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Implications for Alien Rescue's Future Enhancements through Comparisons with University-developed Educational Games

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Implications for Alien Rescue's Future Enhancements through Comparisons with University-developed Educational Games

by

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Abstract

Implications for Alien Rescue's Future Enhancements through Comparisons with University-developed Educational Games

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Educational games are digital games designed specifically for education. Educational game developers need to take pedagogy into consideration when designing games for learning. Otherwise, students will fail to recognize the curricular value in the game. In 2017, Alien Rescue (AR), an online problem-based 3D immersive learning environment for sixth grade science, released its 6th iteration. The stability that this version of AR has provided is welcomed by schools that collaborate with the AR team. However, the AR team wants to offer more than just stability in the long run, but to also better address students' learning in science. As a member of the AR team, I intend to review university-created educational games to gain insights so that we can make better enhancements for AR. Through comparing four university-developed educational games, the report summarizes four points that the AR team could consider in making improvements: (a) evaluating the necessity of switching to Unity3D based on future development needs; (b) continuing to prioritize web support; (c) extending the implementation of current game mechanisms with new features; (d) developing derivative versions based on Alien Rescue.

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CHAPTER 1 INTRODUCTION

Background Information

In 2017, Alien Rescue (AR, https://alienrescue.edb.utexas.edu/), an online problem-based 3D immersive learning environment for sixth grade science, released its 6th iteration. AR embeds a virtual background in the game, placing players in a space station as a space scientist. The players' task is to help six species of aliens, who lost their home, find new habitats in the solar system. In this new version, the AR team has improved the game experience with modern technologies and also introduced a series of new features, such as a notebook that allows students to take notes and save them automatically. The stability this version of AR has provided is welcomed by schools that collaborate with the AR team. However, the AR team wants to offer more than just stability in the long run, but also better address students' learning in science. As a member of the AR team, I intend to review university-created educational games to gain insights so that we can make better enhancements for AR. These educational games are:

1. ecoX series by Harvard University.
2. EcoNauts by the University of Wisconsin at Madison.
3. Atlantis Remixed by Arizona State University.
4. Fair Play by the University of Wisconsin at Madison.

All these games, including AR, share attributes in common. For example, they all stress problem-solving and are designed within a 3D environment. However, they are distinct from each other in various aspects, such as game mechanisms (open-ended inquiry, third person role playing, and etc.) and support for educators (teachers manual, analytics dashboard, and etc.). This report aims to summarize the pros and cons of these distinctions.

Research questions

Seven research questions are designed to guide this report. They are:

1. What platforms do these educational games target (computers, web, or mobile)?
2. What technologies are these educational games using for development and their strengths and weaknesses?
3. What pedagogical considerations are these educational games implementing?
4. What game mechanisms are these educational games adopting?
5. What features do these educational games have and their strengths and weaknesses?

Significance

K-12 classrooms often position individual learners as objects to be changed, which could lead to passive learning (Barab, Pettyjohn, Gresalfi, Volk, & Solomou, 2012). Such classrooms also tend to treat content as facts to be acquired for a test, which proves to be personally disempowering, conceptually inadequate, and consequentially insignificant (Barab et al., 2012). On the other hand, one of the benefits of a video game is its ability to position players in an active role, whose decision-making might influence the entire virtual context. A context with meaningfulness to learners tends to show high levels of engagement and performance (Moje, Overby, Tysvaer, & Morris, 2008). Meanwhile, using video games for learning provides the possibility for educators to utilize data-driven strategies in classrooms, which could potentially help them target and tackle problems that students have collectively and individually. To better develop Alien Rescue so as to serve students and teachers more efficiently, the report intends to probe into four educational games and attempts to apply their insights to Alien Rescue.

Terms Used

Here are the definitions of the several key terms used in this report, which are summarized through the review of literature: (a) *games* are virtual contexts that center on

problem solving with the freedom to experience and fail without fixed identities; (b) *serious games* are games used for purposes other than mere entertainment; (c) *educational games* are digital games specifically designed for education; (d) *game mechanisms* are methods designed for interaction with the game state, thus providing gameplay; (e) *gameplay* is the pattern defined through the game rules; (f) *designed experiences* are experiences resulting from the intersection of design constraints and players' intentions; (g) *transformational play* is an instructional method that positions students as change agents (active protagonists) who must understand and apply academic content as conceptual tools in order to effectively transform problematic scenarios; (h) *problem-based learning* is an instructional approach that exemplifies authentic learning and emphasizes solving problems in richly contextualized settings.

Report organization

This report is composed of four chapters. The first chapter serves as the introduction, addressing the purpose of this report and research questions. The second chapter is a review of literature, hoping to clarify the definition of five terms (games in general, serious games, educational games, game mechanisms, and gameplay) and how to design games for educational purposes. The third chapter gives an overview on the four educational games to be compared with AR. The last chapter analyzes the four games based on research questions, compares the four games with AR, summarizes the previous suggestions, and discusses implications for the Alien Rescue team to consider in making enhancements.

CHAPTER 2 LITERATURE REVIEW

This chapter defines terms and concepts through literature review. These terms and concepts are closely related to the report: gathering insights from four educational games, comparing these games with AR, and coming up with a conclusion on the aspects of AR which could be improved. Since this is a report on games, it is reasonable to first clarify the definition of a game. Then this chapter explains the types of games educators might be interested in, those being serious games and educational games. Differences between serious games and educational games are also addressed to clear up potential confusion. In the second section, the report discusses the definition of game mechanics and different types of game mechanics. In the last section, the report lists several strategies for educational game design.

Games in general, Serious games, and educational games

"What is a game?" I asked myself this question when I first had the idea to do research with games. In real life, terms such as games, computer games, and video games are often used interchangeably (O'Neil, Wainess, & Baker 2005). However, a board game is also a game, while it is not a computer game. So, what should we really refer to when talking about games? What common attributes do games in different forms share?

Games require a "stance of playfulness" (as cited in Klopfer, Osterweil, & Salen, 2009, p. 7), which is a cognitive attitude tied directly to the creative, improvisational, and subversive qualities of play. This indicates that games are tightly connected with play, and play is the act of gaming (Klopfer et al, 2009). According to Klopfer et al. (2009), "play is exercising freedom along five distinct axes: (a) freedom to fail; (b) freedom to experiment; (c) freedom to fashion identities; (d) freedom of effort; (e) freedom of interpretation" (p. 4). Thus games, which perform play, are also presented in these axes. A game is also a "system in which players engage in artificial conflict, defined by rules, that results in a quantifiable

outcome" (Salen & Zimmerman, 2004, p. 80). Gee (2008) shared a similar idea: "games can be looked at as compelling tools for 'deep learning' if they succeed at creating "virtual experiences centered on problem solving that recruit learning and mastery as a form of pleasure" (p. 36). Therefore, to Gee, games create virtual experiences that are encompassed with problem-solving.

Then what is a serious game? The term is an oxymoron, but it is meant to be an oxymoron (Djaouti, Alvarez, Jessel, & Rampnoux, 2011). The idea that games can be used for purposes other than fun was first formulated by Abt (as cited in Djaouti et al., 2011, p. 3), who gave a clear definition: "Games may be played seriously or casually. We are concerned with serious games in the sense that these games have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement. This does not mean that serious games are not, or should not be, entertaining". The game itself might not be necessarily designed for education, but needs to be used in an educational context in order to be considered serious. This means that, for example, a board game originally designed for fun can be used in a military training context to teach strategic thinking and the principles of tactical warfare (Breuer, & Bente, 2010). Zyda (2005) gave a more open definition: "Serious games have more than just story, art, and software, however. They involve pedagogy: activities that educate or instruct, thereby imparting knowledge or skill. This addition makes games serious." All the definitions above share the key idea that "serious games are games used for purposes other than mere entertainment" (Susi, Johannesson, & Backlund, 2007, p. 1).

