Diverse Player Experiences in the Design of Science Games for Bioinformatics Learning

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ABSTRACT
While a growing number of serious games have been developed around science and engineering concepts, few are designed with an understanding of the socio-emotional aspects of gameplay. Positive affect has been shown to increase learning performance and retention. In this paper, we address enjoyment generated during the design of a bioinformatics computer game. We provide insights from a co-design process with high school students, and discuss the results of an initial user study in a biology classroom. We identify three areas of design focus for emotionally compelling science games that offer ways to integrate diverse player experiences: serendipitous experiences, emotion-laden ethics, and skill transfer. Our framework has design implications for creating science-based learning games, as well as more broadly in the design and implementation of other collaborative science learning environments.

Categories and Subject Descriptors
H.5.2. [User Interfaces]: User Centered Design.

General Terms
Design.

Keywords
Games, bioinformatics, design, science learning.

1. INTRODUCTION
Diverse participation in science, technology, and engineering (STEM) fields at an early age is important, especially for underrepresented minorities and women [19, 20]. Given that video games are an estimated 30 billion dollar global industry and continue to make their way into homes and classrooms worldwide [25], gaming provides a potential way to engage a diverse number of students in STEM concepts. There has been an increasing body of research on the benefits of serious games, or games with a purpose [4, 21].

Emotion or affect has been shown to be an important indicator of interest, engagement, and creativity in tasks [9]. Additionally, social technologies that support collaboration and peer connection can play an important role in fostering a positive youth identity [3]. There is still further research needed to establish the role of affect within the framework of designing a STEM learning game.

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In the design of the game *MAX5* we were particularly interested in which aspects of gameplay were engaging to players, and to better understand how we might facilitate positive emotions regarding the use of science and computing tools.

In the design of a bioinformatics (information technology and computational tools for biological research) focused game, we did not want to create an educational game as a dressed up set of "educational" quizzes, but wanted a way to truly engage students in an immersive environment. Rather than quizzing a student with an exhaustive set of facts about bioinformatics, we choose to provide an emotionally engaging context for these facts, so that when students might encounter the subject later from teachers or professors, rather than being supplied with disconnected facts, they would be revealing missing pieces of a puzzle they already want to solve.

Lazzaro's research [16] offers key insights into gamers' emotional experiences, calling attention to four areas of fun and associated emotions: hard fun, offering a sense of accomplishment once the task has been completed; easy fun, which encompasses a "curiosity" filled experience; serious fun, where players experience frustration and relief doing real work; and people fun, in which players gain fulfillment through social interactions. Similarly, we found Lucero and Arrasvuori's Playful Experiences (PLEX) framework [18] a helpful context for understanding player motivations by accounting for twenty-two categories of playful experiences. Both models provide broader areas of consideration for game designers, yet in our ongoing empirical research with high school students, they did not fully account for the areas of emotional engagement that emerged from the design of a science-centered game.

Many games are designed utilizing user-centered processes, but few educational games are co-designed with youth. Our interest in having a diverse number of students engage directly as co-designers draws heavily on theoretical concepts of constructivist learning, in which students actively construct knowledge and their ideas as opposed to simply absorbing them [30, 32]. Co-design has been successfully utilized as a method to directly involve stakeholders in the design process of educational software using brainstorming, iterative prototyping and evaluation sessions over an ongoing period [24, 28]. We feel that many of the unique aspects of the game came out of the co-design process with high school students. In our research, we utilized a co-design process, observations of gameplay, interviews, and surveys to examine enjoyment and emotional relevancy in science learning games. These areas of enjoyment are then discussed in relation to three areas of design attention for emotionally compelling science games: serendipitous experiences, ethics, and experience and skill transfer.

2. BACKGROUND

There are a growing number of games that integrate STEM concepts into a collaborative player environment. The game *Whyville* offers a learning virtual world for tweens, with 3.4 million registered users in 2009 [20]. In the game, players must work together to fight an epidemic using Center for Disease Control tools. The game is broadly targeted, with an educational focus aimed more at elementary and early middle school students, teaching writing skills, Internet safety, and basic math. The citizen science game, *Foldit*, has allowed thousands of players to solve protein folding puzzles and in the process develop new strategies and algorithms for protein structure prediction [7].

