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> Consider the difference in size between some of the very tiniest and the very largest creatures on Earth. A small bacterium weighs a s little as 0.00000000001 gram. A blue whale weighs about 100,000,000 grams. Yet a bacterium can kill a whale....Such is the adaptability and versatility of microorganisms as compared with humans and other so-called "higher" organisms, that they will doubtless continue to colonize and alter the face of the Earth long after we and the rest of our cohabitants have left the stage forever. Microbes, not macrobes, rule the world.
>
> - Bernard Dixon, 1994

1. Introduction

The need to study pathogens and the immune system is becoming more apparent today then ever before. As a result of human actions: environmental destruction, overuse and misuse of antibiotics, and the use of some commercial products has led to a population explosion of bacteria. We are facing an epidemic (Garrett, 1994). The tragic results of disease and spread of disease can be linked to human actions. The need to understand how our immune system fights disease, how to improve its defenses, and how to stop diseases from spreading is becoming increasingly significant. This introduction provides three discussions: the importance of studying microorganisms, the potential of games for learning, and the benefits of learning about the immune system with a game.

1.1. Microorganisms

Environmental Destruction
Human destruction of the rain forest, polluting the oceans, and the greenhouse effect have shifted the natural balance of ecosystems to microorganisms.

> By one calculation a single gram of typical human feces contained one billion viruses. And in a liter of raw human waste there were more than 100,000 infectious viruses – none of which were vulnerable to mere chlorine treatment. Chlorine might eliminate the bacteria – though increasing chlorine resistance in bacterial populations was rendering such chemical sanitation insufficient – but viral elimination required more extensive filtration and tertiary treatment. (Garrett, 1994)

These microorganisms, especially in third world countries, usually end up in a body of water (rivers, lakes, and oceans). They attach onto the algae, incubate as a result of increased Ultra Violet light from the depleted Ozone layer, and infect the food supply. Nature had kept the microorganisms in check; however, human actions have shifted the balance of power.

Antibiotics
Human arrogance misled the medical industry to believe that bacterial diseases could be eradicated with heavy antibiotic use in the 1960s and 1970s. Unfortunately, there are now bacteria strains resistant to all forms of antibiotics (~18%). Moreover, humans have increasingly used antibiotics on animals, which have led to unwanted diseases and resistant bacteria strains as well. Unless there is a medical breakthrough to antibiotic research we have no other defense mechanism other than our immune system. (Garrett, 1994)

Products
Products like super-absorbent tampons have led to Toxic Shock Syndrome which is caused by a common bacteria called Staphylococcus aureus. S. aureus grew in an ideal living environment, multiplied, and mutated into an antibiotic resistant for of bacteria that causes our immune

system to attack itself. Therefore, due to the use of tampons, a new form of S. aureus came to existence. (Garrett, 1994)

Moreover, many household products, like antibacterial hand soap, advertise they kill "99.99% of germs." The difference between antibacterial hand soap and antibiotic medicine is that the soap is much harsher because it does not have to be ingested. The remaining .01% is now resistant to some of the most advanced and harsh antibacterial chemicals out there. Due to the rapid growth of bacteria, the .01% will quickly become 1% and mimic the evolutionary path that bacteria in our bodies have taken. Lastly, .01% seems like a harmless number, but out of one billion forms of bacteria that would mean 100,000 resistant strains of bacteria remain.

Implications
Human actions have led to a population growth of new powerful strains of microorganisms. People must understand that as a result of our actions, the damage that we cause to the environment, arrogance that we can defeat microorganisms, and the products that we use we are creating a potential catastrophic situation. The last defense is our immune system.

1.2. Why a Computer Game?

Using computer games as a learning tool seems to be an ideal medium for teaching teenagers because it is a part of their culture. (Green, et. al. 1998) Moreover, it is a natural way to learn.

> Play and imitation are natural learning strategies at which children are experts. Having children play games to learn is simply asking them to do what comes naturally. (Rieber, 1996)

Teenagers spend a lot of time playing computer games and it would be an ideal situation for educators if we can tap into this time for learning.

Motivation is another reason why a computer game is appropriate. It has been well documented the power of computer games by the amount of time people play them.