But then it leads to another question: what is the difference between serious games and educational games? Can they be used interchangeably? "Educational game is still a newly emerging concept in our country, and there is no explicit definition nowadays". (Song & Zhang, 2008, p. 4). Based upon the literature review of this topic, I found that educational

games are often referred to educational video games, computer based games or game based learning (Conati, 2002, Din & Calao, 2001, Gredler, 1996). If we agree on this interchangeability, then we can see the first distinction between serious games and educational games: a serious game is not necessarily digital, while an educational game is. Based on this, from the perspective of design, educational games are designed to have educational impacts while also to be entertaining (Prensky, 2003, Zhao & Zhu, 2006, Şenel & Akman, 2016). Another distinction is that serious games are not necessarily designed for educational purposes, as long as they are used in a learning context. As mentioned above, a board game could also be considered a serious game when the game is used for education such as military training, even though the game is originally designed for leisure. However, educational games are embedded with educational goals. Breuer and Bente (2010) came up with this graph for the relationship between serious games and similar educational concepts (see Figure 1):

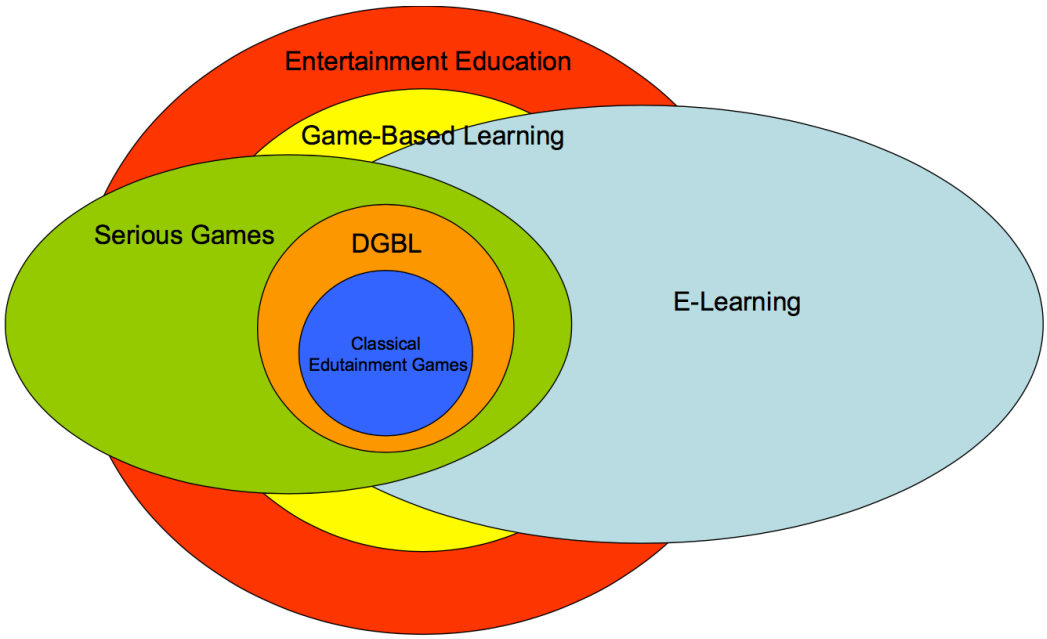

Figure 1. The relations between serious games and similar educational concepts. Adapted from "Why so serious? On the relation of serious games and learning" by J. Breuer, & G. Bente, 2010, *Computer Game Culture, 4*, p. 11.

Entertainment education refers to any attempt to make learning enjoyable. Game-based learning is a subset of entertainment education, which is designed for learning, but with various forms (digital or non-digital). Serious games only partially overlap with game-based learning because serious games could also be used in contexts other than education, such as art and therapy. Digital game-based learning (DGBL) is a special section of serious games, which refers to digital games taking education as the main or sole purpose (Breuer & Bente, 2010). Although Breuer and Bente did not cover "educational games" in this graph, through the definition mentioned above, we could say educational games share the position similar to DGBL.

Game mechanisms

To better analyze games, we need to know what to analyze. Two of the core elements that determine how a game works are its mechanisms and gameplay. Game mechanisms are methods designed for interaction with the game state, thus providing gameplay (Sicart, 2008). Gameplay is the pattern defined through the game rules (Egenfeldt-Nielsen, Smith, & Tosca, 2016, Salen & Zimmerman, 2004). Game mechanisms are the foundation and gameplay is the result. For example, in AR, students are assigned the role of space scientist to solve a series of simulated issues, e.g. helping aliens who lost their homelands to find new habitats. The mechanisms used by AR are role-playing and simulation. In the game, players need to visit different databases such as "Concepts Database" to learn about space science and basic mathematics. This regular visit of in-game tools is the gameplay of AR, which is the pattern players will tend to follow in the game. This pattern (using in-game tools to solve problems) is one of the results caused by the role-playing and simulation game mechanisms implemented by AR. There are various game mechanisms, and since it is not the goal of this report to research on game mechanisms, I will borrow the following mechanisms for analysis organized by Ke (see Table 1):

Table 1. Genres of learning games classified via core mechanics and narrative design

Game Type	Mechanisms
Action	Quick thinking and reflexes (e.g., in jumping, shooting)
Adventure	Long-term obstacle overcoming, involving constant exploration, item collection, and puzzle solving
Strategy	Strategic deployment via system thinking and planning
Role-playing	Interacting with characters, information collection, and decision making
Simulation	Interacting with and discovering an underlying, simulated model or system
Construction	Design, build, and resource management

Notes. Game Type refers to the type of a video game. Adapted from "*Designing and integrating purposeful learning in game play: a systematic review*," by F. Ke, 2016, *Educational Technology Research and Development, 64(2),* p. 4.

Educational games design

Games might not be educating enough simply based on the argument that games have a potential educational value. "If games are 'possibility spaces,' then researchers need to account for how players inhabit them and the mechanisms by which meanings become interpreted from these experiences (Squire, 2006, p. 2)". Turkle (2003) said that without access to the underlying model, students will fail to recognize simulation bias or the "hidden curriculum" of what is left out (as cited in Squire, 2006, p. 3). Thus, educators need to support players' learning with pedagogy when it comes to educational games.

Several pedagogical considerations could help educators in designing games. The first one is to use games as designed experiences. Squire (2006, p. 8) defined designed experiences as "experiences resulting from the intersection of design constraints and players' intentions". Educational games need to be designed with a set of rules where students can learn by performing a certain role, learn through failure, and develop identities as expert problem solvers (Gee, 2003, as cited in Squire, 2006).

Another instructional method educators could consider in using to design educational games is transformational play. Transformational play is an extension of Dewey's idea of "transactivity" (1938): every experience acted upon and undergone modifies the one who acts and undergoes. It involves positioning students as change agents (active protagonists) who must understand and apply academic content as conceptual tools in order to effectively transform problematic scenarios (as cited in Barab et al., 2012). This type of consequential engagement is very difficult to accomplish in schools and even in non-interactive media (Gresalfi, Barab, Siyahhan, & Christensen, 2009). It is important to note that simply playing a game does not mean one is engaging in transformational play. Only when players are taking on a role of a protagonist that demands using conceptual understandings to understand, and eventually make decisions on problem solving can we say one is experiencing transformational play.

Problem-based learning (PBL) is also worth taking into consideration when designing educational games. PBL is "an instructional approach that exemplifies authentic learning and emphasizes solving problems in richly contextualized settings" (Liu, Horton, Toprac, & Yuen, 2012, p. 3). PBL's stress in placing learning in real world contexts has been found to offer opportunities to transfer knowledge and skills from school settings to authentic settings more easily (Hmelo & Ferrari, 1997).

Designed experiences, transformational play, and problem-based learning could all be beneficial to students' problem-solving skills, which are the skills that transform an initial problem state into a desired goal state (Newell & Simon, 1972). Research showed that problem-solving ability is an indication for self-efficacy (King, Glasgow, Toobert, et al., 2010, Pajares, & Miller, 1994), which is people's confidence in performing a task successfully (Bandura, 1997). AR's research showed that self-efficacy towards science learning could be used to predict achievement (Liu, Hsieh, Cho, & Schallert, 2006).