Research on the aspects of gameplay that youth find most enjoyable has shown varying needs and preferences. In a study on student educational video game preferences, Trespalacios et al. [33] found that middle-school students prefer playing multiplayer games because they have the opportunity to play with friends and collaborate to reach end goals. In a hallmark study that adapted a popular game for educational purposes, Squire et al. [29] offered a course to help underserved children become expert *Civilization 3* game players and learn more about how games are made. They found that when playing in pairs the children had increased levels of engagement because they could share strategies with each other and share the burden of challenges.

There has been limited research on games that included students directly in the design process. *Immune Attack* was a video game developed at George Mason University in a program designed to bring high school students together to learn STEM content while designing video games using Game Maker [15]. It was through the process of building the game that students mastered immunology concepts in order to incorporate them into video game prototypes. We believe that our contribution is unique in having teens engage as co-designers in a game that gains a broader audience of peers in other classrooms beyond just as a learning tool for the student designers themselves.

3. ABOUT THE GAME

Players within the game *MAX5* take on the role of bioinformatics agents within the world of the Advanced Future Research Lab, a futuristic global scientific organization. In playing the game, players form teams and use biology software tools to solve clues as they track the outbreak of a growing influenza pandemic. Players communicate via in-game chat. Players successfully complete levels by collecting enough DNA samples to determine the original source of the lethal virus.

While scholars have called for the importance of integrating bioinformatics into undergraduate curriculum [1, 8], it is rare to see bioinformatics topics gain more than a brief mention in most high school biology classrooms. We are partnered with the Northwest Association for Biomedical Research (NWABR), an organization that has created a curriculum for high school classes, providing a route for secondary education teachers to use bioinformatics tools and lessons in their class [23]. Many of the concepts from the game were adapted from this curriculum.

Tools used in-game include a simulation of the Basic Local Alignment Search Tool (BLAST) [2], which is used to compare a nucleotide DNA sequence segment against sequences within a database to determine the statistical significance of matches and discover the possible strain. A BLAST search is also performed to decide whether animals should be quarantined to prevent the spread of the lethal virus within the game (Figures 1 & 2).

Figure 1. A *MAX5* player collects a DNA sample.

Figure 2. A BLAST search result in the game, where a player must make a decision about the closest virus match.

The game also utilizes a tool similar to the bioinformatics software tool JalView [14], as a way to visualize and edit multiple sequence alignments. Players can select DNA samples they find and visualize their sequence to discover codes hidden among the nucleotide sequence and use this information to unlock clues within the game.

4. METHODOLOGY

Data collected included qualitative observations and field notes from a year-and-a-half long co-design process with high school students, as well as data from interviews, and a preliminary study with students in a biology classroom. We have used pseudonyms in this paper and identifying details have been altered to protect the confidentiality of participants.

4.1 Co-Design with Youth

Seven high school students ages 15-18 from Pacific Northwest United States public schools (4 female, 3 male) participated as co-designers of the game in 2012 and 2013. Students came from a diverse range of socio-economic and ethnic backgrounds and five different schools. Co-design sessions lasted 90 minutes and students participated in ten or more sessions held at a university design lab. High school students met with a team of four to five graduate students and researchers to generate game ideas and mechanics, design levels, and create narrative aspects of the game. In the co-design sessions, high school students were informed of the core learning goals and were asked to brainstorm engaging game mechanics and interfaces through the use of whiteboard sketches, note cards, and written work sheets (Figure 3). The youth also worked together on equal footing with researchers to create scene environments and contribute programming scripts using the Unity3D game engine. Iterative prototypes were assessed and evaluated by co-designers and researchers throughout the design lifecycle, reflecting a process similar to that used in previous research on co-design for educational software [24].

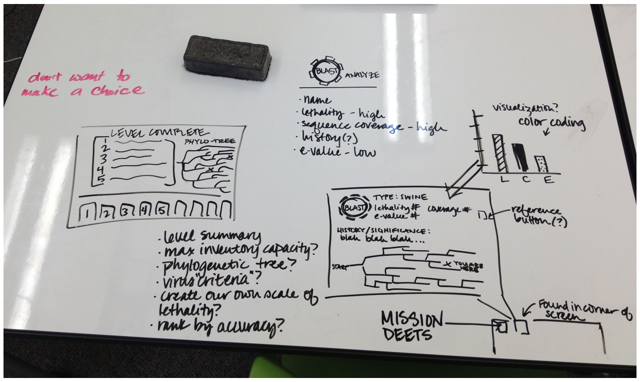

Figure 3. A high school student co-designer's drawings for game information displays.

