BioRubeBot: A Multiple Discipline Approach to Capstone Projects in Biology and Computer Science

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Abstract

Here we show that the creation of BioRubeBot is a teaching tool for a Computer Science (CS) capstone project that promotes interdisciplinary learning and team building. In addition, we provide evidence that the CS students are creating an understandable and sticky molecular biology game. The result is a Serious Educational Game (SEG) that has obvious relevancy to the traditional classroom through gameplay based upon common molecular biology motifs. Finally, this game has been tested both formally and semi-formally, strengthening its potential use as a learning tool that can connect school to play and vice versa.

Introduction

In today's 21st century classroom, the traditionalist teaching philosophies, which posit the teacher as the content authority that will impart needed knowledge to the "blank slate" student, is the antithesis of what is essential for modern science students. Instead, science teachers are encouraged to embrace the more inquiry-based and student-centered constructivist philosophy for effective teaching and learning. Historically grounded in the beliefs of John Dewey, Jean Piaget, and Lev Vygotsky, the constructivist theory affirms a holistic idea of learning, where knowledge is gained by meaning making through interaction and association of prior knowledge and experiences. Constructivists consider individuals not as absorbers of disconnected information, but as "constructors" and "re-constructors" of knowledge as they negotiate understanding. In a student-centered, inquiry-based, constructivist science classroom, lessons

ISBN 978-1-60643-379-9

will involve a variety of strategies and techniques. These can include problem-solving, simulations, and various technologies [1]. Consequently, the BioRubeBot (Biology Rube Goldberg Robot) educational game embraces the constructivist approach in the teaching of molecular biology to 21st Century science students.

BioRubeBot is a necessary advancement for molecular biology teaching in a 21st century biology classroom. Traditional molecular biology instruction uses pictures, plain text, and static models for teaching subcellular activities within cells. These immobile representations do not require the user to engage in concept manipulation, nor do they accurately depict the dynamic nature of the cell. BioRubeBot is a Serious Educational Game (SEG) that enhances learning by encouraging the user's ability to visualize and manipulate proteins through time, with text-based definitions accessible at hot-points within the game. In order to develop this game, we are recruiting interested Computer Science (CS) students to participate in an interdisciplinary game development project. Interdisciplinary projects are also an excellent constructivist teaching strategy that can improve retention, increase student satisfaction, improve a student's ability to interact on an interdisciplinary team, and aid in the development of real-world job skills. The primary goal of the BioRubeBot project is to fulfill these needs for CS students while producing an effective molecular biology game.

This paper provides preliminary evidence that we are achieving the three subgoals of this project, which include: (1) expose undergraduate computer science majors to interdisciplinary teamwork, (2) develop a SEG that is an effective classroom learning tool, and (3) engage children aged 8 to 15 years in a molecular biology game that exposes them to protein interactions and terminology. We show that CS students at Athens State University voiced a great deal of engagement and satisfaction with the development of this biology based game. In addition, we provide evidence that their perception of the team often changed over time and they were aware of the delegation of duties. Furthermore, we provide evidence that both the game development and the game itself increased the CS students' awareness of biological concepts, is playable by biology students that are aware of the concepts within the game, and it can engage children aged 8-15 in a semi-structured environment.

Background and Prior Work

The American Time Use Survey [2] notes that 15 to 19-year-old persons spend 52 minutes playing video games or in recreational computer use on weekends. By comparison, the same group spent only 4 minutes reading. Furthermore, Young et al. [3] noted that in 2009, 60% of those in the age range between 8 and 18 were playing video games on an average day. These trends clearly indicate that video games, particularly on mobile devices, are an opportunity for informal STEM (Science, Technology, Engineering, and Mathematics) learning. Despite interest in this area, few examples of such games can be found in the application stores for mobile device platforms.

Within the games that can be found, content knowledge is primarily found in the storyline [4]. The result is TL;DR (too long; didn't read) syndrome. This is because the typical game player is more interested in the game play, rather than spending extensive time reading information provided in the storyline. Players will gloss over written content, especially when it contains information that is difficult to understand or irrelevant to gameplay [5], [6]. Furthermore, in educational games that, for example, have a first person shooter style, gameplay rules typically have little relevancy to developing STEM problem-solving skills [7] - [9]. The result is that the player feels the game is a bit like "Chocolate covered broccoli" [7] and the reality becomes that it is possible for the player to proceed through games by 'button mashing' [9] without using critical thinking skills.