Apart from what has been mentioned above, Ke (2016) pointed out that three aspects could serve as guidelines for educational game design: (a) find gameplay in the domain knowledge. For example, making the gameplay in an environment that is directly related to the subject, or simulating the core problems in the game. Studies showed that combing domain knowledge could enrich learning and pedagogical use of educational games (Hamalainen, 2008); (b) game-mechanic-based, game-narrative-confined learning actions. We cannot make a game fun without a valid game mechanic, but this mechanic should also support learning (e.g. a metrics incentive system for learning motivation). To supplement the mechanic, we could also include a narrative feature in the game, though not required; (c) Non-intrusive, meta-reflective learning scaffolds. Scaffolds in a game should trigger players' meta-reflection, and help relieve cognitive load of players.

Apart from the above three aspects by Ke, game experience should also be designed to encourage problem-solving strategies, as this could lead to a greater predictability of learning outcomes (Gauthier, Corrin, & Jenkinson, 2015). Designed experience might not just be limited to in-game design, but also include the media where gaming happens, as "learners will benefit more from the use of a particular medium with certain capabilities if the capabilities are employed by the instructional method to provide certain representations" (Kozma, 1994, p. 12). For example, mobile games could be a good alternative to computer

games, as there is a significant population base (144.1 million mobile gamers in the U.S), and the nature of its portability makes it advantageous for situated learning, which promotes learning in authentic contexts (contexts that are or reflect our real life). For instance, to learn about the ecosystem in our daily life, teachers could lead a field trip with students to a lake area, learning ecological concepts with the aid of mobile phone applications, the experience of which positions students in a real-life scenario.

Summary

From what has been mentioned above, the report will use the following definitions: (a) *games* are virtual contexts that center on problem solving with the freedom to experience and fail without fashioned identities; (b) *serious games* are games used for purposes other than mere entertainment; (c) *educational games* are digital games specifically designed for education; (d) *game mechanisms* are methods designed for interaction with the game state, thus providing gameplay; (e) *gameplay* are the pattern defined through the game rules.

To design a game for educational purposes systematically, educators need to embed pedagogical considerations into the game. Designed experiences, transformational play, and problem-based learning could offer guidelines to educators. Meanwhile, Ke summarized three points through a review of literature on game design, which could help educational game designers: (a) find gameplay in the domain knowledge; (b) stress game-mechanic-based, game-narrative-confined learning actions; (c) implement non-intrusive, meta-reflective learning scaffolds.

CHAPTER 3 ANALYSIS OF EDUCATIONAL GAMES DEVELOPED BY UNIVERSITIES

This chapter discusses four educational games developed by universities, which are

1. ecoX series by Harvard University. (http://ecolearn.gse.harvard.edu/ecoMUVE/overview.php)
2. EcoNauts by the University of Wisconsin at Madison. (http://www.gameslearningsociety.org/econauts_microsite/)
3. Atlantis Remixed by Arizona State University. (http://atlantisremixed.org/doctors-cure/, http://atlantisremixed.org/mystery-of-taiga-river/)
4. Fair Play by the University of Wisconsin at Madison. (http://gameslearningsociety.org/fairplay_microsite/)

The introduction of these four games is meant to give an overview of each game on their development background, game content, game mechanism, and gameplay. They are described as educational games because they are in a digital format, and are also designed specifically for learning.

EcoX Series

EcoX series is a series of educational games and materials developed by the Harvard Graduate School of Education for middle school students to learn about ecosystems and causal patterns. EcoMuve is the base of the other three Eco series, which placed users into a 3D environment (see Figure 2).

Figure 2. An overlook of the 3D environment of EcoMuve. Retrieved from EcoMuve [Computer software]

The game does not specify the role of players, but let them experience an environmental change – fish in the pond start to die. The players will need to gather 17 types of data, such as water temperature, dissolved oxygen, phosphates and so on over a period of time to understand the causal pattern in the ecosystem (see Figure 3 and Figure 4).

Measurement	June 30th	July 6th	July 10th	July 16th	July 22nd	July 25th	July 28th	August 15th
Water temperature (°C)	22	19	21.5					
Dissolved oxygen (mg/L)	8.4	9.5	9.4					
Phosphates (mg/L)	0.01	0.1	0.03					
Nitrates (mg/L)	0.15	0.56	0.33					
Turbidity (NTU)	5	25	35					
pH	7.2	6.7	8					
Chlorophyll A (µg/L)	20	10	50					
Air temperature (°C)	25.5	20	24.5					
Wind speed (m/s)	1.5	4.5	3					
Cloud cover (%)	40	100	0					
Bacteria population (cells/ml)								
Bluegill population								
Bluegreen algae population (cells/ml)								
Green algae population (cells/ml)								
Heron population								
Largemouth bass population								
Minnow population								

Import Show Graph

Figure 3. A table of data that a user gathers within the game. Retrieved from EcoMuve [Computer software]

Figure 4. The data table can also be converted into a graph so that users can compare a specific group of variables. Retrieved from EcoMuve [Computer software]

EcoMobile is a side project of EcoMuve, which is not a real piece of software. Rather, it is a set of curricular materials that helps teachers to deliver lectures on environment in real life with the aid of mobile phone applications. In the curriculum, it suggests that teachers use Augmented Reality Interactive Storytelling (ARIS, a fundamental augmented reality[1] mobile application and free to download on both iOS and Android stores). For example, teachers will print QR codes beforehand, and place these QR codes in a course-related environment, allowing them to lead a field trip with students to explore the ecosystem by scanning the QR codes. EcoXPT is entirely built upon EcoMuve, meaning they share the same storyline and gaming materials. The major difference is that EcoXPT offers a lab in the game which allows students to conduct experiments for trial and error to achieve authentic experimentation. For instance, they can use different variables to test against one hypothesis (see Figure 5)

[1] Augmented reality is a live direct or indirect view of a physical, real-world environment whose elements are augmented by computer-generated sensory input such as sound, video, graphics or GPS data.

Figure 5. Lab interface - students can control variables to test hypothesis. EcoMuve Harvard (2012, May 11). "EcoMUVE demo video." [YouTube]. Retrieved from https://youtu.be/LZ7pAuMOBO4

EcoNauts

EcoNauts is an educational game developed by the Games Learning Society from the University of Wisconsin at Madison. It immerses players in a rich environment (2.5D), making difficult-to-observe ecological phenomena visible in a living landscape containing trees, lakes and land. Players need to explore and examine the setting to explain the relationships between choices that humans make and their environmental consequences. For example, players can construct factories near lakes, but this will result in a loss of points, as factories could be detrimental to a lake's ecosystem. This game deploys strategy and construction mechanisms similar to Civilization, a commercial strategy game, but much less complex. Worth noticing is that this game provides a multiplayer mode, in which the player who is the first to earn 8,000 dollars will win. Players will need to collect resources such as wood and money through placing forestry cutters on the game map, and then utilize the wood obtained to construct buildings that can make money. These forestry cutters are not "intelligent," as they stop working immediately once the trees around them are cut off, which

require players to think about what might be the optimal location to place the cutters in order to save time. Each construction could come with potential pollution, which in turn, could affect resource acquirement.