> We know that motivation plays an extremely important role in education. To adults, play is just what children do. But that's the point. Play implies doing something, not being passive. Playing while learning increases the time spent on the task, an important predictor of retained knowledge.
>
> - Nora Sabelli, National Science Foundation

Creating a learning environment within a game would capitalize on a wonderful opportunity. (Malone and Lepper, 1987)

Engagement is another benefit of computer games. People can spend hours playing a game and lose their sense of time. Moreover, people learn the complex problem solving skills needed to solve the game. (Keller, 1992)

The main objective of most games is to win. In order to win, the player must use appropriate strategies, including learning the strengths and weaknesses of both the immune system and pathogens, to gain a better understanding of how things work. This is a good example of technology transforming thinking.

1.3. Benefits of an Immune System Game

Immune System Complexity
Learning how the immune system works is complex and there are many misconceptions. A teacher I interviewed stated that there are two student misconceptions: "how the immune system truly works" and "the specific roles of the immune system's organisms." Misconceptions can result from abstract terms, incoherent textbooks or lack of conducting hands on experiments.

> In particular, we have to realize the utility of games, not just for their motivational characteristics, but also for the way they provide structure and organization to complex domains. (Rieber, Smith, Noah, 1998)

The power of a simulation or a game is that learners can actually see how the immune system functions. More importantly, it allows them to conduct "hands on" experiments.

Ability to Experiment
Currently, students are unable to experiment with the human immune system and strains of bacteria for many reasons, including, costs, ethics, and the potential health danger. Oftentimes, "learning by doing" is more effective than learning by reading. Hopefully, hands on learning can alter student misconceptions about how the immune system functions and what the immune system has to go through by learning the exact strategies that both the immune system and pathogens use against one another. A game or simulation is the only possible way at the moment. (Taylor and Jackson, 1996)

Health
Similar to the ability to experiment, changing health related behavior is one of the main goals of this project and is difficult to do in real life. Seeing the effects of not washing your hands, or not getting enough sleep, or doing the things that adds stress to the immune system is greatly increased with a game.

> By grades 9-12, many students have a fairly sound understanding of the overall functioning of some human systems, such as the digestive, respiratory, and circulatory systems. They might not have a clear understanding of others, such as the human nervous, endocrine, and immune systems. Therefore, students may have difficulty with specific mechanisms and processes related to health issues. (National Science Education Standards, 1995)

A game is able to simulate the consequences of a behavior and as a result the player is directly affected. An immune system game could simulate sexually transmitted diseases or how people get sick with influenza without the player actually getting sick.

1.4. Implications

A computer game will allow the learner to see the immune system and the pathogens in an interactive way at the cellular level. This has never been done before and is another good example of technology transforming thinking. Thus, the literature I review should inform the design of an immune system game. First, are games an effective learning environment? The next most important element is theoretical. The game should entail both learning and game design theory. Does the literature address this and can it inform the design of the game? What are the instructional theoretical implications? What should the user interface be like? What do

people enjoy? The literature reviewed will be broad in terms of learning and game design theory, but will try to focus on games that focus on biology or health related issues.

2. Literature Review

All of the articles reviewed mentioned Malone and Lepper's 1987 article on intrinsic motivation. Other than that there are a wide range of differences. To better understand the differences, the articles are organized by effectiveness of games, theory, and an analysis of biology/health games.

First, I want to briefly mention gender and violence. Although both of these issues are fascinating, they are out of the scope of this paper because gender and violence could be a research paper by themselves. The literature suggest there are gender differences in how we play and communicate. (Alloway and Gilbert, 1998) Does this mean that games should be tailored for each gender? Or is this perpetuating gender stereotypes?

Rieber (1996) reported that many of the users he tested thought that violence was distracting and should not be in a game. During class it was mentioned that violence is unnecessary as long as the game includes action. The implications from the literature on gender and violence will inform the design of the immune system game.

2.1. Effectiveness of Games for Learning

Hogle (1996) suggests that "gaming in its various form can increase retention of subject material and improve reasoning skills and higher order thinking."

