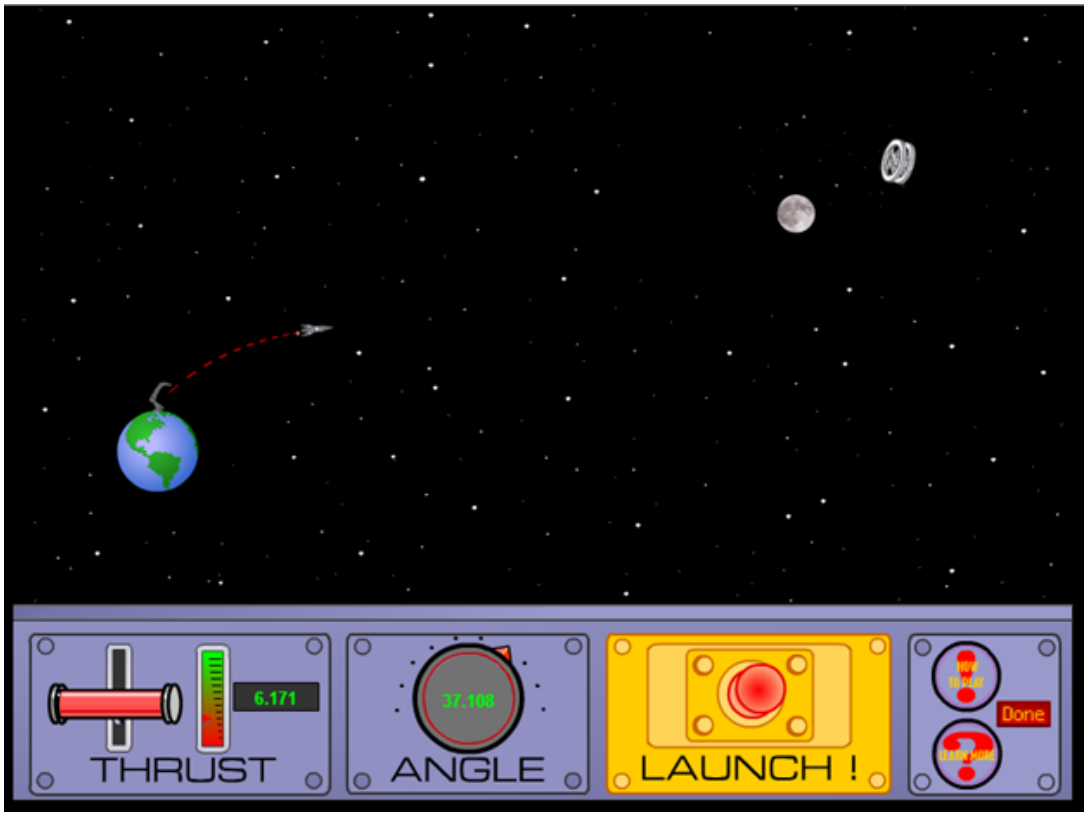


Figure 11: *Kinetic City* Lab Games "Gravity Launch" and "Touch of Class"

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	3	3	5	3

Game:

Kinetic City is a game center aimed at introducing a variety of STEM topics to elementary school students through a variety of mini-games and hands-on labs. The mini-games examined ranged from biological classification to anatomy to the physics of gravity (shown above), and although they covered a broad number of topics, the actual physical number of games was quite minimal.

Analysis:

The Overall User Experience was done well in that it allowed for ease of access between the variety of games and the User Interface was fairly easy to use and responsive. Unlike other games listed here, the browser-based game database didn't adjust to the window, and although the monitor used monitor is fairly large in comparison to what most people have, this wouldn't be an issue if the game screen itself were a bit larger to accommodate the large scaled text in the games. The GUI would also have been better if there were an option to exit out of a game to the main menu at any time as opposed to the end of the game, which currently can only be done with the back button.

The Gameplay mechanics were fairly simple, making use of a whimsical art style to accentuate basic puzzle and matching games. The two games played built around anatomy and biology were both matching games, which, while redundant, did actually explain the different functions of different organs and the classifications of several animals. The only place the gameplay fell short was in the "Gravity Launch" game shown above, because most of the game was testing launching rockets and hoping they went where you hoped they would. The gameplay would have been better done if the game showed the projected path of the rocket prior to launch.

Despite less than original gameplay in most cases, the educational value of Kinetic City was high, as they offered thorough explanations of the subject matter and then used the games as a way to test the player's knowledge. Although, as a result of the gameplay, the entertainment value suffered as the gameplay wasn't as varied as it could have been.

Life Preservers

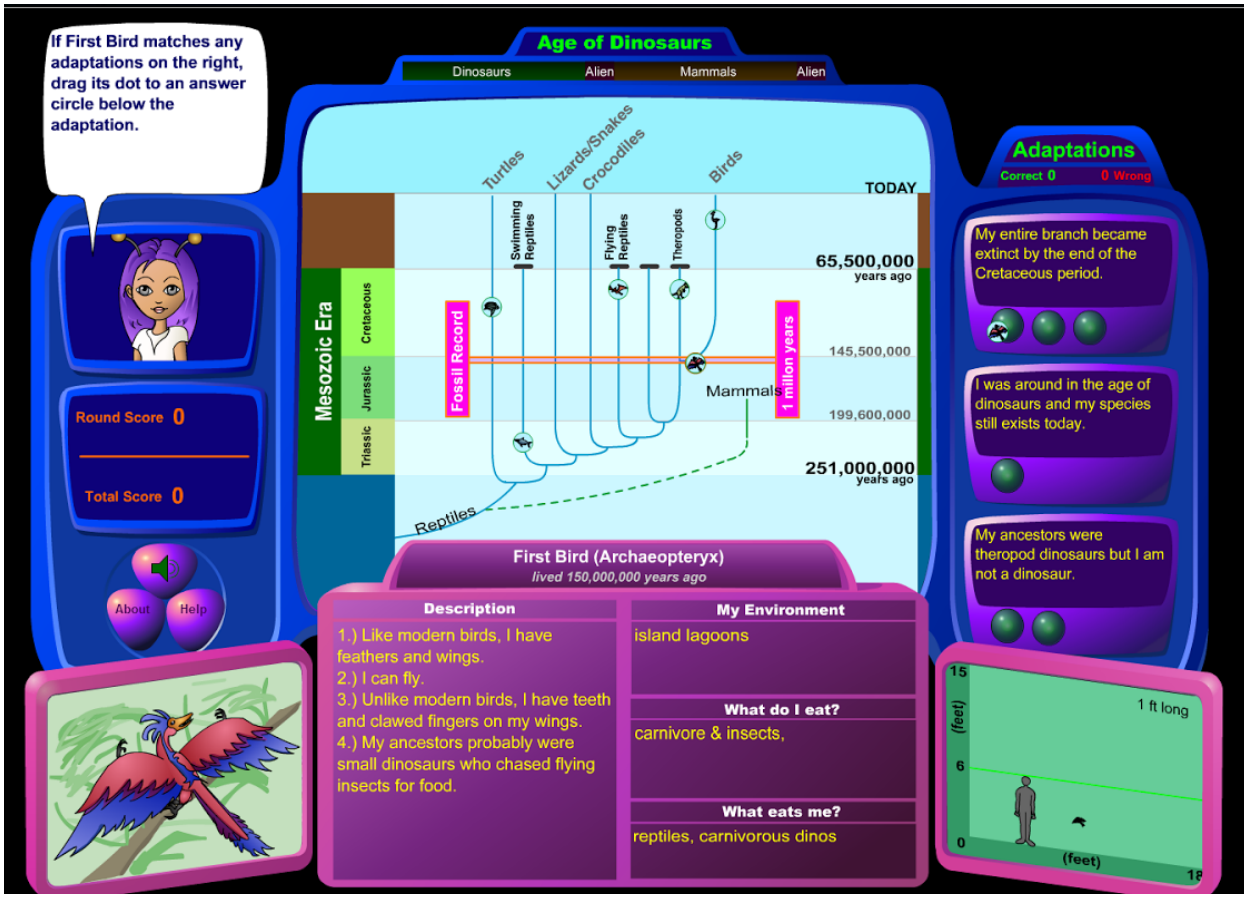


Figure 12: The game interface of *Life Preservers* displaying information about a species.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
2	2	3	5	2

Game:

Life Preservers educates the audience about Earth's history, evolution, as well as the causes and effects of introduced species. The game utilizes a drag-and-drop quiz style interaction. The game provides a single user interface as shown in the figure above, thereby relying on updating the presentation of game content/results on either the left, center, or right columns of the UI, during the course of game play.

Analysis:

Life Preservers provides a lot of information about a few species but does not include as much general, useful knowledge as expected. The game does involve theoretical situations in which the player

must think critically, but only does so twice throughout the entire game. The story line is very general about saving the world, but does not connect or empathize much with the player.

The GUI is somewhat problematic as the small size of the drag-able sprites make it difficult to select and place. The colors and alien character also are not as visually appealing to its audience in the main selection area. However, the other cartoon visuals are nice and appealing to a younger audience.

The gameplay is simple, using information that is present to answer the questions about specific species. However, the game does not encourage learning all the information present, but rather weeding through the given data to answer the question.