Figure 6. Wood-crafting cars are cutting woods. GLSCenter (2014, October 16). "Econauts Gameplay Video." [YouTube]. Retrieved from https://youtu.be/HvUeIjcOlCM

Figure 7. Using woods to construct. GLSCenter (2014, October 16). "Econauts Gameplay Video." [YouTube]. Retrieved from https://youtu.be/HvUeIjcOlCM

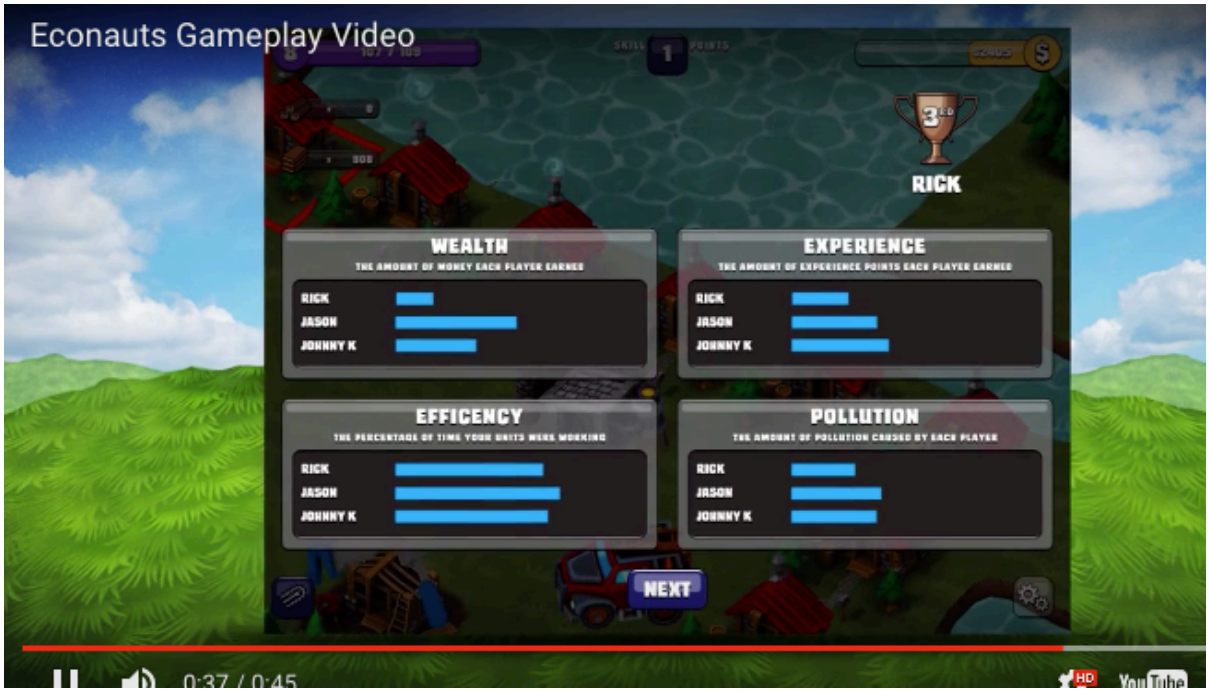

Figure 8. Game results after one player won. GLSCenter (2014, October 16). "Econauts Gameplay Video." [YouTube]. Retrieved from https://youtu.be/HvUeIjcOlCM

Atlantis Remixed Series

The Atlantis Remixed series is a set of games that share most of the game mechanics with their precedent – Quest Atlantis. This series introduced two new "chapters[2]" with improved 3D environment and UI. One chapter is "The Doctor's Cure," which tells the background story of a village that is suffering from a rare plague, and players need to find out who is the criminal and what is the cure (https://gamesandimpact.org/transformational-play/). The other new chapter is "Mystery of Taiga River," which, similar to EcoMuve and EcoNauts, addresses environmental topics such as pH, turbidity and nutrient run-off as well as systematic thinking through dragging and dropping a fixed set of evidence collected by the user (see Figure 9), similar to EcoXPT's laboratory feature.

[2] Quest Atlantis uses chapter to refer to an individual storyline in the game

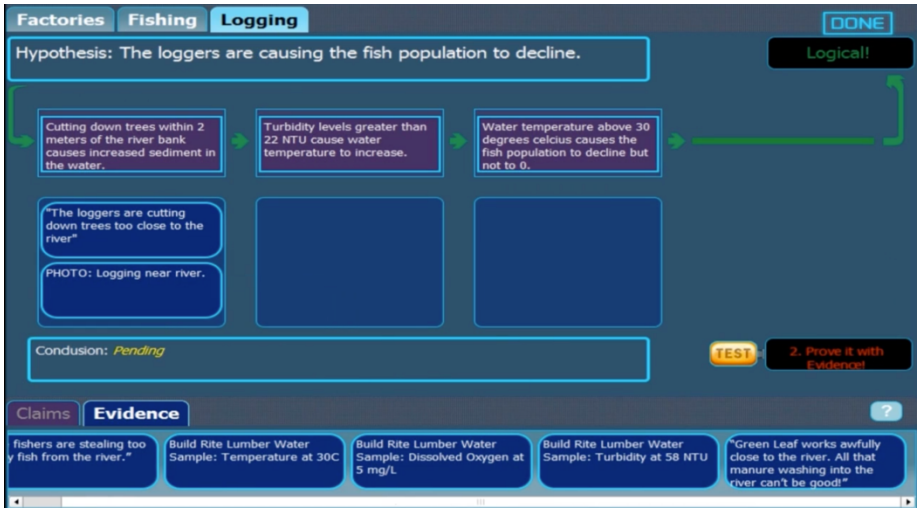

Figure 9. Drag and drop evidence to test hypothesis. Atlantisremixed (2012, May 10). "Atlantis Remixed: The Doctor's Cure." [YouTube]. Retrieved from https://youtu.be/btDiCZtwYCI

Both chapters share the same infrastructure, such as character control, a UI system and a quest system. They differentiate with each other through placing users in a different story and context.

Figure 10. Character control. Atlantisremixed (2012, May 10). "Atlantis Remixed: The Doctor's Cure." [YouTube]. Retrieved from https://youtu.be/btDiCZtwYCI

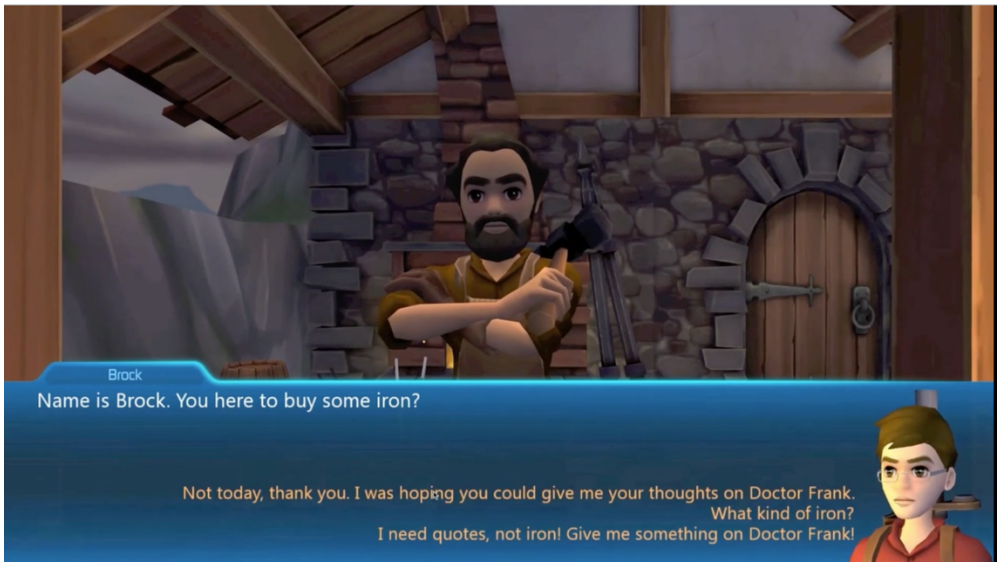

Figure 11. Quest system. Atlantisremixed (2012, May 10). "Atlantis Remixed: The Doctor's Cure." [YouTube]. Retrieved from https://youtu.be/btDiCZtwYCI

Figure 12. Drag and drop evidence to test hypothesis. Atlantisremixed (2012, May 10). "Atlantis Remixed: The Doctor's Cure." [YouTube]. Retrieved from https://youtu.be/btDiCZtwYCI

Fair Play

The Game Learning Society from the University of Wisconsin at Madison also developed Fair Play, directed by Kurt Squire**.** In Fair Play, players take on the role of Jamal Davis, a young Black graduate student who is on his way to becoming a renowned professor. As Jamal, players must conquer implicit bias, explore surroundings, and build Jamal's network to prove his full research potential. The game provides sufficient opportunity for

players to experience implicit biases, particularly in encounters with other characters, as they navigate the world of academia as Jamal. “Throughout the game there are instances that exemplify several kinds of racial biases (Racial microaggressions, color blind attitude, etc.), to which the player is given a list of responses. The player must choose the best response to these biases while trying to improve relationships with the game's characters to improve his academic career.” (retrieved from http://gameslearningsociety.org/fairplay_microsite/)

Fair Play has five chapters during which you will navigate through the challenges inherent to graduate school, such as securing funding, writing publications, and much more. It is quite a short game, and players can go through the game within approximately two hours. The gameplay is mostly about walking and talking to people, and making choices during the conversation. There is an Almanac, which is the “inventory” that holds all the concepts learned on implicit biases throughout the game; however, these items will only be unlocked when players actually experience them instead of them being present when the game starts.