Retention
Hogle argues that the accumulated learning may not be more effective than conventional instruction, it can help in the retention of the material and may have a longer term effect than other means of instruction. Moreover, games have shown an ability to "change attitudes and holding student interest." (Dempsey, et. al., 1993; Jacobs & Dempsey, 1993; Lieberman, 1998)

Problem Solving Skills
Keller (1992) details the problem solving skills learned from playing a video game.

> Many games require induction, starting with small bits of information and using that information to get farther along in the game; deduction, extracting information from what is already there, and using it to get farther in the game; reflective thinking, in that the next time they may try a different way to solve a problem, because the previous attempt failed; application of what worked in one situation to another situation; hypothesizing of what will happen when they try a certain move; synthesizing of different strategies from different games; and evaluation, or judging the worth of different games, or even moves within games.

Hogle (1996) also believes that games can provide practical reasoning and improve cognitive learning strategies. These include:

- Organizational strategies (paying attention, self-evaluating, and self-monitoring)
- Affective strategies (anxiety reduction and self-encouragement)
- Memory strategies (grouping, imagery, and structured review)
- Compensatory strategies (guessing meaning intelligently)

Dempsey et. al. 1994 reflect these findings too.

Unintentional Learning
Playing a game leads to unintentional learning. Players get a sense of the game environment, character strength and weaknesses, and develop strategies to help them succeed in the game.

> Implicit learning occurs when a subject is not consciously intending to learn, is not aware of what they have learned, and yet they acquire new knowledge. (Hogle, 1996)

For example, a player playing a football game will begin learning the offensive and defensive plays, knowing when to use a particular play, and which plays are successful. Moreover, players help and learn by watching others play the game. Green, Reid, and Bigum (1998) observed two boys playing a video game and noticed that both players learned from each other, even though one was "non-active." They argue that "through practice and in company that Louis is able to further his understanding of the game" and that "both boys are now well-positioned to develop a meta-knowledge of the programming principle of this particular game." (Green, Reid, and Bigum, 1998)

Implications
The goal of educational games is to take the unintentional learning, use the existing problem solving skills, and make the learning more intentional.

> Most games are intended to be entertaining, not instructional. Often, the reason a person chooses to play a game is to experience the fun of engaging in the gaming activity. Learning is usually incidental, or intentional only for the purposes of one becoming a better gamer. The challenge for educators, therefore, is to take the learning that does take place in a game from activities, such as exploring a route through a maze or improving a motor skill on a keyboard, and apply that incidental knowledge or ability to an intentional learning task. (Dempsey, et. al. 1996)

Therefore, people do learn from games, but players only learn what is necessary to advance in the game. Thus the immune system game should make the learning more intentional by having what is learned necessary to the advancement of the next level.

2.2. Learning and Design Theory

There are many learning and design theories that the articles suggest using to inform the design of games, but, only the most frequently mentioned will be discussed.

Intrinsic Motivation

By far the most referenced article is Malone and Lepper's (1987) intrinsic motivation. All of the articles mentioned that games can be a good instructional tool because kids will play them on their own because they are fun and exciting.

Self-regulated learning

Building on intrinsic motivation is self-regulated learning. Self-regulated learning is a person taking responsibility and appropriate actions to ensure that learning occurs.

> Self-regulated learning has three main characteristics. First, learners find the environment to be intrinsically motivating. Second, self-regulated learners are metacognitively active. Learners actively engage in planning and goal-setting and are able to monitor and evaluate their own learning. Third, self-regulated learners are

> behaviorally active in that they take the necessary steps to select and structure the environment to best suit their own learning styles. (Rieber, 1996)

Games are good at self-regulated learning because players must learn and apply the necessary knowledge to problem solve a puzzle or get past a certain point in the game.

Cognitive Apprenticeship

Brown, Collins, and Duguid (1989) argue that learning is experiential and must be in context. It also helps that there is a fair amount of scaffolding and fading to ensure that the learner understands the material. (Dempsey, Rasmussen, Lucassen, 1994, Rieber, 1996) Rieber also mentions Dewey and that "knowledge must be meaningful and relevant to the individual."

Adaptability

Following the guidelines of Dewey, games should adapt to the player's skill and ability.