Little Alchemy

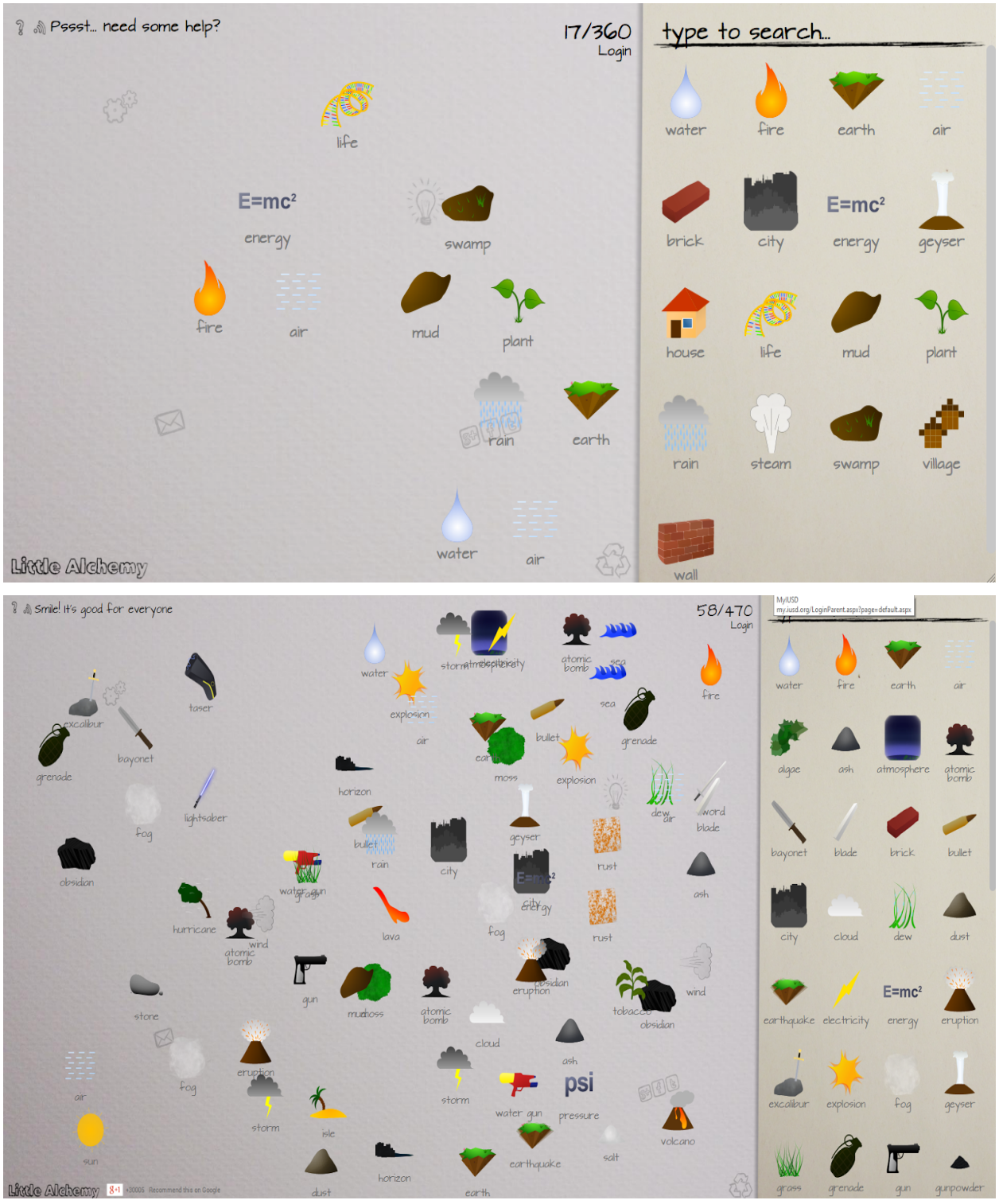


Figure 13: The game interface of *Little Alchemy showing progress through* different play sessions.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	2	4

Game:

Little Alchemy is a game based on entertainment and creative thinking, rather than on science (chemistry). The goal is to collect combine elements to gather as many acceptable combinations as possible of provided starting resources shown on the right side. Players start with four basic elements, earth, wind, water and fire, and then combine them to create other composed elements, and up to 480 distinct compositions are now possible.

Analysis:

Little Alchemy draws curious explorers into seeing what combinations exist and how many they can gather. Though nothing in this game is particularly unique, the simplicity of finding all the secrets appeals to a wide audience, who would play this game leisurely. Towards the end however, players might stop using creative reasoning but rely on brute force testing to find possibilities that they might have missed otherwise. Thus, the enjoyment may decrease for some after a first hundred elements that they find.

The GUI is made well enough to not detract too much from the game. Though some problems exist when too many elements are on the screen and overlap each other, or when combining elements may not register with so many elements on screen.

Though the gameplay and mechanics of dragging elements over another to create new ones is very simple, the fraction of elements found shown on screen allows players to see their progress and approach the completion of the game. As the game goes on, each element gets increasingly more difficult to discover, and the game can easily draw on for hours.

Nanocrafter

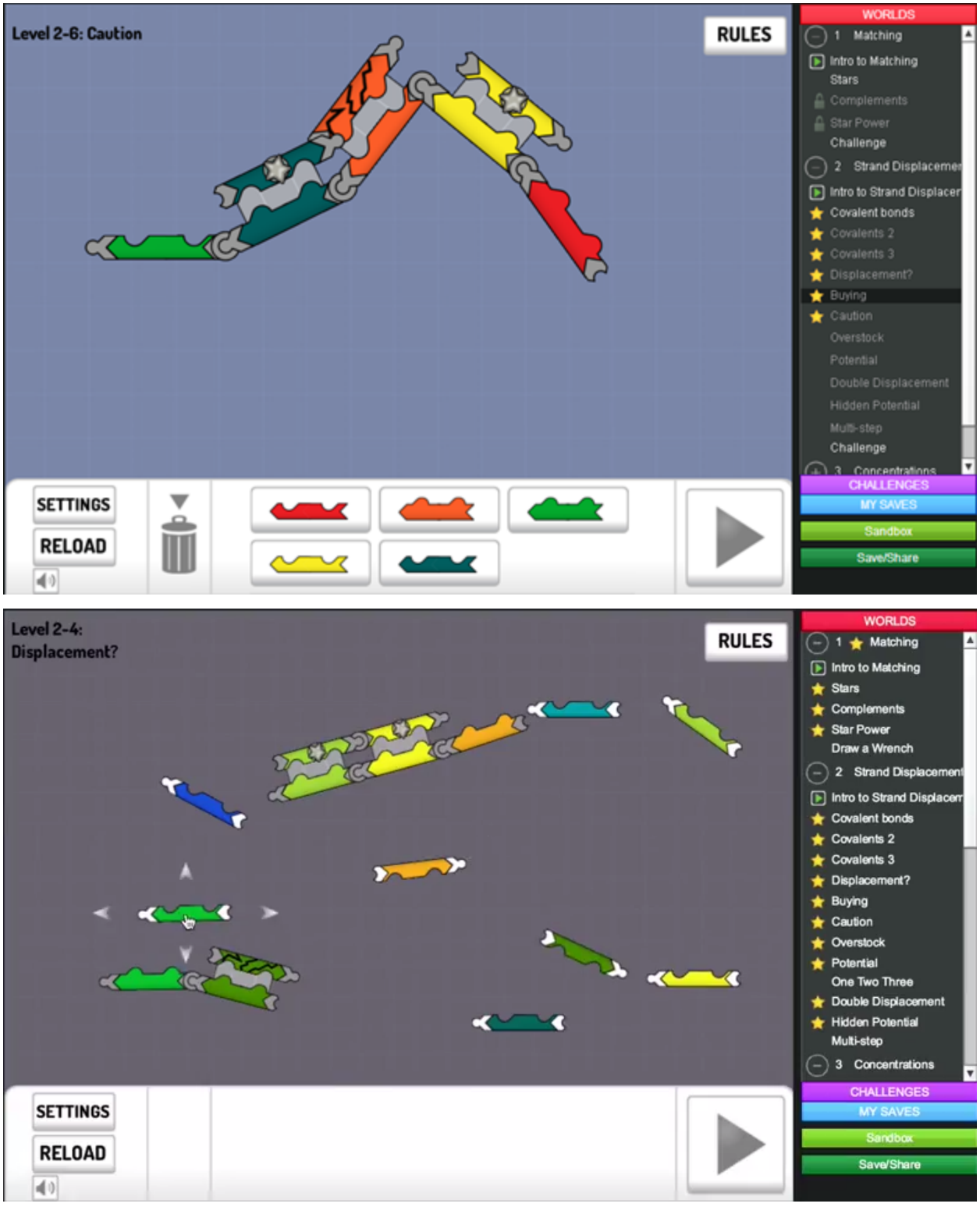


Figure 14: Core Interface of *Nanocrafter.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	3	5	5	4

Game:

Nanocrafter is a puzzle game built around teaching the structure of DNA through the reconnection of various types of bonds (hydrogen and covalent). The game is built around separating certain marked DNA strands from the puzzle and keeping certain strands connected in order to complete the level.

Analysis:

The User Experience was well done, but there was nothing out of the ordinary which would have given it a higher score. The highlighting on some of the levels was off, as seen above, and if the text stood out more, it would have been clearer as to what level was active. Outside of the text shading, the GUI functioned well. The menu on the bottom for picking out strands of DNA was small so that meant a lot of scrolling to find which specific piece you needed, and would have been easier if the menu was larger or if there was a smaller selection of pieces to choose from, a system that was probably incorporated for the more complex puzzles.

The gameplay was very well done, and outside of the regular replacement mechanisms, the developers created special instances where combination replacements could be made, which made for an interesting mechanic. The one that stood out most was the one that allowed you to replace the DNA strands by linking the replacement to another DNA strand that would fit into the open piece next to the strand that was meant to be replaced. This allowed for the automatic replacement of both strands at once.

The educational value of the game is very high because not only did the game explain the different types of DNA bonds and connections, but it also used those bonds in the gameplay, which solidifies the topic which the player had learned. The entertainment value is also high because the puzzles themselves were quite entertaining to do and the combination reconnections mentioned earlier provide a sense of accomplishment after completing some of the more complex ones.