4.2 Semi-Structured Interviews

Semi-structured interviews lasting approximately twenty minutes were conducted with fifteen high school students (ages 14-19; 6 female, 9 male) during the alpha stage of the game's design. These students were separate from the students that were engaged as co-designers in order to gain new perspectives that were not shaped by the students having taken part in the game's development over an extended period. Subjects were recruited using snowball sampling and through an email sent to NWABR's institutional partners. Interview questions covered topics related to video gameplay and enjoyment, design ideas specific to *MAX5*, and questions about collaboration with peers and classmates. All students interviewed had also engaged in a play-testing session of a *MAX5* game prototype.

4.3 Classroom Study

Data on gameplay, enjoyment, affect, and chat within the game was collected in a combined 9th and 10th grade biology classroom within a public high school in the Pacific Northwest United States. We were fortunate to have access to a highly diverse school setting within a school district where approximately 80% of the students were eligible for free or reduced school meals. Within the classroom approximately 15% of the students identified as Black, African-American or African, 42% identified as Asian, 12% as multiracial, 8% as Hispanic, and 19% as White, and 4% declined to identify. The game was integrated into a class lesson plan over a two-day period. The classroom in our study had engaged in a two-week section using NWABR's curriculum on the use of a BLAST search and bioinformatics tools for genetic analysis prior to gameplay. The game served as a supplement to the lesson, and we were primarily interested in understanding what areas of a science game were emotionally compelling rather than measuring the effects of the game as a stand-alone learning module. Twenty-eight students (13 female) took part in the study.

Teams were randomly generated as pairs upon the players' log in. Gameplay lasted approximately thirty-five minutes during each of the two class periods. An introductory tutorial and two levels were given during the first class period, and two additional levels were provided during the next day. Online surveys collecting demographic information, as well as questions on gameplay enjoyment were given to participants after playing the game. Additionally, six participants were randomly selected to be video recorded during gameplay to capture more in-depth interactions and reactions.

4.4 Analytic Methods

Semi-structured interviews with fifteen students and field notes from design sessions with high school students were analyzed using a conventional content analysis approach [13] to identify themes relevant to players' emotional experience.

5. RESULTS & DISCUSSION

Conducting a classroom study is a challenging endeavor, but worthwhile because it yields results of high value to game designers who may not have the time to conduct this type of research, or the opportunity to work closely with a teacher in a diverse public school classroom setting. Since our goal was to attract a diverse group of students to STEM fields, we felt it was worth the additional effort and the exposure to greater variability than in a formal lab setting to conduct our experiments in an actual classroom. As more games are integrated into classroom curricula, we hope that our experience provides helpful considerations for teachers and researchers.

5.1 Designing for a Classroom

One of the bottlenecks we faced in integrating the game into the classroom experience was the limitation of available technologies. The biology classroom had 16 computers, which were not enough for the 28 students to play the game simultaneously. Additionally, the computers in the classrooms were five to six years older than the models available in the school's computer lab, and there was significant lag experienced when playing the game on them. These challenges made it necessary for the teacher to reserve the computer lab several weeks in advance of our study.

While *MAX5* was developed for PCs, when observing a classroom, we saw the growing potential use of personal smart phones or tablets for learning content. In observing students engaging in a bioinformatics lesson plan (separate from gameplay) in one of our partner classrooms, several students were seen huddled over phones at their desks while other students were at computer stations in the classroom. Upon inquiry, the students showed that their personal mobile devices were being used to access the National Center for Biotechnology Information BLAST website to use the online tool.

When asked about this usage, the teacher noted that it was increasingly common for students to use smart phones in the classroom when performing exercises online, since these were much faster than the computers provided in the classroom, and there were not enough computers for each student. The use of mobile phones in the classroom provides increased opportunities for global participation in educational technology [6] and research suggests that mobile device use might increase engagement in classroom learning [31]. While PCs are still the more ubiquitous platform in classrooms, we anticipate an increase in development for mobile platforms and personal devices marking a transformation for the use of games and interactive technology in classrooms. Questions remain as to when such devices will truly be accessible to the majority of students, and how issues of privacy, information sharing, and connectivity should be properly addressed.