> Learners will choose to participate in tasks that they perceive as neither too easy nor too difficult. Designing a game with just the right amount of challenge is an extremely difficult task. Many computer games solve this problem by increasing or decreasing the game's difficulty according to the performance of the player. (Rieber, 1996)

Feedback

In order for a game to be an effective learning tool, it must provide immediate feedback to a player's action so that he or she can correct his or her mistake. (Rieber, 1996; Hogle, 1996; Lieberman, 1998)

> Games can also be designed with layers of complexity, a common element to many commercial computer entertainment games. Feedback can also easily be provided in order for learners to quickly evaluate their progress against the established game goal. (Rieber, 1996)

Experiential Learning

Another Dewey belief was that "learning by doing" is one of the best forms of learning. Unfortunately, due to lack of resources, safety, and practicality students are unable to learn by doing in many cases (e.g. flying an airplane). Games are a practical next choice because they can simulate "real" life.

> Video games have interactive capabilities that lend themselves well to experiential learning – and games can be particularly effective when they incorporate well-established instructional design principles. (Lieberman, 1998)

Discovery Learning

Games must be designed so that the interface is intuitive because in a study that Dempsey, et. al. (1996) completed, over 79% of the players they studied preferred "trial and error" as the way to learn how to play a game.

> Strategies in playing computer games included trial and error, reading instructions, reliance on prior knowledge or experiences and development of a personal gaming playing strategies by the subject. Trial and error was, by far, the predominant strategy used even in cases where the subjects reported that they know a more efficient strategy. (Dempsey, et. al. 1996)

Although many players used the "trial and error" approach, the game design must take into account the differences in style among players.

2.3. Biology/Health Games

Participatory Simulations
Collela (in press) from the MIT Media Laboratory has shown the value of using technology to transform student thinking. High school biology students wore infrared capable badges that were programmed to simulate the social life of a virus. Students all started "healthy" and were told to socialize with other students. In the meantime, the badges were programmed so that some of the students were carriers of the disease and as more students talked to one another the more likely they were to get infected. Some of the badges also were programmed so that some students were immune. The game like feature of this simulation was for students to talk to as many people as possible before they got sick. Students learned in a fun way how viruses spread in a community, that certain people are naturally immune, and that being infected is natural. In other words, they learned how viruses work.

The primary goals was to help students think in a scientific way, understanding the "rules of the virus (or game)," that each situation would be different, and "enabling students to devise their own solutions."

The participatory simulations project is similar to the immune system game that I am proposing because it deals with viruses, and tries to transform scientific thinking. The main differences are that it is about the social life of a virus and thus it is more geared toward the macro level versus a micro level examination of a virus, and that the game is not on a computer screen.

Bronkie
Lieberman (1998) examined a video game titled *Bronkie*. *Bronkie* was originally released for the Super Nintendo system and will be released shortly for Windows-based machines. It was designed for kids 8-14. The game, supporting Bandura's theories of self-efficacy and social cognitive theory, is designed to inform youth with asthma about their disease. The two main characters of the video game, Bronkie and Trakie, live in a polluted dinosaur world. The point of the game is to have children (or players) help save the dinosaur world from the clouds of dust formed from meteors crashing through the atmosphere. They help Bronkie and Trakie avoid the triggers that cause asthma (dust, animals, etc.) in a 2-D puzzle action game (similar to *Super Mario Brothers*). Children learn not only to take on an active role in the game (their own lives) but also to identify what may or may not cause their own asthma to flare up.

> Video games provide opportunities to rehearse new skills in a realistic and interactive environment and allow players to see the consequences of every choice they have made. Video games are especially motivating if they include appealing stories and characters, compelling challenges, and immediate feedback, so that players learn by making decisions and seeing the outcomes.

Bronkie is the most similar of the products reviewed because the goals are relatively the same to the game I am proposing. The game genre and asthma are the main differences.

The game appeared to have used a sound theoretical model (Malone and Lepper, 1987; and Bandura, 1995) but surprisingly did not include an assessment of the learning. Did the game meet its goals of changing behavior, teaching kids to take control of their asthma, being able to talk to their parents or other adults, and/or decreased emergency care visits? Unfortunately, these questions were not answered.