Phylo

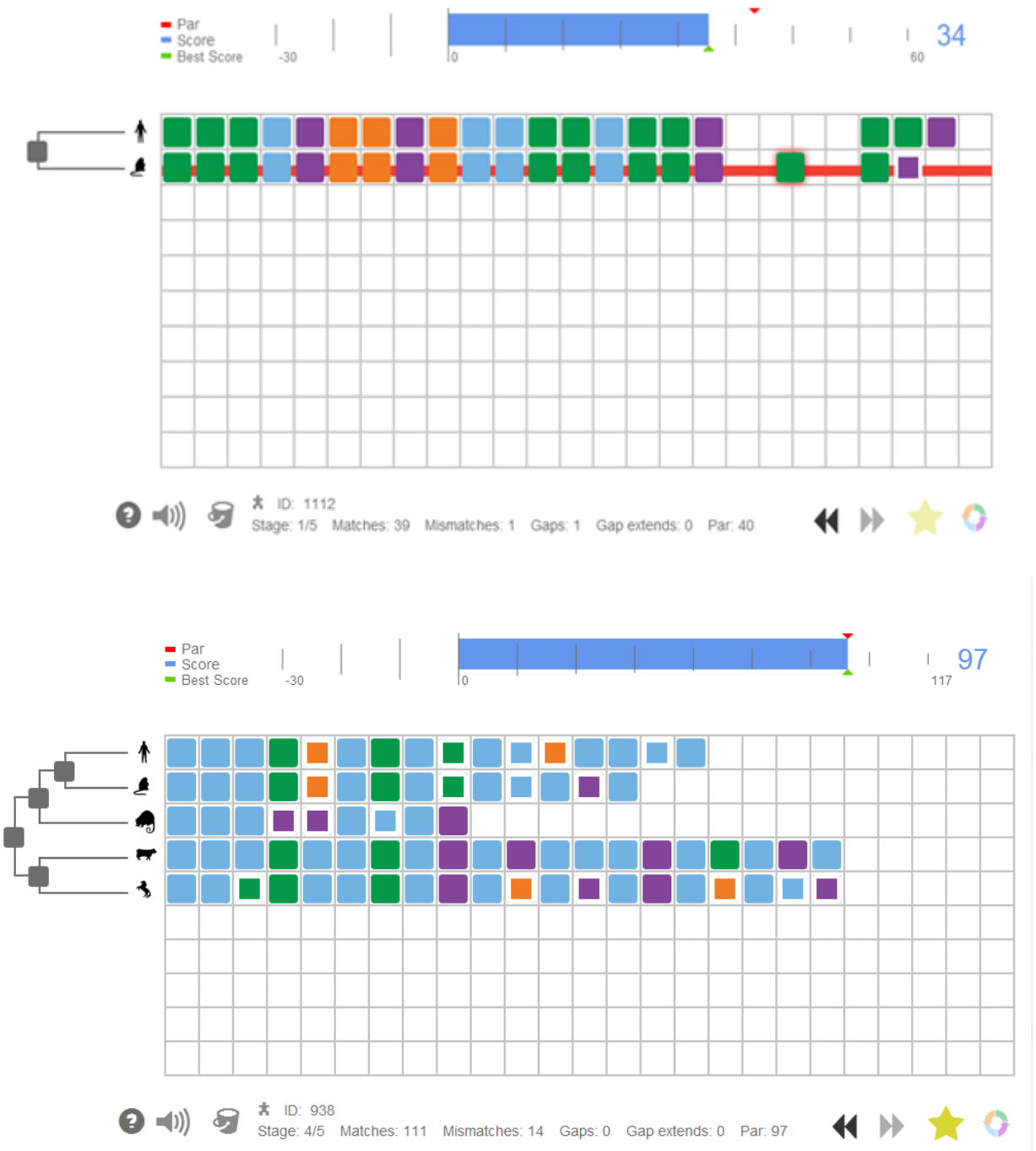


Figure 15: Core Interface of *Phylo.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	2	3

Game:

Phylo is a puzzle game about optimizing the sequence alignment of various DNA structures. Like in flow jam, discrepancies in the puzzle (such as gaps or mismatches) are inevitable, and the goal of the player is to find the most optimal sequence of colored blocks.

Analysis:

The Overall User Experience is well done. The game makes use of intuitive block dragging, so that if a dragged block comes in contact with other blocks while being moved, they begin to move as a group. There were no bugs apparent during the playtesting experience. The only reason points have been marked down is because at first it seems the game is about to place you into gameplay without the explanation of a tutorial. However, when you launch your first level, a tutorial prompt automatically appears, quite unexpectedly. Also, a player may visit the tutorial button on the top at any given time.

The GUI was handled very well. The dragging, as noted above, was very intuitive, and the red lines serve as an indicator of where the block can possibly be dragged. All the information needed for the player is given on the top of the screen and changes in real-time and the undo and redo buttons have the ability to take you as far back as the beginning of the puzzle even after dozens of moves. The only shortcoming is that the tutorial explains that some genes have more priority, but fails to explain the point significance of these and also misleads the player as the tutorial shows them in different colors as opposed to the all-gray interface of the genes in the actual game on the left.

The game mechanics were quite simple and well done, as noted above, but were reminiscent of other games such as the aforementioned Flow Jam. The complexity of the puzzles increases as you progress, because further stages in the level use previous stages as parts of their puzzle, so the player must match more and more block sets. The educational value, however, was low, because although the game, like most listed here tests your puzzle solving skills, the game never really explains the significance of the gene optimization from an education perspective in the actual gameplay and actually learning the material requires a student/teacher login – outside of the game itself.

The entertainment value is high because not only due to the increasing complexity, but also because of the minimalist GUI and the replay value. There are thousands of random levels related to specific diseases – all of which are structured differently and with various levels of difficulty. Players can choose from random levels or choose levels related to specific diseases. This allows for endless options for playable levels.

Play to Cure: Genes in Space

Figure 16: Screenshots of the game interface of *Play to Cure: Genes in Space.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	5	3	1	3

Game:

Play to Cure is a mobile app game available on Android and iOS that crowd-sources data from player experiences to analyze genetic data.

Analysis:

Play to Cure succeeds in creating a game to help research, but may not be engaging enough to entice users and avoid mindless repetition. uses The repetitive gameplay is backed up by additional features such as leveling up as incentives for continual replay. However, it is not readily obvious how the player game results help genetic research.

The GUI is very intuitive with simple button layouts and smooth controls of the ship navigation and route mapping. The visuals are also well designed to add to space theme of the game. Nothing obstructs the player from its basic gameplay but does not stand out

Players choose their route beforehand to map out dense areas with collectable material that is used for points and upgrading. During their "flight," players also have simple controls that are used to fly through rings that correlate with the predefined route, and a firing mechanic to shoot asteroids. However, the gameplay still is very repetitive and quickly loses its appeal.

Some additional features include a ship upgrade system as well as leveling system for registered users. However, this does not seem to play much role in the actual gameplay and does not give enough motivation to continue.

Race to Mars: On Orbit

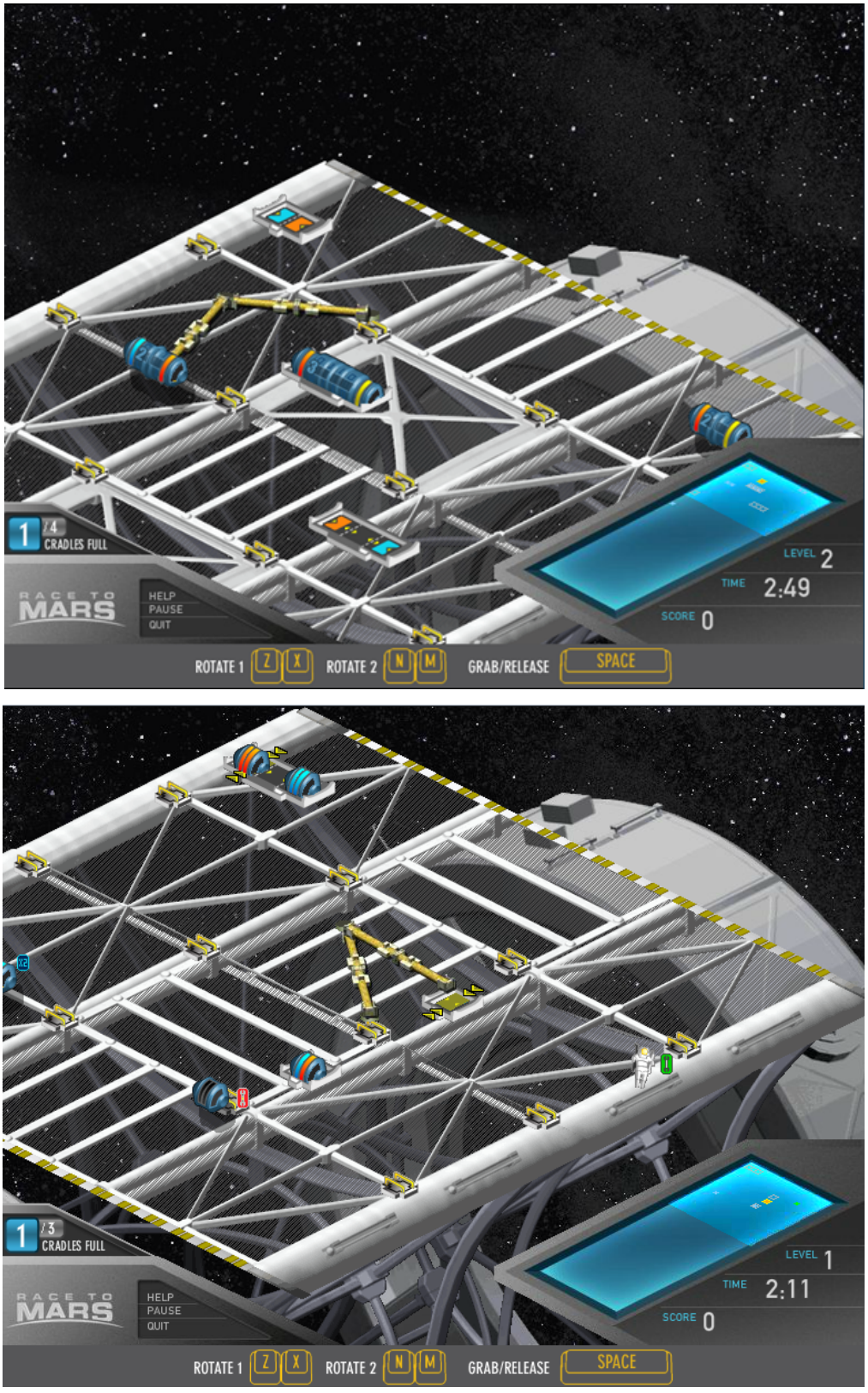


Figure 17: *Race To Mars: On Orbit* Core Game Interface.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	2	3

Game:

RTM: On Orbit is a simulation game where players take the role of a robotic arm that is in the process of building the ship that will take humans to Mars.