5.2 Enjoyment in Play

In our research, we discovered a diverse array of motivations and areas of enjoyment in playing the game. Players in the classroom were given an open-ended text response box in the post-survey to respond to the question "What did you find enjoyable about the game?" An analysis of questionnaire results was conducted to identify common keywords and group similar answers together; seven categories emerged (Figure 4).

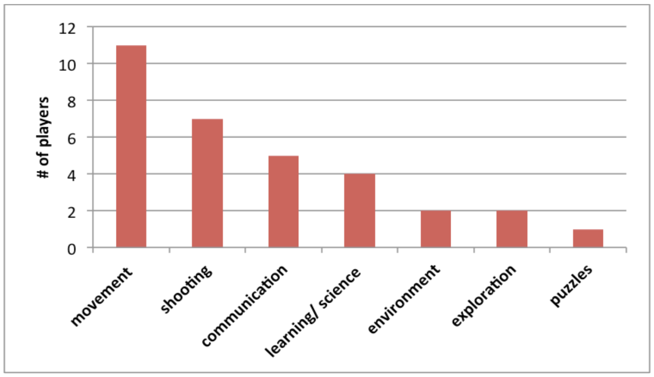

Figure 4. Most frequently listed aspects of game enjoyment.

Table 1 provides the keywords used to code each category as well as examples of responses from each. Player responses were coded for more than one category if they listed aspects relevant to multiple categories. Many of these categories share similarities with existing frameworks on motivation in play, such as the PLEX framework's twenty-two playful experience categories [18] and Lazzaro's four areas of gameplay fun [16]. We build on this previous research by identifying areas of design attention particularly relevant to science learning games.

Table 1. The coding schema and example responses for enjoyable aspects of gameplay.

Code	Keywords	Examples of Comments
Movement	moving, walking, jumping.	"The movement was more free in the town, and it was more puzzling it was cool." "I tried to jump. Hilarity ensued."
Shooting	shoot(ing), gun, firing.	"What I found enjoyable in the game was the fact that you had to use your brain while shooting things."
Communication	chat, communication, talking with.	"Communicating with others to help me throughout the game."
Learning/ Science	analysis of DNA/ nucleotide, science, learning, education.	"It was a neat way to incorporate science DNA sequencing with a game."
Environment	environment.	"I enjoyed the environment the game was in. I liked the style."
Exploration	exploration, moving around.	"You can explore plus it is a adventure."
Puzzles	solving, use of passwords.	"I was able to find the password for the door on the J-view (visualization tool) and work from there."

5.3 Design Framework

While student responses in the above section illustrate diverse aspects of gameplay that players found enjoyable, designers are still left with the challenge of how best to integrate these into a game. In the following sections we discuss three areas of design focus that provide ways to address players' diverse motivations within a science-focused game environment.

5.3.1 Serendipitous Experiences

Serendipity, or "the art of making an unsought finding" [34], has been noted as being an important aspect of enjoyable player experiences in games [26]. In science the role of serendipity has a long history of discussion and research attention, as discoveries frequently come from unexpected observations [5, 11, 22]. We found in our observations of students playing *MAX5* that often the first moment of dramatic unexpected behavior while exploring the game environment was cause for a distinct sense of surprise and delight.

Joseph, a precocious 17-year-old with a budding interest in programming was working quietly in a group design session one afternoon when suddenly a long period of silence was broken with a loud pleasurable scream and a fit of laughter. "The pigs are flying!" he exclaimed excitedly, choking back his laugh. The rest of the group, consisting of several other high school students and graduate students, quickly clustered around his laptop to see what he meant. Sure enough, one of the swine that the players were meant to collect a DNA sample from, could be seen galloping high above the player in the sky, unaware of the laws of physics it was violating. Apparently one of the physics programming functions on the animal had gone awry. Another student erupted into laughter "Can you BLAST it?" she asked. "I'm not sure," Joseph replied. Then came another burst of excitement and laughter from the group as he successfully shot a blue laser bubble around the swine to perform a database search of its DNA and stopping the in-game animal as it galloped in mid-air. This unintended programming error turned into a highly pleasurable and surprising experience for the students. In fact, what we had been quick to call a "bug," remained in Joseph's level design at the end of the year as a surprising and humorous moment he recreated for other students to see.