Figure 13. In-game view. Retrieved from Fair Play [Computer software]

Figure 14. Almanac list. Retrieved from Fair Play [Computer software]

Figure 15. Detail of an Almanac item. Retrieved from Fair Play [Computer software]

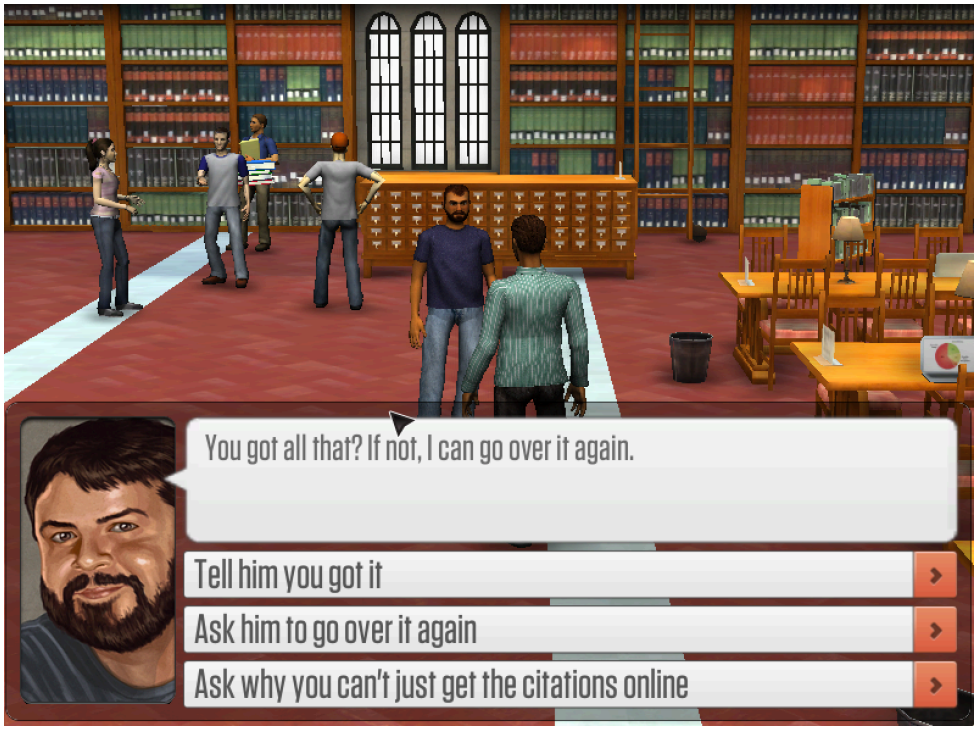

Figure 16. Example of an ongoing conversation and choices. Retrieved from Fair Play [Computer software]

CHAPTER 4 DISCUSSION & IMPLICATIONS

This chapter compares the four games mentioned above with Alien Rescue, discussing their advantages and disadvantages based on the seven research questions: (a) What platforms do these educational games target (computers, web, or mobile); (b) What technologies are these educational games using for development and their strengths and weaknesses; (c) What pedagogical considerations are these educational games implementing; (d) What game mechanisms are these educational games adopting; (e) What features do these educational games have and their strengths and weaknesses.

Then the chapter discusses implications on what AR could learn from these games. Finally, the chapter summarizes previous content and formulates conclusions.

Comparisons of the four games with regard to Alien Rescue

What platforms do these educational games target (computers, web, or mobile)

All four games target computers, while AR is targeting the web using WebGL, which requires zero configuration or installation for end users (although it does have minimum requirements for hardware that can support WebGL). Although there is a product called EcoMobile in the ecoX series, it is not a mobile version of the game, but a set of course materials for teachers.

Using computers as the build target has the following advantages:

1. Native running environment allows the game to use computing resources more efficiently, which gives developers more freedom on creativity, as they can include a fairly complex environment and interaction for the game. This might be the only choice when the game requires a complicated gaming system.
2. The quality of rendering is the best compared with other options including web pages and mobile devices.

However, releasing on the computer platform also has several disadvantages:

1. Incapability of hot fix. Hot fix is a word used in the software engineering world, which means to fix a piece of software's bugs without asking users to re-install. While this is possible for computer software, it requires specific knowledge and tools to address. On the other hand, a web application just needs to patch bugs on the hosting server, and every end user's experience will be almost identical because the users are visiting the same URL (web link) and getting resources from the same server.
2. Large file size. Although computers' running environments are more powerful than web and mobile devices, they also come with a higher cost. Due to the complexity of operating systems[3], the final product size is normally much bigger than web or mobile applications. This means that students might need to install the game before the class, which also leads to logistical issues: How should teachers arrange the time? What if a student fails to install the game, and teachers do not know how to solve the issue? Should the teachers proceed with the class with that student left behind?
3. Inflexibility of cross-platform. Computer or mobile games can only be run in a unique environment. However, web applications can be run throughout almost every platform, as long as an up-to-date browser is supported, especially when this application is responsive. For example, a Windows game cannot be run on MacOS. Although there are tools such as Unity3D that allow developers to output different build targets with one code base, it is still problematic. First of all, more often than not, these cross-platform compilation tools need to compile the source code into different languages of which the operating system is built. This compilation process is not perfect. If there are glitches in the process, developers

[3] The system a computer is running on, such as Windows, MacOS, and Linux

are unlikely to fix them. Secondly, even if the compilation is perfect, it is still time-consuming, as you will need to build multiple times for different platforms. For instance, you will need to build once for Windows users, and another time for MacOS users, each of which could take ten minutes to hours depending on the game size.

Using the web as the release platform certainly wins over those targeting computers, as the web could serve as the bridge between all operating systems and devices. Users do not need to download or install a separate application just because they are switching from Windows to MacOS, or from computers to mobile phones. It is true that web applications have limited access to computing resources compared with native applications. However, for educational games, which often implement relatively simple gameplay, the resources allocated for browsers are usually far from being sufficient.

What technologies are these educational games using for development? What strengths and weaknesses do the technologies used by these educational games have?

Game engines. It is interesting to find that all these four games use Unity3D as the game engine, while Alien Rescue is the only one that does not, which uses Blend4Web as the framework for game development. However, being different does not suggest Alien Rescue is falling behind; instead, it shows a spirit of exploration.

Blend4Web is made up of two parts: a JavaScript library which bootstraps the game engine in web development, and a Software Development Kit (SDK) for Blender. The SDK allows 3D modelers and developers to use Blender as a game engine (e.g. set up physics for objects or define a physical boundary for objects to trigger actions when colliding with players). As a light-weight engine, Blend4Web offers a great experience for web development, since developers do not need to compile the source code as they would in Unity3D. Even though Blend4Web offers much less than Unity3D when it comes to game

development, its nature of agility could be a major reason as to why projects would choose it over Unity3D. What is more, Unity3D's WebGL build is not a full implementation of WebGL, which makes it flawed when running on mobile devices. But for Blend4Web, as its name suggests, is made for the web, and thus its WebGL build is more stable than Unity's.

However, Blend4Web is a relatively new engine, which might have compromised its popularity. The development experience with it regarding development speed and support is relatively poor compared with other game engines:

1. Unclear documentation. Although it does have documentation covering all of its features, the content is opaque, which makes it difficult for new developers to follow.
2. Poor community support. Often, poor documentation could be mitigated by seeking help from developers in the community, such as internal forums and stackoverflow. But because Blend4Web is yet unknown by lots of developers, seeking help online has become extremely hard.