Analysis:

The Overall User Experience is well done, and the only area that were odd were the user play controls. The controls, which require moving the two levers on the arm with z/x and n/m take a bit of getting used to. Luckily, the opening levels are really simple and allow the user to be accustomed to the controls. The GUI is well designed and has the usual mini-map and statistics. While not particularly new in terms of information delivery, the GUI's design was a step above what I'd seen in the other games, and fit into the Isometric game style very well.

The gameplay mechanics were done well, using an innovative twist on the matching mechanic. The arm also could move by latching onto certain marked areas on the ship and worked quite a bit like walking on two hands. This movement would be combined with the placement of randomly generated floating canisters which needed to be placed in certain cradles. Another element which stood out was that sometimes the latches would break, and astronauts, which also spawned randomly, would need to be brought in to fix them before the arm could move to them. Through this, the player would either need to find a way to bypass the latch or repair it while balancing the canister placement.

While the gameplay was unique compared to the other puzzle solving games I've played, the educational value was quite low because other the gameplay noted above, there wasn't really any knowledge about Mars or the construction of the spaceship delivered through game play. However, the random generation of the canisters did add a skill factor which raised the entertainment value in the game.

Rover XPL

Figure 18: The game interface of *Rover XPL*.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	3	4	3

Game:

Rover XPL demonstrates the expected landscape of Mars through an interactive game that allows players to maneuver a rover on Mars. The game appears to have been developed using the Unreal game engine. Game play focuses on navigating a rich terrain map of Mars that utilizes a texture map and digital elevation map collected from satellite images/sources of Mars.

Analysis:

Though Rover XPL does have game-like mechanics which include points and an objective to be somewhere, the game mostly serves as a demonstration that features the Mars topography and geographic and climate changes.

The GUI is very intuitive with minimal problems. Visuals were not very high quality as expected from a 7-year-old game, but still accurate in showing the intended features.
The gameplay were generally very simple, with the only basic mechanic being the controls of the rover. A slight annoyance was the inability to climb even gradual slopes, but that may be used to demonstrate the capabilities and limitations of the actual intended rover. In addition, the gameplay soon became repetitive after a couple missions, which all include driving to a given destination. These really do not pose much of a challenge, but serve instead as a demonstration for the experience of the Mars landscape as predicted.

Extra:

The rover game intends to simulate the prototype rover missions set in the mid 2020s and the missions that they present are only some of the capabilities of what the rover can do and detect.

Radix Endeavour

Figure 19: Screenshot of *Radix Endeavour*.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
2	3	4	4	3

Game:

The Radix Endeavour is a MMOG game based around teaching STEM (Science, Technology, Engineering, Math) topics to players. It takes the form of an Isometric open-world multiplayer RPG.

Analysis:

The Overall User Experience could have been better, but that was partially attributed to the fact that the game was tested in Mid-July and there were no players in the game, which felt strange for an MMOG. The GUI could have also been better, but even in many non-educational games, RPG GUIs far too cluttered as they need to document multiple sets of menus such as Inventory and Quests.

The gameplay mechanics are reminiscent of other Isometric RPGs where NPCs give the players quests that must be completed for a reward or experience. The quests have a large amount of variety from fence building to collecting plants. In the process, the NPCs explain to players scientific and mathematical concepts. For instance, in the quest we demoed, the NPC explained the basics of genetics and chromosomes. The NPCs explain the concept very well and it ties into the gameplay because the knowledge is necessary to complete the quests.

The entertainment value could have been higher as well, once again attributed to the lack of players over the summer, which in itself places in question the entertainment value of the game. Although, during the school year, the game probably has a high replay value since there are a variety of quests and the human interaction between players no doubt creates unique experiences that don't come in single-player, linear games.

Refraction

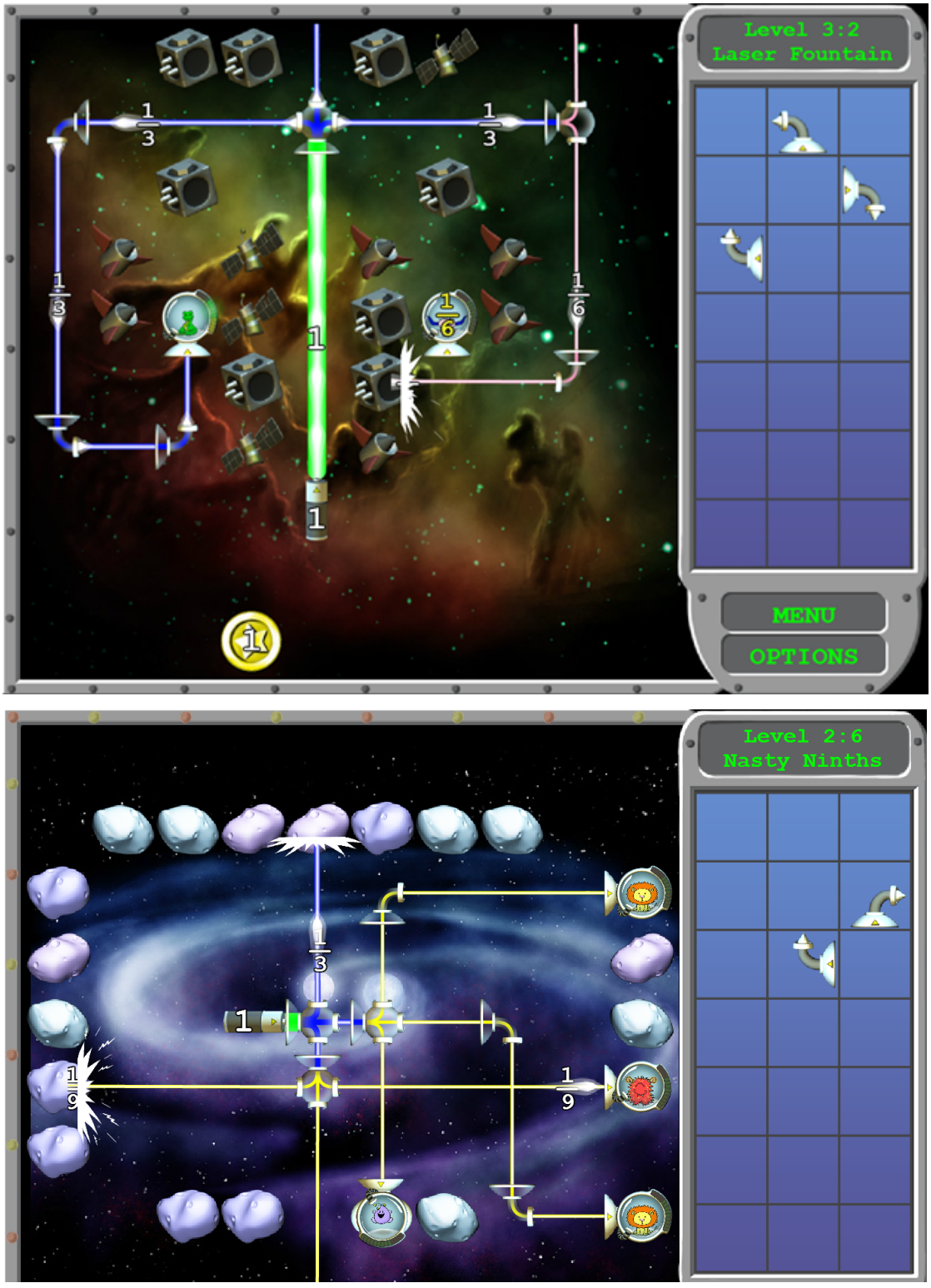


Figure 20: Screenshot of *Refraction.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	3	3

Game:

Refraction is a puzzle game where players are supposed to use special "laser benders" to bend lasers so that they power spaceships and can save the animals within them.

Analysis:

The Overall User Experience, like most others, was well done. No bugs were encountered during limited play, and there were no glaring errors in the game. Although, it is worth pointing out, and this is a trend in many of the games listed here, but the developers seem to be a bit overzealous when it comes to the victory animation. Once the player completes a level, confetti and fireworks come out of every corner of the screen, and in some instances, on a powerful computer with several Chrome tabs open as well as Microsoft Word and Steam, this browser-based game would stutter just a little bit on this animation.

The GUI was well done, but nothing extraordinary. The one complaint is that it takes more clicks than optimal to get to the reset button, which, while in the menu tab, should be on the core GUI. Otherwise, the game does a good job at delivering information by showing the strength of the lasers in real-time.

The gameplay consisted of using "laser benders" to reroute the lasers into the funnels of the broken down spaceships. Funnels can only take a certain amount of energy, so sometimes, the player must use special funnels to split up the laser into multiple parts. This creates situations where the player must use combinations of these laser-splitting funnels in order to achieve smaller values of power. Additionally, the number of benders you can sue are limited.

Despite being a good puzzle game, the educational value isn't very high because while the game has to do with lasers, it never explains concepts such as refraction (even though it is in the title), and while it seems to concentrate on educating the user on fractions instead, it never emphasizes this. The game is entertaining though, primarily because of the challenge of collecting tokens which make use of a trophy system within the game. These add to the replay value, as collecting coins with lasers can be challenging in some cases, and warrants going back to previous levels to get a "100% Completion," per say.