Students playing a prototype of *MAX5* in the classroom were also observed testing the limits of the game environment, with a sense of enjoyment coming from unexpected behavior. When one student observed that he could hop over a city wall into the area outside of it, he excitedly pointed this out to the girl at his side, and was soon showing her how she could jump over the wall as well to explore the uncharted area beyond the limits of the level. In this way students' natural inclinations to explore the level environment provide an opportunity for surprise and delight.

It is particularly relevant for designers to be aware of these serendipitous moments of discovery in science games, since it is these moments that game players are likely to share with their peers. We suggest that it is important for game designers to support these moments of serendipity and discovery in gameplay by focusing on novel interactions and ways to explore the game environment when engaged in scientific tasks. These moments also serve as a platform for players to share, recreate, and even teach the performance of these new experiences to other players.

5.3.2 Emotion-laden Ethics

In a call for a more holistic science curriculum, scholars note the underlying importance of ethical thought as a core area of science learning, suggesting that students should account for the effects of technology on society [1] and take into account the role of diverse local cultures [12]. It is a notable challenge for designers of learning games to balance the thrilling sense of excitement that many games take advantage of in shooting or fending off enemies with the thoughtful empathy and awareness of other peoples' needs and emotions.

A 16-year-old girl, playing the game for the first time, explored the lab room in front of her, walking towards a table, then pausing looking down in front of her. "Awwwwww" she gushed, "look at the little chicken." She watched the chicken in the game as it pecked its way back and forth in the room. Then suddenly she looked up excitedly, exclaiming, "How do I kill it!" While there was no affordance to "kill" anything in the game, the question of how to treat various species brought both pleasurable and at times critical reactions from students. A 15-year-old girl noted that she wanted to attack things in the game, so she could "shoot them" or as she stated, "the simplest thing, the cliché is to add guns." The BLAST search launcher became a way for players to form a bubble around animals and take DNA samples and analyze data matches, but the game clearly stated "no chickens (or other animals) were harmed in this process."

The high school student designers engaged in spirited discussions around methods of shooting in the game, and whether the "shooting could be a net instead of a bullet" (we selected a bubble), and how best to handle DNA collection from humans using such a device. In one design session a 16-year-old female student went through all of the options for DNA collection, saying with concern "We don't want the people to be treated as animals." She then recommended a plan to gather the people into a room to collect their genetic samples. Instead of "shoving them into a room, we should talk to them, saying 'Please go to this room.' And maybe if they know they are infected they would be reasonable." Such an empathic response differs markedly from the "how do I kill it" response first discussed. Weighing the enjoyment of in-game actions (e.g., shooting or fighting) with appropriate and critical ethical decision-making skills has long been a topic for scholarly and public debate [27]. Game design offers a valuable arena to explore science and technology ethics, and by embedding ethics within emotion-laden actions players can then reflect upon and discuss their decision-making process.

5.3.3 *Experience and Skill Transfer*

In observations and interviews we found that students were able to enjoy game interactions more fully if they had previously experienced and enjoyed similar styles of gameplay. Eddie, a high-energy youth, who boastfully reported to us that he had played every type of game we listed on the survey, had a highly analytical style of play and could talk at great length about his thought process. In one gameplay session, he completed two levels in less than fifteen minutes, while many players were still struggling through their first. When ascending a particularly difficult building to find a clue, he described his thinking in detail: "I was first testing jumping height against the height of the building, then rotating around it, looking for platforms to jump onto," noticing footholds along the way; he then made his way up the building at each foothold testing the height as he went. He said that this was intuitive to him, given the many games he had played that had similar mechanics. Interestingly, while Eddie did chat with his teammate and provide clues on in-game locations, gameplay techniques like the one described above were not explicitly shared with his teammate.

While a great many teens might play video games [17], previous research has shown that there are a wide variety of genres played, and that not all gamers enjoy the same styles of play. A small percentage of youth are often high volume gamers and highly adept across numerous genres, while many others tend to gravitate towards a few specific types of games [10]. Similarly, we found in our study that while there were a few students who played every genre, many more were well versed with a particular type of game (Figure 5).