While the biological concepts and terminology described here as being used in BioRubeBot gameplay may seem advanced for users aged 8-15, J.P. Gee [10] argues that, if a child is able to understand the complex, fantastical terminology in games such as YuGiOh, why not technical terminology that is relevant to future learning? A smattering of research supports this argument in the context of a classroom [6], but little analysis has been performed in an informal setting where a lesson plan is not provided. We expect that, with an appropriately paced tutorial, players in this age range should be fully capable of mastering game rules regardless of the terms used. Furthermore, the use of invented terms may create an unnecessary barrier for future learning, as students are required to 'forget' game terminology and relearn the correct terminology [11].

Flow

In order to develop an effective molecular biology learning game, we are basing our game design on three basic game development principles: flow, stickiness, and sandboxing. *Flow* is defined as the state of deep absorption that is intrinsically enjoyable [12]. In game play, a player experiencing a flow state is deeply focused upon the game play and unconsciously loses awareness of the world. M. Csikzentmihalyi suggests three conditions required to achieve a state of flow [13]: (1) one must be involved in an activity with a clear set of goals and progress, (2) the task at hand must have clear and immediate feedback, and (3) one must have an effective balance between the perceived challenges of the task and their own perceived skills. Establishing these conditions in game play fosters an enjoyable experience that motivates the player to continue to play the game. A motivated player in a state of flow is in a state of concentration and eagerness that places them into a state that aids in the learning process. [14]

In terms of game play, achieving flow imposes four requirements on game design [14]: clear tasks, feedback, balanced and attainable goals, and concentration. A game with *clear tasks* must have clear and easily understandable goals. At the same time, *feedback* must be provided to the player so that she or he can determine whether or not game choices are progressing towards game goals. It is also important that these goals are *balanced and attainable*: game play must be challenging but not unachievable or overly long. Finally, *concentration* means that game play must focus the player on the game and avoid distracting the player from important in-game tasks.

In order to insure that a game achieves these four requirements, it is essential that the game be tested by the target audience.

Stickiness

Consider physics-based puzzle games such as Angry Birds and The Incredible Machine (Figure 1). These games provide a series of simple rules that, on their own, are clear and attainable. Then, as rules are added, the game difficulty increases, leading to concentration. The result is a game that has what is termed *stickiness*: a form of psychological dependence behavior that leads a person to return to an activity. When it comes to game design, this leads to continued game play over time [15]. Sticky games exhibit greater engagement on the part of the player [16] and from greater engagement comes more opportunities for learning experiences.

Sandboxes

Sandbox levels, on the other hand, provide players with a level beyond a structured, goal-driven environment. It is important to provide a censure free space in educational games because, while learning through failure from increasingly difficult challenges is an advantage that games provide, failure can also be intimidating [17]. This is an important aspect of learning, maintaining flow, and sticky game design that current mobile, molecular biology SEGs fail to fill [4]. Along these lines, the sandbox has multiple benefits: it is important for (i) the retention of players who are uncomfortable with failure [18], (ii) encouraging advanced users to independently explore difficult concepts, and (iii) a teacher who wishes to adapt the game to the classroom [10]. Both fear of failure and boredom interrupt a state of flow [19], [20]. A sandbox level allows a weak player to engage with the game freely, creatively, and without fear [21], [22]. It also provides an opportunity for a strong player to explore when the normal levels become too rote. Finally, for BioRubeBot to be used as a link between play and school, it is important that the game be easy to implement in the dynamic nature of the classroom. The less adaptable a material, the less likely a teacher will be able to use it effectively in his or her classroom [17], [23], [24]. The sandbox will allow teachers to adapt BioRubeBot as a teaching tool for different textbooks and peer-reviewed literature.

Game Design

BioRubeBot is designed so that learning occurs through problem-based gameplay that is constructed upon principles of sub-cellular protein interactions. This has been accomplished in much the same way that physics puzzle games such as The Incredible Machine or Mouse Trap utilize the rules of physics on common objects to solve puzzles. Figure 1 shows a screen shot of an example of this type of problem solving gameplay from The Incredible Machine. The different props – pipes, treadmills, light switches, mice, and dynamite – interact with each other using representations of the rules of physics such as those for gravity, springs, levers, treadmills, bomb explosions, etc. The user places the props in the game field so that the props solve the puzzle through their interactions after the user selects the "Start" button. As the player progresses, they must solve increasingly complex puzzles.