Storm Bound

Figure 21: The game interface of *Storm Bound.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
3	5	4	2	3

Game:

Storm Bound is a game that aims to utilize crowd-sourcing for formal verification of software. The game adds a story and visuals to entice users to help indirectly analyze software for flaws. The main play space is the central large rectangle where different visual patterns are presented to player to analyze and decode.

Analysis:

Overall, Storm Bound is a very complex game that may be successful if it retains users after its tutorial process. However, the game itself gives little indication of a correct or completed task, players can become confused and lack motivation.

The GUI is intuitive and easy to use, but may be confusing as objects move around in the game without a clear justification. The visuals are impressive, and focuses on making the setting look futuristic and technologically advanced.

The gameplay is somewhat confusing and too complicated to describe concisely. Despite the long tutorial that is given, when the player is on his or her own, it is still not exactly intuitive what must be done.

The game features many additional features as well that help give the player more incentive. These include levels and experience points, achievements, and a storyline. The storyline utilizes an enemy threat as its main objective and purpose, but is also endless to ensure a ceaseless gameplay.

Vampire Vision

Figure 22: The game interface of *Vampire Vision* after different periods of play tasks.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	5	2	5

Game:

Vampire Vision intends to improve player's visual perception in an entertaining mini-game-type game. The goal is to train players to observe key details or anomalies in a large area.

Analysis:

Vampire Vision is very entertaining, but it is hard to see how beneficial this game would be for visual perception. Many games feature the same mechanic of training the player to notice a certain key feature, but their main intent is for entertainment. This game feels very similar in that it is engaging and could target a wide audience, but may not provide anything very meaningful to them. Even so, the main gameplay and additional features this game provides makes it among the most entertaining.

The GUI is very intuitive and unobstructive, with accurate selection despite how often the characters obstruct each other. Visuals included cartoon and silly characters that give the game a more playful and engaging feel. Because the game has a heavy emphasis on details and visual cues, the visuals are important for variation and subtle changes.

The gameplay is relatively simple, finding all the characters that do not match a certain criteria as fast and accurately as possible. However, because the criteria are always different, and not limited to static hints, but include variations in behavior as well, the game is very engaging and has a high replay value. The increase in difficult also trains the player to get increasingly better and constantly encourages a challenge.

Wolfquest

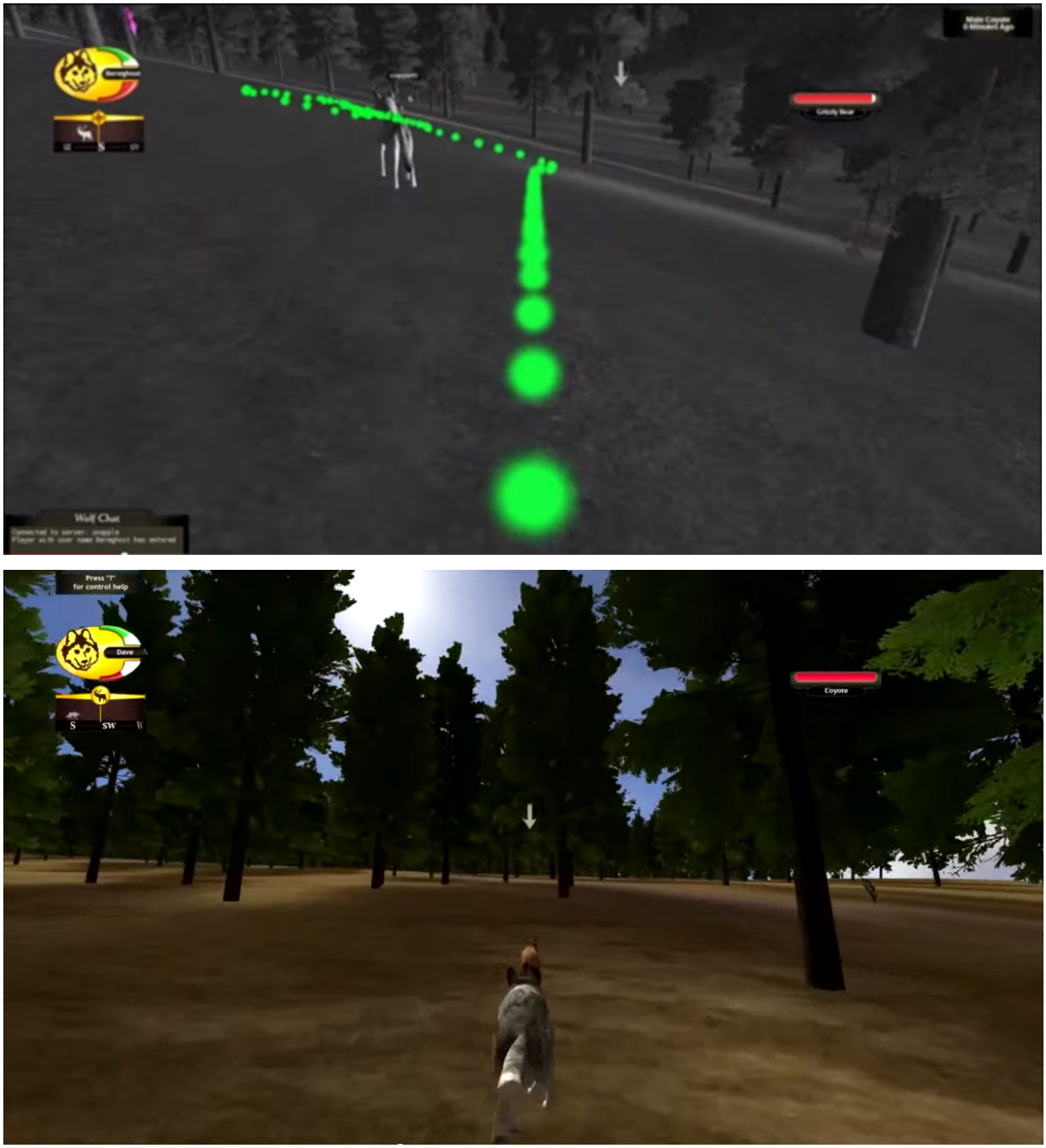


Figure 23: Screenshot of *Wolfquest.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	4	4	4

Game:

Wolfquest is an open-world 3D multi/single player game where players take the role of wolves in Yellowstone National Park with the goal of surviving and raising a litter of young wolves.

Analysis:

The Overall User Experience is well done. There weren't any bugs encountered in the play period. However, one unique aspect of Wolfquest compared to the other games on this list (outside of *Radix*) was the user's ability to customize their in-game character. The controls were well thought out, but the animation of the wolves could have been smoother. They seemed to walk awkwardly when making tight turns. The GUI was well done and kept minimal in terms of elements. The game makes use of spatial UI elements when bears chase the wolves through the use of green dots to track the wolves (as seen above).

Gameplay mechanics were similar to that of a regular survival game, where the player must balance the stats of their character while hunting food and avoiding predators. On top of the core survival mechanics, the player is also tasked with not only keeping their litter alive, but also pursuing quests related to their litter, such as finding a mate.

The educational value of the game is moderately high, because while the game doesn't teach the player about the behaviors of wolves so that the player can abide by them, the game does show the player the ecology of Yellowstone and the challenges the wildlife in the park faces to survive. The entertainment value is high as well because the game poses a variety of challenges and the free-roam design of the game makes it entertaining to explore, while not necessarily graphically impressive.

The game has a high replay value not only because of its free-roam design, but also because of its open-ended survival systems. The player is allowed to approach the tasks in any way they like so it makes sense to replay missions in more interesting ways. Also, the player is tasked with the goal of surviving, which in itself will warrant multiple tries. Additionally, the game comes with multiplayer functionality.

Xylem

Figure 24: Basic Game Interface for *Xylem.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
4	4	3	4	3

Game:

Xylem is an iPad-exclusive game made to help players identify possible math equations through the concept of plant structure. They are given all of the possible math functions (+,-,etc.) and a series of variables which they can use in order to find an equation which satisfies all of the circumstances, given as Growth Phases.

Analysis:

The Overall User Experience was well done. A mixture of folklore about the island the game takes place on, as well as an innovative take on math equations allows for the player to have an entertaining experience and also gain some knowledge on plants, although the core focus of the game is mathematics.

The GUI is well done for the most part, and the game explains what every symbols stands for (for example, the # in a circle shown in the picture above is the number of growth phase, and operates much like a sequential equation). The only issue with the GUI is that when switching between menus, the leafs which stood in for arrow keys were a bit difficult to see and led us to believe that we had fully finished the tutorial.

The mechanics of the game were based on actual math equations, so there isn't much creative freedom there, although the concept through which the equations are expressed was new and allowed the developers to place a scientific aspect to what would have been otherwise an entirely mathematics based game. The tutorial was quite lengthy and spent many levels introducing and strengthening core concepts, which could have easily been done in the actual levels themselves.

The game has plenty of educational value in terms of mathematics and equation structure, but the reason the score for that section isn't higher is because although the concept of using plants as a delivery mechanism for the mathematics portion of the game, the game does little to actually teach about plant life and focuses more on equations rather than biology. In terms of entertainment value, the story and setting add an atmosphere to the game which leads to an experience that isn't solely equation-based, although the narrative isn't particularly imaginative.