Player ID:	Fighting	Adventure	Sidescrollers	Puzzle	RPGs	MMOs	Music	MOBAs	Other	Total number of categories played:
1	Yes	Yes	Yes	Yes	Yes	Yes		Yes	Yes	8
3	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes		8
28	Yes	Yes	Yes	Yes	Yes	Yes		Yes		7
4	Yes	Yes	Yes	Yes	Yes		Yes			6
6	Yes	Yes	Yes	Yes	Yes		Yes			6
16		Yes	Yes	Yes	Yes	Yes			Yes	6
25	Yes	Yes	Yes	Yes	Yes			Yes		6
26	Yes	Yes	Yes		Yes	Yes		Yes		6
8		Yes	Yes	Yes	Yes				Yes	5
11	Yes	Yes	Yes	Yes	Yes					5
13	Yes	Yes	Yes	Yes	Yes					5
17	Yes	Yes	Yes	Yes			Yes			5
2	Yes					Yes	Yes	Yes		4
7		Yes	Yes	Yes			Yes			4
9		Yes	Yes	Yes			Yes			4
18	Yes	Yes	Yes							3
10					Yes	Yes		Yes		3
19	Yes					Yes				2
22	Yes									1
24				Yes						1
5	Yes									1
21										0
15										0
# of people per category	15	15	15	14	12	8	7	6	3	

Figure 5. Players' responses to types of games played organized by genre: fighting, adventure, side-scroller, puzzle, role-playing games (RPG), massively multiplayer online (MMO), music, and multiplayer online battle arena (MOBA).

In our observations of gameplay in the classroom, the more experienced players stood out in stark contrast to the less experienced in their comfort with movement and interactions while playing. In our analysis of the chat logs, while many players showed a willingness to share information with their teammates, there were gaps in communication where the more experienced player could have helped the less experienced but evidently did not. It is possible that players like Eddie might assume that their teammate is already aware of the strategies of gameplay (such as how to wall jump), or that some less experienced players did not feel as comfortable asking question via the chat interface.

One girl noted several times in her interview that she was not a particularly "good" video gamer, saying, "I like video games but I'm not very good; I like Portal a lot…puzzle games, RPGs (role-playing games), stuff that doesn't involve technical skills." After rattling off several other types of games she enjoys, she noted laughing, "And not online, not online, because other people are better than you." These experiences suggest that there are opportunities for game designers to leverage the knowledge of more experienced players, encouraging them to share gameplay and learning strategies with less experienced (or simply less confident) players in an effort to generate more enjoyable play.

6. CONCLUSION

This research represents ongoing efforts to better understand the role of affect and enjoyment in collaborative science games, offering insights into designing games for integration into a science classroom. We drew on a year-and-a-half co-design process with seven high school students, interviews with fifteen students, and a preliminary classroom study, to explore enjoyable aspects of gameplay. While players found diverse aspects of their play experience enjoyable, we offer a framework that addresses how this enjoyment can be integrated into a collaborative science game, contributing three areas of design focus: serendipitous experiences, emotion-laden ethics, and experience and skill transfer.

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8. REFERENCES

[1] Altman, R. B. 1998. A curriculum for bioinformatics: the time is ripe. *Bioinformatics*, *14*(7), 549-550.

[2] Basic Local Alignment Search Tool (BLAST). http://blast.ncbi.nlm.nih.gov/Blast.cgi

[3] Bers, M. 2007. Positive technological development: Working with computers, children, and the internet. *MassPsych*, *51*(1), 5-7.

[4] Bogost. I. 2007. *Persuasive Games: The expressive power of video games.* MIT Press, Cambridge, MA, USA.

[5] Bosenman, M. F. 1988. Serendipity and scientific discovery. *The Journal of Creative Behavior*, *22*(2), 132-138.

[6] Chan, T. W. et al. 2006. One-to-one technology-enhanced learning: An opportunity for global research collaboration. *Research and Practice in Technology Enhanced Learning*, *1*(01), 3-29.

[7] Cooper, S. et al. 2010. Predicting protein structures with a multiplayer online game. *Nature*, *466*(7307), 756-760.

[8] Doom, T., Raymer, M., Krane, D., and Garcia, O. 2002. A proposed undergraduate bioinformatics curriculum for computer scientists. In *ACM SIGCSE Bulletin* (Vol. 34, No. 1, pp. 78-81). ACM.