These limitations might push us to re-consider AR's choice of game engine depending on what AR will be in the next iteration: do we want to have a more complex and interactive 3D environment? Unity3D is a more ideal tool when it comes to complex game development, since it has the following strengths:

1. Smooth user experience. Games built with Unity3D have among the best user experiences, as the engine is highly optimized and uses computer memories efficiently. The value of it is even more evident in a resource-limited environment, such as a browser.
2. Great development experience. Unity3D not only offers a good experience for developers but also for people without programming backgrounds, such as designers. This is because Unity3D tries to provide GUI (graphical user interface)

alternatives as much as possible for all the functionalities. For example, developers can just use a node graph to determine how an animation should be played (see Figures 17 and 18); Meanwhile, it allows developers and designers to preview the animation logic.

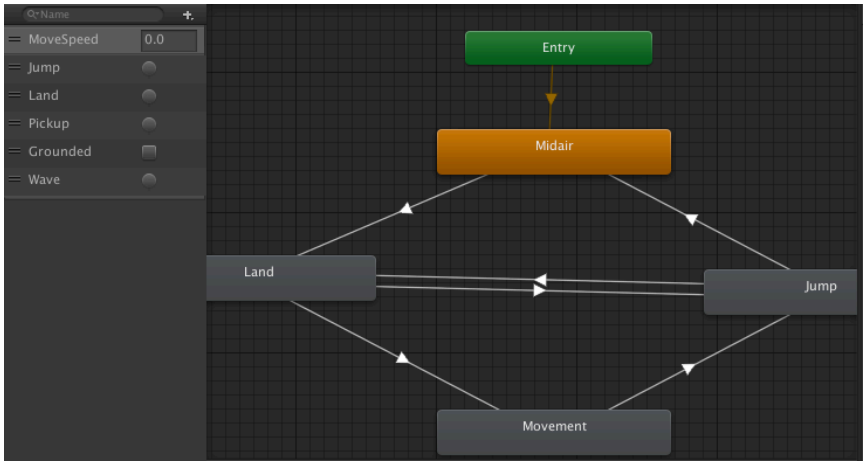

Figure 17. Use node graph for animation logic. Retrieved from Unity3D [Computer software]

Figure 18. Animation preview. Retrieved from Unity3D [Computer software]

3. The flexibility of release targets. As mentioned before, Unity3D allows developers to use one universal code base to output to different build targets such

as Windows, MacOS, Linux, iOS, and Android. Even though the process takes time, the technical barrier to using this feature is incredibly trivial because of Unity.

4. Well documented application programming interfaces (APIs[4]). As a developer myself, I sincerely feel that proper documentation for a development library is the prerequisite to being popular, as it directly affects the learning curve of developers. Personally, Unity3D, amongst all other game engines such as Unreal, Cocoas2D, and Construct 2, has the most detailed and well-structured documentation of its APIs. Ill-documented APIs can confuse developers, thus delaying the speed of development.
5. Mature ecosystem. Being one of the most popular game engines in the world, Unity3D could be described as battle-tested, which also helps its ecosystem to be developed maturely. This ecosystem includes but is not limited to its asset store (both free and charged assets are available such as 3D models, scripts, and widgets), community support (internal forum and stackoverflow[5]), and cloud service (which offers dashboard for analytics and cloud build, namely using a Unity's server to output the game file so as to save time and resource).

However, nothing is perfect, neither is Unity3D:

1. Relatively bigger build size[6]. Unity3D is often criticized for its build size, as it is true that it often has the biggest file size compared to other counterparts. Although

[4] The functionalities and features a library offers, which often hide the low-level complexities behind the scene, thus helping developers interact with the library easily. For example, if a Unity3D developer wants to play audio, the developer can just use AudioSource.play API offered by Unity. However, this piece of API might do a lot more work than it looks. For example, the API will need to interact with hardware to play sound, which the developer does not need to worry about.

[5] A well-known Q&A online community covering various topics including programming

[6] Build size is similar to build target, except that build size refers to the size of the output product.

this problem has been alleviated in the last two years, the minimum build size of it is still larger than others.

2. Closed-source. Another issue developers often complain about Unity3D is its closed-source nature. This means that if there are any bugs in the engine, all developers can do is to report these bugs and wait for Unity to fix them, and the waiting time is not definite. This especially should be a concern for people who hope to develop educational games with original features or mechanisms, as this often means developers will need to create lots of functionalities that are not provided by Unity3D and thus tend to have hidden issues.

Proprietary frameworks. Besides the difference on choices of game engines, there are other technical distinctions worth noticing such as proprietary frameworks (development frameworks developed and maintained by oneself). EcoNauts is using Assessment Data Aggregator for Game Environments (ADAGE) for data collection, which is a framework built for Unity to gather users' in-game logs. As said on ADAGE's website, "By leveraging the Assessment Data Aggregator for Gaming Environments (ADAGE) system, Econauts can remotely log game data. Information regarding player choices and experiences are uploaded and stored so that players, educators, and researchers can examine real-time gameplay in an attempt to evaluate performance and refine techniques" (retrieved from http://www.gameslearningsociety.org/econauts_microsite/). ADAGE is developed and maintained by Game Learning Society. It offers data logging solutions for both the server and client side. The server side is the terminal which processes data accessing requests and data storage, while the client side, in this case, is the game itself, which is responsible for sending the data requests. ADAGE, on the server side, is using Ruby on Rail as the infrastructure, and C# on the client side (for Unity3D). As this is not an open-sourced project, it is hard to give an objective evaluation of using this technology without reviewing its code implementation.

However, the framework's ease of reuse is an advantage. As EcoNauts developers develop this framework themselves, they can customize the framework according to their needs, and reuse this framework in their other projects without much work. Nevertheless, the downside is also apparent, as developing a library could take lots of effort, and there are open sourced projects available and also in good quality. For limited budget projects such as Alien Rescue, this approach might not be ideal.

What pedagogical considerations are these educational games implementing?

Although all four games highlight different pedagogical considerations for game design, such as self-efficacy, designed experience and transformational play, as well as the problem-based learning stressed by Alien Rescue, they overlap with each other: the games are following the guideline to simulate contexts regarding certain types of academic problems, with or without fantasy, so that players can experiment without the fear of failure.

EcoMuve, similar with AR, emphasizes constructivism for its learning design hoping to improve students' self-efficacy. The game itself includes two modules, Pond and Forest. Players are placed in the same environment but with a different game incident and context. Each module is a two-week inquiry-based ecosystems curriculum. The game aims to create an immersive virtual environment for students which "can transform the learning experience by superimposing perceptual overlays on phenomena to support student understanding" (Metcalf, Kamarainen, Tutwiler, Grotzer, & Dede, 2011). In EcoMuve, players need to explore the virtual environment and try out the tools available (such as the camera tool to capture species' description, see Figures 19 and 20) to complete the task, which resonates with AR as we provide ten tools to help students.