Circuits

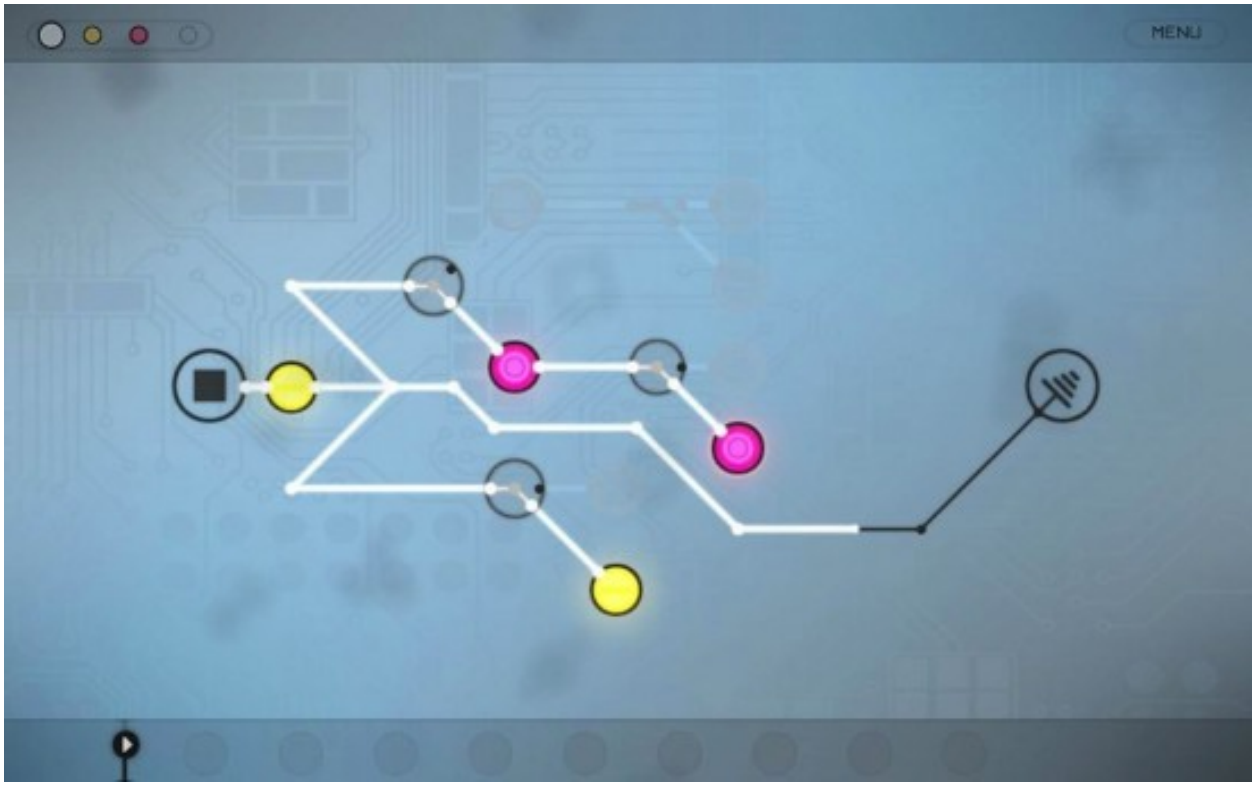


Figure 25: The game interface of *Circuits*.

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	4	1	5

Game:

In Circuits, each level presents a puzzle that aims to reconstruct a given song using small segments of the song.

Analysis:

Overall, circuits is a very appealing game in its visuals, soundtrack, and simple yet challenging puzzle design. The earlier levels are designed to introduce certain concepts that are used more prevalently in later levels.

The GUI is very simple to use, with large enough selectable areas that do not present any troubles. Though it uses a drag-and-drop design, the buttons are easily arranged and The visuals are very minimalist, except the background, which enhances the relaxing nature of this game as well as add to the *techno* theme of this game.

The game mechanics are very simple, dragging music-circles from a toolbar to indicated circles on screen, but the increasing challenge of the game as levels become more complex makes this game very engaging and fun to play. As multiple branches and simultaneous parts come into play, players must depend a lot more on what they can hear to replicate the music.

This game also has other unique features that make it enjoyable and gives it replay value. Because this game is available on Steam, the achievements that one acquires is visible on a shared profile along with many other games. The achievements also do not include anything repetitive, but offer more challenges to complete. The music is also extremely pleasant to listen to and include a mixture of electronic ambient, dubstep, and epic orchestra.

Strata

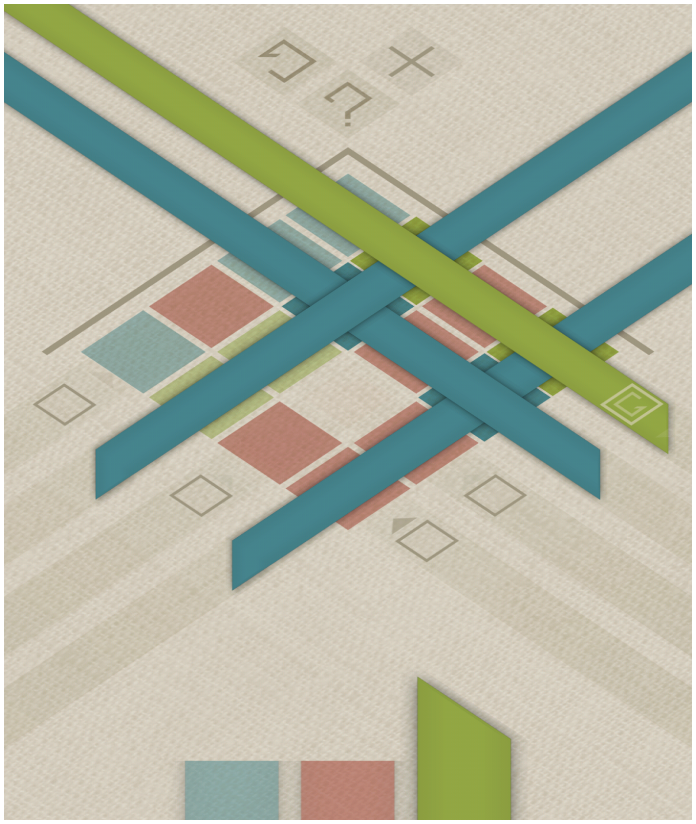


Figure 26: The game interface of *Strata.*

UX:	GUI:	Gameplay Mechanics:	Educational Value:	Entertainment Value (Fun):
5	5	5	1	4

Game:

Strata is a puzzle game that offers levels that players complete by matching the pattern underneath.

Analysis:

Strata presents very simple but challenging (at first) puzzles that constantly challenge the player. Its unique puzzle concept is incredibly refreshing, and the complexity of the puzzles are hidden wihtin its simple gameplay.

The GUI is very nice, with smooth transitions and animations that respond to user input. The visuals also play a big role in the ambience of the game and its simple and elegant design makes this game visually appealing.

The game mechanics include selecting all rows and columns in a specific order. Each selection will place a ribbon over the row or column, and because each tile will have 2 ribbons (row & column), the top ribbon must match the cell underneath. Thus, players must find a strategy or pattern in order to solve these puzzles. An undo button is present, but an additional "Perfect" level is shown if a level is completed without it.

This level feature along with achievements give a completionist incentive to beat all levels without the use of the undo. The achievements are also synced with Google Play that is visible to everyone on the player's profile. The game also has relaxing ambient music that add to the overall feel of the game. In addition, although there are in-app purchases to unlock more levels, the game already gives hundreds of free levels to complete before running out of content.

Comparison #1: *Cell Craft* & *Starcraft*

Figure 27: Screenshot of *StarCraft* by Blizzard Entertainment

While the names of the two games match in terms of number of syllables, vowels, and consonants, the similarities between the two continue even further. As mentioned in the analysis of Cell Craft, the game embodies the core mechanics of a RTS game, or "real-time strategy." Much like in Blizzard Entertainment's classic game, *Starcraft*, Cell Craft is built around the careful balance of expansion and resources as the player builds specialized buildings which serve the purpose of deploying AI characters to defend the base against increasingly hostile waves of invaders. Perhaps the most noticeable difference between the two, outside of Cell Craft's lack of an isometric 3D art style and alien-saturated plot, is that in Cell Craft, the players "base of operations" is remarkably flexible - capable of moving around the game map with relative ease - whereas in Starcraft, the base is stationary. However, this difference comes with tradeoffs. In Cell Craft, the mobility of the base means all of the structures within are self-contained and unable to leave the cell, and therefore it is the job of the moving megastructure to move itself to collect the appropriate resources, sometimes taking it's entire setup, nucleus included, even deeper into virus-infected territory. In Starcraft, while the base maybe stationary, core structures inside face less of a risk, as the AI characters that perform combat, if properly maneuvered, keep enemies from approaching the precious recourse generators within the base.

One point of weakness within Cell Craft was it's replay value, which fell short due to the repetitiveness of it's gameplay when it came to collecting resources. The reason for this may be that the map the cell called home was featureless, a problem that does not exist in the universe of Starcraft. In starcraft, the map plays a concrete role in the manipulation of combat units as well as the distribution of enemies. Multiple pathways of attack and obstacles make the enemies and combat units behave as if they were fighting a war, utilizing choke points and flanking to attack or defend the players base, whereas in Cell Craft, viruses swarm the cell from all sides and the player must rely on the fortitude of his/her structures to survive rather than tactical gameplay.

Comparison #2: *WolfQuest* & *DayZ*

Figure 28: Screenshot of *DayZ* by Bohemia Interactive

Both WolfQuest and DayZ are open-world titles built around exploration and survival. Taking common game mechanics from the survival genre,the two games task the player with the goal of surviving and thriving through the collection of resources and evasion of ruthless enemies. In Wolfquest, the player takes control of a wolf in Yellowstone, while in DayZ, the player takes the role of a surviving human in the midst of a zombie apocalypse. Being an educational game, Wolfquest doesn't necessarily have combat mechanics, or at least those as expansive as the ones in DayZ. Whereas the wolves in Wolfquest can only pounce and bite their prey, normally making running the best option for players, especially when faced with a tough opponent such as a bear, DayZ gives players access to a bevy of tools for their rampage against the *28 Days Later*-esque undead. But what Wolfquest lacks in combat, it makes up for in an advanced tracking system. As mentioned in the individual descriptions of the educational games above, WolfQuest uses simulated scent tracking when evading bears, which makes it harder for the player to effectively escape one upon encounter. DayZ has a tracking system based on sight, which may seem primitive, but given that the zombies can easily outrun the player, a complex tracking system isn't necessary when a charging enemy leaves counterattack as the only option.