[9] Fabri, M., Moore, D.J., and Hobbs, D.J. 2004. Mediating the Expression of Emotion in Educational Collaborative Virtual Environments: An Experimental Study, in *International Journal of Virtual Reality*, *7*(2), 66-81.

[10] Greenberg, B. S., Sherry, J., Lachlan, K., Lucas, K., and Holmstrom, A. 2010. Orientations to video games among gender and age groups. *Simulation & Gaming*, *41*(2), 238-259.

[11] Hitchner, S. B. 1975. Guest Editorial: Serendipity in Science: Discovery of the B-1 Strain of Newcastle Disease Virus. *Avian Diseases*, *19*(2), 215-223.

[12] Hongladarom, S. 2006. Ethics of bioinformatics: a convergence between bioethics and computer ethics. *Asian Biotech and Dev Rev* 9: 37-44.

[13] Hsieh, H. F. and Shannon, S. E. 2005. Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

[14] Jalview. http://www.jalview.org/

[15] Khalili, N., et al. 2011. Students Designing Video Games about Immunology: Insights for Science Learning. *Computers in the Schools*, 28(3): 228-240.

[16] Lazzaro, N. 2004. Why We Play Games: Four Keys to More Emotion Without Story. http://www.xeodesign.com/whyweplaygames/xeodesign_whyweplaygames.pdf

[17] Lenhart A, Kahne J, Middaugh A, Evans C, and Vitak J. 2008. Teens, Videogames and Civics. Washington, DC: Pew Research Center. http://www.pewinternet.org/Reports/2008/Teens-Video-Games-and-Civics.aspx

[18] Lucero, A. and Arrasvuori, J. 2010. PLEX Cards: a source of inspiration when designing for playfulness. In *Proceedings of the 3rd International Conference on Fun and Games* (pp. 28-37). ACM.

[19] Margolis, J. and Fisher, A. 2003. Unlocking the clubhouse: Women in computing. MIT Press, Cambridge, MA, USA.

[20] Mayo, M. 2007. Games for science and engineering education. In *Communications of the ACM*, 50(7), 31–35.

[21] McGonigal, J. 2011. *Reality is Broken: Why Games Make Us Better and How They Can Change the World*. Penguin, London.

[22] Meyers, M. A. 1995. Glen W. Hartman Lecture. Science, creativity, and serendipity. *American Journal of Roentgenology*, *165*(4), 755-764.

[23] Northwest Association for Biomedical Research (NWABR). http://nwabr.org

[24] Penuel, W. R., Roschelle, J., and Shechtman, N. 2007. Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning*, *2*(01), 51-74.

[25] Prensky, M. 2001. *Digital Game-Based Learning,* New York, NY: McGraw-Hill.

[26] Sanchez, E. 2011. When games meet learning. *ICT and Informatics in a Globalized World of Education Facing the Future-Reflecting the Past*, 9-13.

[27] Sicart, M. 2009. *The ethics of computer games*. The MIT Press.

[28] Spikol, D., Milrad, M., Maldonado, H., and Pea, R. 2009. Integrating co-design practices into the development of mobile science collaboratories. In *Advanced Learning Technologies, 2009. ICALT 2009. Ninth IEEE International Conference on* (pp. 393-397). IEEE.

[29] Squire, K., Giovanetto, L., Devane, B. and Durga, S. 2005. Building a Self-Organizing Game-Based Learning Environment. *Tech Trends*, 49(5), 34-74.

[30] Strommen, E.F and Lincoln, B. 1992. Constructivism, technology, and the future of classroom learning. *Education and Urban Society*, 24 (4), 466-476.

[31] Swan, K. et al. 2005. Uses and effects of mobile computing devices in K-8 classrooms. *Journal of Research on Technology in Education*, *38*(1), 99.

[32] Tam, M. 2000. Constructivism, Instructional Design, and Technology: Implications for Transforming Distance learning. *Educational Technology & Society* 3(2), 50-60.

[33] Trespalacios, J., Chamberlin, B., and Gallagher, R. R. 2011. Collaboration, Engagement & Fun: How Youth Preferences in Video Gaming can Inform 21st Century Education. *TechTrends*, *55*(6), 49-54.

[34] Van Andel, P. 1994. Anatomy of the Unsought Finding. Serendipity: Origin, History, Domains, Traditions, Appearances, Patterns and Programmability. *The British Journal for the Philosophy of Science*, *45*(2), 631-6.