BlockAIDS
Johnson (1993) studied *BlockAIDS*, a game designed for the Houston Museum of Natural Science. *BlockAIDS* uses a game show format (tic-tac-toe) to help players retain information they read by quizzing them in a rapid manner. Players block the AIDS virus by answering questions correctly. The objective is to get the highest score by answering the most questions in the least amount of time. Two learning objectives were to learn more about HIV and to change behavior.

BlockAIDS's effectiveness is questionable because the author surveyed beliefs about HIV versus studying the actual actions. The author states that two-thirds of a random sample felt they "knew more about AIDS, feel more comfortable talking about AIDS, plan to avoid AIDS risks." The difficulty with trying to change behavior is that people will say one thing and do the complete opposite. Thus the validity and effectiveness of two-thirds of those sampled changed their behavior is suspect. Lastly, the game does not include the theoretical foundation that informed the design of the game.

ImmunoScenarios
Taylor and Jackson (1996) felt the same way about the lack of hands-on experience with learning the human immune system and created a board game. The board is shaped like an antibody (Y shaped) and a disease handout is given to all players explaining the diseases or ailments that the immune system may encounter. Each board space "corresponds to a specific scenario on the disease handout." The game is primarily for undergraduates and is designed for four players.

The intent of the game is to understand the diseases, the immune system, the ways to enhance or harm the immune system (e.g. vaccinations), and the consequences. Although the content may be the same, the main difference is that I am trying to give students an "electron-microscope" view of the immune system. One of the problems is that the game does not address the issue of assessment or effectiveness. Nor does it address the theoretical models that informed the design of the game.

3. Critical Analysis

3.1. Application of Theoretical Guidelines

Many of the learning and game design theory papers presented ideas and instructional guidelines to abide by, but did not attempt to carry them out, test, and verify the validity of their statements. Most of them analyzed the strengths and weaknesses of games that currently exists and assume that those same strengths and weaknesses are the same for an educational game. Although they may be the same, it is difficult to conclude without testing their ideas.

3.2. Do Games Work?

Most of the literature did not address the ineffectiveness of games for learning. Hogle (1996) does mention that the same amount of learning occurs from a game and from a lecture, but quickly dismisses it as something to that can be overcome or is difficult to assess.

> The problem with making claims about the benefits a game may offer as a cognitive tool is that its effectiveness often cannot be directly or easily measured. Several variables must be considered, not the least of which is the intended purpose of the game, as well as the context in which it is used. (Hogle, 1996)

Hogle also argues that because the content learned from games is "implicit," assessment is even more difficult.

> The most difficult issue in the assessment of games as cognitive tools is that games may be environments which foster the learning of implicit knowledge ... Implicit knowledge is not necessarily reflected in people's ability to answer written questions. (Hogle, 1996)

The assumption of Hogle's argument is that assessment is only in the form of a test. *Bronkie* is a good example where assessment should not be in the form of a written test because it is trying to change behavior. Similar to *BlockAIDS*, a survey or written test would not be an ideal assessment tool because what a user says and what a users does can be completely different.

The only article that truly assessed the learning in a satisfactory way is Collela (in press). Using observations and interviews as their assessment tools, they were able to capture what students learned from their experience. Thus they matched what students did and what they said.

3.3. Time?

One of the problems I potentially see with games is the time spent may not equate to increased learning. Related to assessment, no one addressed or studied the time factor. For example, if a user played a game for an hour does it mean they learn more than a user who played a game for half an hour? Also, does the amount of time spent on games valuable, especially when games are usually time intensive? All of these are interesting questions that was not addressed in the articles.

4. Conclusion

The potential of computer games is summed up nicely by Rieber, Smith, and Noah (1998):

> Computer games offer a new possibility for wedding motivation and self-regulated learning within a constructivist framework, one which strives to combine both training and education, practice and reflection, into a seamless learning experience. (Rieber, Smith, and Noah, 1998)

The articles gave many guidelines to follow in order to have a good theoretical foundation, and sound design principles. Participatory Simulations and *Bronkie* are probably the two best applications of theory and practice. The immune system game should entail some, if not all, of the guidelines outlined by the literature and improve upon the Participatory Simulations and *Bronkie* examples. The game should be assessed to ensure the learning effectiveness.

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