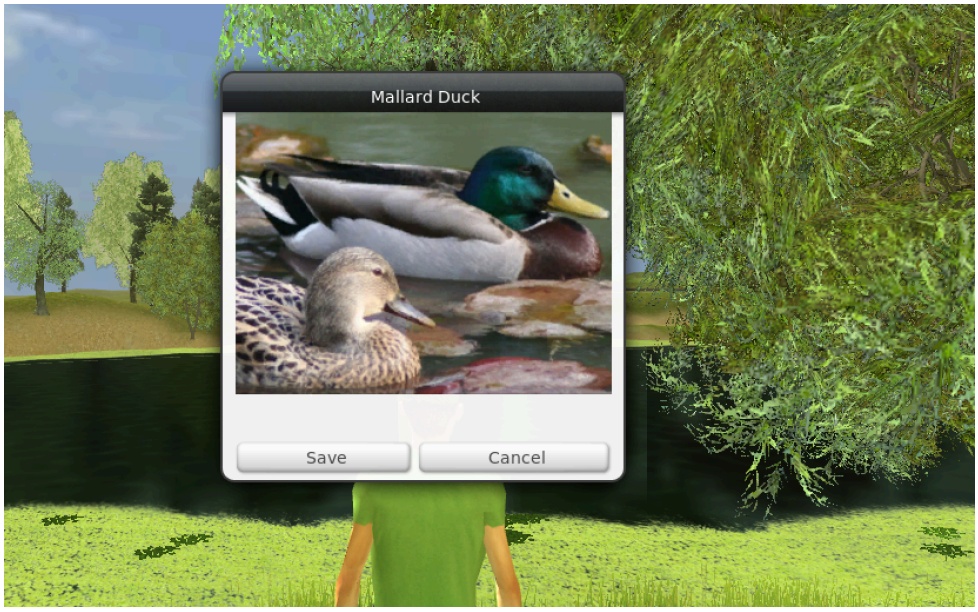

Figure 19. Using the camera tool to learn more about the ecosystem. Retrieved from EcoMuve [Computer software]

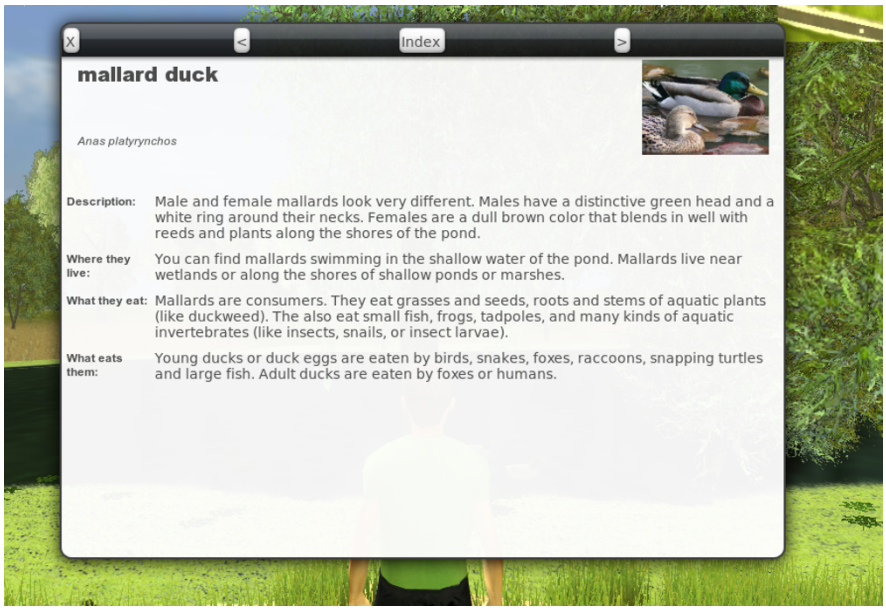

Figure 20. Description of the species captured. Retrieved from EcoMuve [Computer software]

The EcoX series hopes to create a virtual environment that can transform the learning experience by superimposing perceptual overlays on phenomena to support student understanding. EcoNauts and Fair Play hope to design experiences for users that account for how players inhabit them and the mechanisms by which meanings become interpreted from these experiences. Atlantis Remixed hopes players could take on a role of a protagonist that

demands using conceptual understandings to understand and eventually make decisions on problem solving. Finally, Alien Rescue emphasizes a ludic simulation where play is an important mediator for learning, as well as learning stimulation with problem solving.

EcoNauts & Fair Play are following the "designed experience" brought up by Kurt Squire, who is also the leading researcher involved in this game. In EcoNauts, one of the learning objectives is to better understand the environmental science. So, the game was designed to connect the domain knowledge with the gameplay tightly: ignoring the ecosystem could punish the players as the game goes on since a poor decision made on the ecosystem could slow down their process of earning resources, thus losing the game. EcoNauts includes narratives to impart environmental knowledge to the players. An avatar will appear to give instructions for players, and these instructions contain the subject knowledge which could make learning happen. For instance, the avatar will instruct users on how to start construction and where users could construct. This strategy of using a virtual character for narration is prevalent in commercial games, and it often serves as the role for gameplay instruction. For example, the virtual character could help players get familiar with the gaming environment and controls. EcoNauts makes use of this strategy and does not limit this character to just giving instructions on gameplay. In the meantime, the character also introduces knowledge on ecology so that players can learn about the ecosystem through the conversation (see Figure 21). Alien Rescue could learn from this when it comes to a feedback system. We could extend the virtual character we already have, the commander who speaks to the players at the very beginning. Whenever the players visit the mission database or send a probe, this virtual character will pop up and give feedback based on players' action.

Figure 21. An avatar will appear now and then to instruct students what to do. Retrieved from EcoNauts [Computer software]

Atlantis Remixed uses transformational play as its theoretical framework. For example, in the "The Doctor's Cure" chapter, players are transformed into an investigator whose mission is to find out what causes a plague in a village. Players will need to "talk" to different NPCs (non-player characters) to collect evidence, with which they will need to write persuasive arguments for submission.

What game mechanisms are these educational games adopting?

Due to the nature of educational games, which need to address academic subjects through gameplay, role-playing and simulation become the popular choices for game mechanisms. Role-playing could give players a sense of immersion, thus potentially motivating learning, and simulation allows a combination of academic content with virtual experience. All the games mentioned including Alien Rescue have implemented role-playing, simulation or both in their design. However, implementation details and strategies of each game vary.

EcoMuve uses role-playing and simulation as the core game mechanisms. Players are given an avatar to control and asked to gather information on the ecosystem (a pond and

forest in the 3D environment, which have different species) they are placed in, with which they will need to make decisions on what has upset the ecosystem. The ecosystem in the game simulates the one we have in real life, which has been presented with visual representations. “For example, students see the surface of the pond become noticeably greener during the algae bloom” (Metcalf et al., 2011, p. 87). Overall, the game mechanisms used by EcoMuve also coincide with those implemented by Alien Rescue, as players in Alien Rescue are transformed into a space scientist who needs to solve virtual problems that mirror real-world issues. However, differences lie between these two games.

In EcoMuve, the problem is presented more dynamically, as students will see changed environment as the story goes on, which creates a more realistic and immersive context. In the meantime, the learning happens a bit differently. In EcoMuve, students need to collect needed data manually for analysis. Though this collecting process is not exciting, the idea makes the game more interactive and thus potentially more engaging. On the other side, Alien Rescue packages all the required information to several places, and students can view the content directly.

EcoNauts is using strategy, construction, and a metrics system as its game mechanisms. The players will need to deploy resources strategically with systematic thinking and planning. The metrics system serves as the tool to enhance feedback and motivation. All these mechanisms are distinguished from AR’s. For the current design of AR, it might be not applicable to use strategy or construction as the mechanism. However, the metrics system could be researched more to contribute to the AR design. For example, there could be a leaderboard in AR, which ranks students in the same class according to the number of successful probes they have. Or a badge system could be implemented to reward students. For instance, students will get badges when they first open different consoles, and will get rare badges when they use different tools with a high frequency. The leaderboard could also

integrate the badge system, ranking students according to the number of badges they have. The leaderboard and badge system could be used to compensate for the lack of feedback AR currently experiences.

Atlantis Remixed shares the same game mechanisms with Alien Rescue, which are role playing and simulation, but it also merges an adventure mechanic into the gameplay, as players need to explore the virtual environment continuously and collect needed items to help them solve puzzles. The distinctions between Atlantis Remixed and Alien Rescue probably lie in the visual enhancements and scaffolding. Atlantis Remixed tries to immerse players with a highly refined 3D environment and offers a fixed set of "evidence" to help users understand the problem. However, in Alien Rescue, visual appeal though still important is not highly prioritized, and we provide few clues for students. For example, both games require players to write a justification for the solution they found. In Atlantis Remixed, users do not need to actively read lots of information to test a hypothesis, as they will get evidence by talking to different NPCs and then assemble the collected evidence together. Alien Rescue, on the other hand, requires students to proactively seek answers through reading the learning content offered in the game, and come up with a solution by themselves.