DayZ and WolfQuest both excel in their multiplayer, and both use a similar game mechanic. Through utilizing teamwork and pack behavior, both DayZ and WolfQuest allow for "clans" or "packs" to go on quests that necessitate teamwork. While the raiding of other players clans may not exist in WolfQuest, hunting down a herd of bull elk on Amethyst Mountain takes just as much effort and

coordination, given that the combat required isn't as varied as it is in DayZ. In the end, both games offer a massive world for players to explore and familiarize themselves with, all while creating a tense atmosphere of survival made even more difficult through the introduction of NPC enemies.

Comparison #3: Radix Endeavour & Runescape

Figure 29: Screenshot of *Runescape* by Jagex via Stackexchange.com

Runescape in an isometric 3D MMORPG built around the fantasy world of "Gielinor," where players are tasked with increasing their skill set while completing quests. Here, we consider the version known as Runescape 2, which existed in the mid 2000s.

Much like Runescape, the Radix Endeavour is built around the same core mechanics of quests and skills in an effort to create replay value through the incentive of levelling up the player's character, which both games allow the player to customize. Similarly, both world are populated not only by players, but also by NPCs, which serve to hand out quests, facilitate trade, or in the case of Runescape - serve as a combat training mechanism.

The key difference between the two games is that the Radix Endeavour, aimed at educating the player, like WolfQuest, lacks a sufficient combat system. This makes sense in the universe of the Radix Endeavour as the populace is entirely non-violent and only asks for favors that require puzzle-solving skills or knowledge. On the other hand, Runescape can at times be heavily combat based, asking the player to tackle hordes of enemies to obtain an item. This is another area where mission structure varies. In the Radix Endeavour, the quests have greater variation in that they range from simple item retrieval, which is the primary quest-type in Runescape, to more complex tasks, such as identifying plants within

the world, for example. In Runescape, the item-retrieval quests, which make up most of the repertoire in the game, vary only in difficulty, whereas the core mission structure stays the same.

From Playtesting to Design of a new Science Learning Game: *Beam*

As part of this research, we sought to implement our findings in our own educational game. The topic we chose to focus on was optics, at a beginners level, as might be appropriate for a high school or new undergraduate student studying introductory physics or photonics. Through this, we aimed to teach the player about basic concepts such as the angles of incidence/reflection as well as the concept of refraction. Currently the game system is in a working status with three levels of varying difficulties introducing some basic gameplay mechanics we found effective in our research.

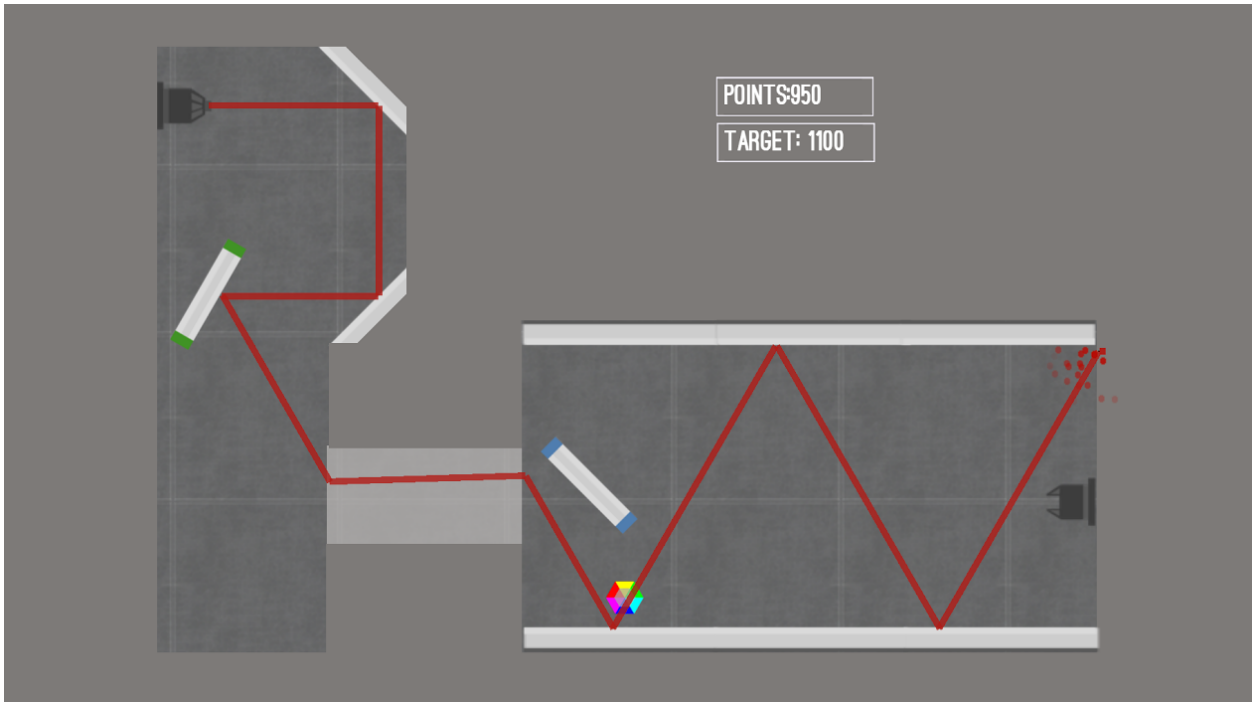


Figure 30. A screenshot of *Beam* game play, showing a photon beam source (upper left) directed through a series of mirrors (narrow white bars) and a refracting lens (light grey rectangle) towards the target (lower right), which in this example results in a near target miss.

Keep in mind that what we're showcasing is in no way a finished product and currently is not in the state where it effectively delivers knowledge to the player, in part because of the current lack of an explanatory factor. We hope to expand this in the future and introduce even more mechanics to vary the gameplay as well as work on building more levels and introduce an explanatory aspect to the game. In addition to this we aim to refine the mechanics so that the player explores the concept through experimentation rather than just "regurgitating information," as many of our teachers call it. We took an example from *Refraction* in terms of core gameplay, where the task of the player is to reroute lasers into a receiver. Expanding on this concept, and concentrating on optics rather than math, we introduced a larger variety of angles, these being the 0, 30, 45, 60, 90 intervals of a 360 degree circle. This was done in order to allow the player to potentially plot out the path of the laser before actually attempting

their configuration through mathematics, provided they understood the concept of reflection. This became important when we penalized the player for starting the laser into the layout.

The goal of game play in Beam is to reach the end of the level with a certain amount of points, and points were subtracted every time the laser was fired in order to penalize the player for trying to guess the layouts but not harshly enough to have them fail the level. This was also utilized in the later levels to increase the difficulty of the level by limiting the amount of retries the player had. We kept the limited number of mirrors given to the player, forcing them to find the best solution with the given materials. We restricted the plane mirrors to three types, ones that could move, ones that could rotate, and ones that could do both. In addition to this, we introduced "gems", which serve the same purpose as achievements, where finding a path for the laser to reach the gem requires the user to experiment with comparably difficult concepts and strange angles.

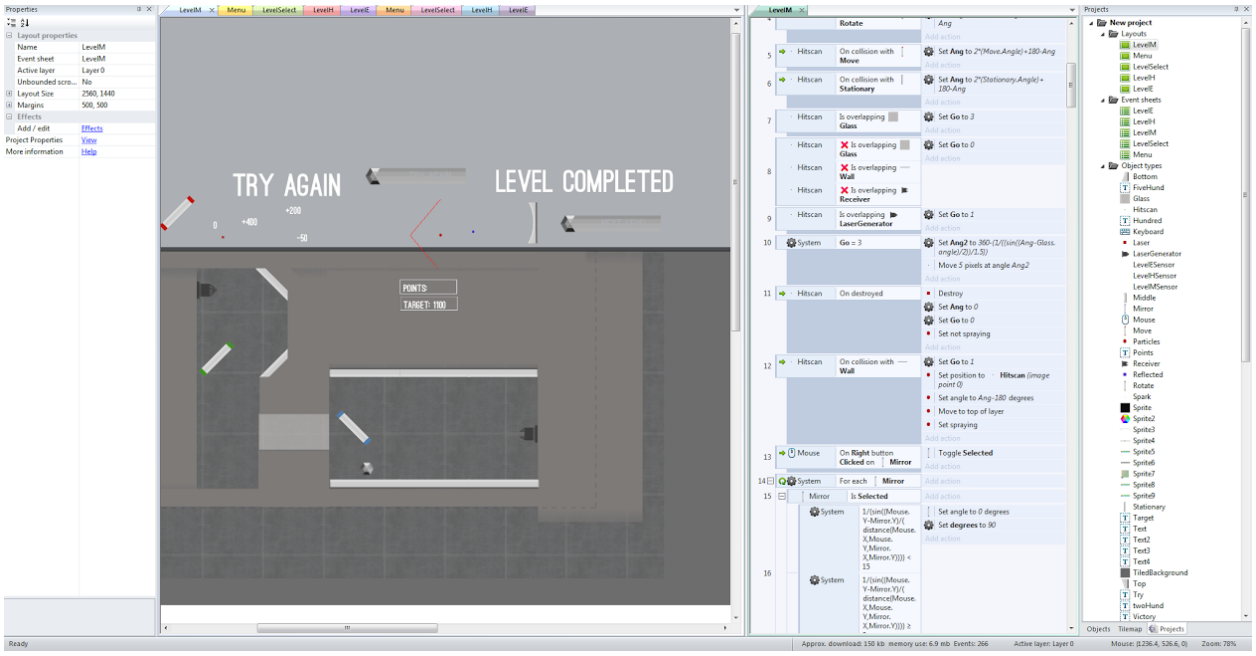


Figure 31. Screenshot of *Beam* running within the Construct 2 game software development environment

The laser in the game was built so that it could be reflected an infinite number of times if the mirrors were provided, and that the player could see the laser travel in real time. Unfortunately, this system came at the cost of altering the lasers paths in real-time, forcing the player to reset the laser at each rerouting. This occurred because the laser determined its pathway by following a miniscule "hitscan" object which tracked the reflection of the lasers and stretched instances of lasers upon collision. This was done to allow for the infinite reflection of the laser without having to deal with the potentially limiting nature of tracking instances.One of our other core focuses was UI. Visually, if the game is as appealing as it is entertaining, this combination retains the users attention longer. We took cues from games such as Strata, Ghost Map, and Circuits and focused on creating a visually appealing and intuitive art style that was relatively uncluttered and provided feedback. This was accomplished by not only color coding the different types of mirrors, but also through the implementation of vanishing UI

elements that appeared only when the user needed them to, for instance when the user rotated the mirrors or activated a laser, altering their values or point balance. One thing we criticized in some games was that they used overly colorful UI elements in excess. While we have nothing against colorful UI elements, we designed ours so that they're used sparingly and fit into the game style. The most prominent of this are the gems and menu icons. These were designed so that they went from grayscale to color when they were selected by the laser and user, respectively. Through this, we created a visually appealing feedback system that provided the user with acknowledgement that they were interacting with that element.