Although these differences can not imply any shortcomings of Alien Rescue's game mechanisms, since they are only different ways to implement role-playing and simulation mechanisms. However, these differences do offer ideas for us to the AR team to test. AR could also think about adding more NPCs to the game to extend the exploration allowed for players so that they feel the game is more interactive. In the meantime, since AR relies on fictional concepts such as aliens, allowing players to actually interact with aliens might help them feel more immersive.

Fair Play, similar with Alien Rescue, mainly adopts role-playing and simulation as its game mechanisms. During the game, players act as Jamal, who needs to talk to different

NPCs to proceed. Players will collect needed information throughout the process, and eventually, make decisions. As for simulation, the whole context of the game is the simulated life of a black graduate student, who needs to face mocked implicit biases inspired by real life. In Fair Play, the role-playing mechanic is presented through "interviews" with NPCs, which is quite a common strategy for a role-playing game. However, in Alien Rescue, role playing is not emphasized continuously but only at the beginning of the game (mission statement video). Personally, I think this distinction results in a lack of game narrative in Alien Rescue. Although narrative is not a necessary element in educational games, it does help to provide players with scaffolding without ruining the sense of flow in game. It could also add more enjoyments to the game.

What features do these educational games have? What strengths and weaknesses do the features provided by these educational games have?

All the four games have their highlights. The followings are features for the AR team to consider in making enhancements.

EcoX series has two features:

1. Using a base version for future iterative development. It is previously mentioned that EcoMuve is the infrastructure for three others (EcoMobile, EcoXPT, EcoMOD), and each of these three versions develops something new on top of EcoMuve. I find this approach interesting, as it offers a sandbox for educators to test ideas without deprecating the previous version and devoting much effort in development. Alien Rescue could use this idea and offer a series of versions for schools. For instance, we could have AlienRescue+VR or AlienRescue+Mobile for schools which have the ability to adopt. Although VR devices are still not common in schools nowadays, offering a VR version could be beneficial. For us in the AR team, we could gain more experience with VR, and get better prepared

for future development. It could also expose AR more to schools so that they know they have AR as an option when they want to try virtual reality.

2. Adopting situated learning with the real world. EcoMobile offers a set of course materials for teachers so that they could combine the real world with the game, which is a good example of situated learning. This is enlightening, as I always try to come up with new features we could have within the game, but often ignore what we could extend outside the game. For Alien Rescue, since astronomy is part of the game, maybe we could come up with a way of using augmented reality to teach students about space outside of the game.

Econauts supports educational data mining. As EcoNauts uses ADAGE for user data collection, which also contains a backend solution (the framework could be used on both client side and server side). It is likely that they have an interface for researchers to do data mining work. The strength is it allows researchers to observe the learning effects more efficiently in a quantitative way. The downside is it requires a relatively complex design and development. However, given that the ability to collect users' data is extremely important for researchers, educational game projects should try to implement this feature as much as possible.

Econauts also supports multiplayer. The players are given the option to play the game with others, which could potentially motivate students better since they might want to "beat" others. In Alien Rescue, we could consider allowing students to form groups with limited size, say four people at most, or we could allow teachers to assign groups through the dashboard. Group members will be able to see each other's avatar in the game, and they will work collectively to solve the problems. Some teachers using AR might already use AR as a group project, and adding this feature could make this process more realistic and possibly more attractive. But downsides also exist, since the multiplayer system requires a much more

complex implementation on the server and client, it adds up the engineering difficulty and time. In my opinion, this could be a feature for Alien Rescue if we have the teachers' dashboard completed.

Atlantis Remixed offers a facilitator dashboard for teachers and researchers, which includes the following features: Cohort Builds, Account Creation, Progress Management, Essay Review System, Choice Tracker and Research Analytics (retrieved from https://gamesandimpact.org/transformational-play/). As AR is developing its dashboard, it is a good idea for us the developers to see what other projects offer. The AR dashboard is designed to offer similar features as Atlantis Remixed. However, AR plans to provide more than these, as we also hope to add a real-time feature to the dashboard so teachers could know in timely fashion how their students are doing in the class.

Apart from the dashboard, similar with ecoX, Atlantis Remixed offers different versions (chapters in this case) using the same infrastructure. As this has been discussed previously, I will not repeat what I have suggested here.

Fair Play not only has quests in the game, but also quizzes to test whether players can identify implicit biases and their definition. This system works naturally with its narrative way of gameplay. For Alien Rescue, we could probably connect this quiz feature with the teachers' dashboard: teachers could analyze their students' behavior, and then come up with a quiz according to the analysis so that they could better understand what content students are most confused with. The form of this quiz could be a pop-up dialogue with one of the NPCs, asking the quiz in an inquisitive manner instead of an imperative one, which might motivate students to get more involved.

Content on implicit biases is unlocked gradually in Fair Play, and players can review the content by going to their inventory of biases – the Almanac. In Alien Rescue, however, we give access to all the content directly at the beginning. There is no implication that one is

better than the other, but it does give us an inspiration on how to make AR more fun: we could add a collection mechanism to AR, which could be different for each user. Making all the art assets could be time-consuming, but I believe there are assets licensed with creative commons that we could use for free.

Summary

Table 2 summarizes the distinctions among the four games and Alien Rescue:

Table 2. Comparisons of the four games with regard to Alien Rescue

	Alien Rescue	**EcoMuve**	**EcoNauts**	**Atlantis Remixed**	**Fair Play**
Release Platform	Web	Computer, mobile	Computer	Computer	Computer
Game Engine	Blend4Web	Unity3D	Unity3D	Unity3D	Unity3D
Educators Support	Teachers' manual	Teachers' manual	Dashboard	Dashboard, teachers' manual	Workshop
Pedagogical Considerations	Problem-based learning	Situated learning	Designed experience	Transformational play	Designed experience
Game Mechanisms	Role-playing, simulation	Role-playing, simulation	Strategy, construction, simulation	Adventure, role-playing	Role-playing, simulation
Distinguished Features	Purely web, agile development frameworks	Mobile derivatives, dynamic environment	Multiplayer mode, virtual narrator, dashboard	Dashboard, different storylines using the same infrastructure	In-game quests, gradually unlocked content

Implications

Based upon the analysis, here are a few considerations that AR team could consider for future enhancements:

1. Evaluate the necessity of switching to Unity3D based on future development needs. If Alien Rescue hopes to extend the environment to a more complex dimension, or deploy a more interactive style of gameplay, then we might want to use Unity3D.
2. Continue to prioritize web support, as its cross-platform attribute could make Alien Rescue more scalable.
3. Extend the implementation of current game mechanisms with new features. Even though Alien Rescue will keep current mechanisms, we could think about the possibility of using different ways to deploy these mechanisms: a more situated environment, a virtual commander to give feedback and instructions, more NPCs for exploration and narration purposes, a multiplayer mode for group projects, in-game quizzes that connect with the teachers' dashboard, and more visually appealing elements and animation.
4. Develop derivative versions based on Alien Rescue. Like the ecoX series, Alien Rescue could develop one or multiple "child" version(s), which is/are not limited to a virtual environment, but could also be implemented in the real world. Alien Rescue could use these versions to test ideas, in a way similar to AB testing used broadly in the game industry.

Conclusion

Educational games are digital games designed specifically for education. We educational game developers need to take pedagogy into consideration when designing a game for learning. Otherwise, students will fail to recognize the curricular value in the game. Furthermore, an educational game is still a type of video game, which cannot thrive without attractive game mechanisms. Role-playing and simulation are two commonly used mechanisms for educational games. However, different strategies could be used to improve

the game experience like a similar mechanism would. Finally, game development is also an important factor that we should pay attention to, from release targets, to technical frameworks selection. Using web as the build target is flexible and is suitable for AR's current status, which stresses agile development and the ability to be cross-platform. Unity3D could be a better option as the game engine if AR wants to add more interactive elements to the 3D environment in the future.

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