Finally, we've recently taken notice of a research article in *Nature Photonics* that was published in September 2014, where scientists were able to teleport an entangled photon over a distance of 12.4 kilometers, as a demonstration of "quantum teleportation." This form of QT may eventually become suitable for very, very fast data telecommunications applications (data transfers at/near speed of light or beyond--superluminal speed). Specifically, we took notice of the diagram (see below) that models and specifies an arrangement of laser beam light/photonic sources, mirrors, lenses, beam-splitters, fiber optic cables, cable spools and more, in ways that are similar in form to what can be supported within Beam. Through the potential implementation of mechanics for objects such as beam splitters and fiber cables, not only do we extend the entertainment and educational value of our Beam game, but we can potentially create a laboratory model where users are free to experiment with laser setups that model and simulate a basic scheme for quantum teleportation. Clearly, such an effort using the Beam game is intended to be informational and entertaining, rather than claiming to be a high fidelity simulation of the complex optical and quantum physics that are core to the scientific demonstration of this approach to quantum teleportation. But given the static diagram that follows, it might be quite interesting and original to see and observe an animated version of the QT process or selected sub-processes, but "slowed down" to a humanly perceivable beam speed that then highlights some of the dynamics of QT using their approach.

Quantum teleportation from a telecom-wavelength photon to a solid-state quantum memory

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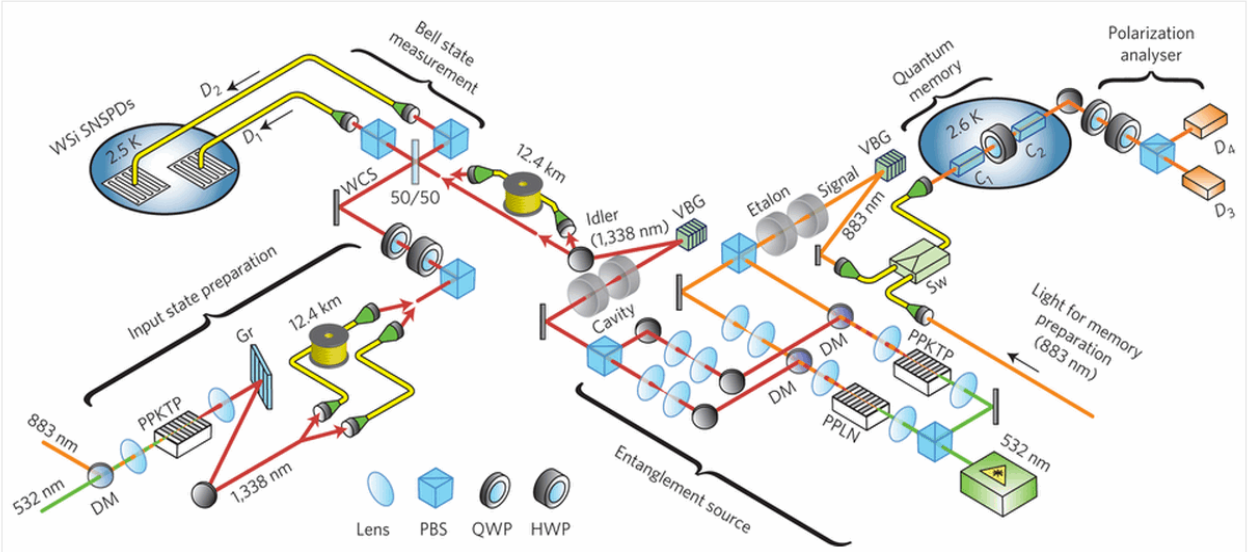

The system includes a source of polarization-entangled photons at 883 nm (the signal) and 1,338 nm (the idler) using filtered spontaneous parametric down-conversion from two nonlinear waveguides (PPLN and PPKTP) coherently pumped with 532 nm light. After the waveguides, the signal and idler modes are separated using dichroic mirrors (DM) and are then individually manipulated to obtain good overlap after recombination at two polarization beam splitters (PBSs), as well as high transmission through the filtering cavity and etalon. A single pair of energy-correlated spectral modes of the signal and idler photons are selected using volume Bragg gratings (VBG). The signal photon is sent to a neodymium-based polarization-preserving quantum memory that was previously prepared as an atomic frequency comb using 883 nm light (see Methods). A switch (Sw) selects either the preparation light or the signal photons. The weak coherent state (WCS) at 1,338 nm is created by means of difference-frequency generation from 532 and 883 nm light. The WCS is then selected using a grating (Gr) and coupled in an optical fibre. The input state to be teleported is prepared using wave plates and sent towards a 50/50 beamsplitter where it is mixed with the idler photon to perform the Bell-state measurement (BSM). The output modes of the beamsplitter are polarization-filtered and sent towards two high-efficiency detectors based on WSi superconducting nanowires (D_1 and D_2) operated at 2.5 K in a closed-cycle cryocooler 10 m away from the quantum memory. A coincidence detection at D_1 and D_2 heralds a successful BSM. The signal photon retrieved from the quantum memory is sent to a polarization-state analyser where it is detected on D_3 or D_4. The idler and WCS photons are each transmitted either over a short distance or over 12.4 km of single-mode optical fibre. See Supplementary Information for details.

Figure 32: This diagram appears as "Figure 1: Experimental set-up" in the paper cited above

If you'd like to explore the structure of the laser system demonstration game's implementation, click the following link: *Beam* Demo. Please note, opening this file requires *Construct 2* game development environment, which can be downloaded from here.

If you'd like to try out the proof-of-concept version of *Beam*, click the following link: http://isr.uci.edu/projects/beam/

Conclusion

For most games, the GUI enables player interaction with a game and is the most obvious link between the player and the intended features of a game. Thus, it is important for a game to not only appeal aesthetically, but also interact intuitively with the player, often with visual cues. The GUI is very useful for adding additional functions that can be manipulated or selected with a mouse, but an overabundance of these functions may end up confusing the player. For instance in *FoldIt*, in which the objective is to maximize the points by manipulating a protein to a more stable configuration, the choices become impossible to manage. For a beginner, maximizing points is limited to arbitrarily choosing available choices without understanding what the intended effect is. However, even this random process may be useful to researchers, who use the results of players' protein configurations for protein structure prediction. These somewhat random choices may explore new conditions that still may be more efficient than an entirely random or sequential algorithm. However, this comes at a cost to the player who can easily become overwhelmed by the choices. Possibly an effort to address this issue, the game also enables a possibility of combining several functions in a desired order as user-defined presets. If well utilized, players might find this a useful tool to avoid repetition, or else as another complex component of this game. To be accessible to a wider audience, the GUI and number of options should ideally be simplified enough to be manageable by any player.

Other precautions with mouse-interactive GUI are the overuse of unnecessary mouse precision and controls. *Life Preservers* features a quiz-themed game, with questions asked based on the information given about the species. This game implements drag-and-drop method of answering questions but ultimately fails to be easily accessible due to the minute size of both the draggable sprites and the target area. Thus, a player might find the selection processes unnecessarily painstaking and repetitive. The GUI of *Pebble it* also disrupts the game, as each basket must be several times for selection and deselection. *Little Alchemy* shares this repetitive design but is not as obstructive to the gameplay. Because the goal of the game is to discover all the existing combinations, the extensive use of the mouse serves as a means of experimentation and becomes a core, necessary component. In a first-person shooter, in which the mouse is vital to the skill-based gameplay, mouse maneuverability becomes a skill instead of an unnecessary nuisance. Only in these cases are the excessive mouse controls and precision justified. Whenever possible, the GUI should incorporate large clickable areas and minimize the amount of unnecessarily clicking and dragging. Important features such as *settings*, *pause*, or *menu* features should be easily accessible without being intrusive as well. Unwarranted pauses disrupt the flow of the gameplay and demonstrate a conspicuous flaw in the game or GUI design. Though often neglected by some game designers, the GUI is an important aspect for human-game interaction and usability.

Beyond the obvious importance of gameplay, added features such as achievements and a ranking system appeal to players and serve as an impetus to continue the game. Achievements, which are often simply meta-goals apart from the main goal of the game, provide an incentive for players to continue to explore the extents of what the game has to offer. In a well designed game, achievements add to the length of gameplay without burdening the player with overly repetitive tasks. Various games

include these features such as *EyeWire*, *FoldIt,* and *Pebble it,* while others feature them as their primary goal such as *Little Alchemy.* A broad category of gamers known as *Completionists* or, in Bartle Test's categories, *Achievers*, are highly motivated in achievement systems, often for the sole sake of completing them. Ranking systems similarly present these challenges for *Achievers,* who enjoy being at the top of the competition. Similarly, levels, contests, and quests offer an incentive for these players. Other player-to-player interactions associated with multiplayer games appeal to other players who focus on social aspects of games as well.