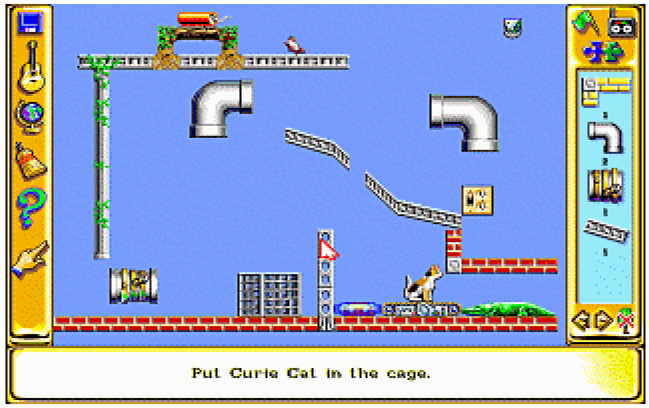

Figure 1: Screen shot of ***The Incredible Machine*** *[25]*

In an introductory cell biology course, protein interactions are often simplified, as represented by the figure from a current cell biology textbook shown in Figure 2. This figure is typical for a cell textbook and it provides a few examples of proteins that are included in larger categories of proteins, such as: kinases, g-proteins, and transcription regulators. Current textbooks support the constructivist pedagogy that learning simple, generic rules about categories of proteins provides the student with a scaffold for learning about additional, more complex interactions. In our first stage of BioRubeBot, we have chosen to represent a biological process called a cell signaling cascade that is typically taught in a cell biology classroom. In a stereotypical signaling cascade, information outside of the cell is transferred to the inside of the nucleus. A CS student generated storyboard for this process can be seen in Figure 3. The set of terms and their definitions that are introduced to the user in the first five levels of BioRubeBot are as follows:

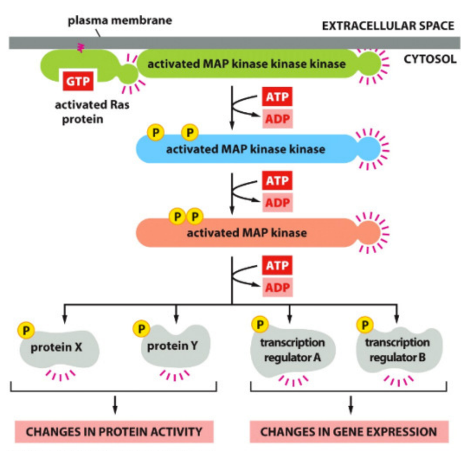

Figure 2: A generic MAPK signaling pathway from a popular textbook, Essential Cell Biology [26].

1. **ATP** (Adenosine Triphosphate): ATP has three phosphates. It can turn an object on by transferring one of these phosphates onto it, but it needs a kinase to help it.
2. **Cell Membrane and Nucleus**: Cell membranes define a cell by keeping the insides in and the outside out! The nucleus is one of many compartments inside of a cell. It holds DNA.
3. **GDP** (Guanosine Diphosphate): GDP has two phosphates. It has to be replaced by GTP for some proteins to work.
4. **G-Protein** (Guanine Nucleotide-Binding Protein): G-proteins bind GTP and GDP, but only one at a time!
5. **GTP** (Guanosine triphosphate): GTP is a lot like ATP. It has three phosphates and can lose one of them, but tends not to transfer that phosphate onto the protein.
6. **Kinase**: Kinases can transfer phosphates from ATP onto proteins.
7. **Nuclear Pore Complex**: Nuclear pore complexes allow for entry into and exit from the nucleus.
8. **Phosphate**: Phosphates are easy to transfer from one place to another, if you have things in their correct places!
9. **Receptor**: Receptors communicate signals between the cell and the outside world.
10. **Signaling Molecule**: Signaling molecules bind to receptors and can activate them.
11. **Transcription Regulator**: Transcription Regulators can turn on DNA transcription.

In the interest of content knowledge transferability, it is desirable that the storyboard closely mimic textbook representations of proteins. This results in game piece design that is limited by predetermined canon. For example, most first person shooters use the highly recognizable image of a gun to indicate to the player that they are able to shoot. Likewise, scientific illustrators tend to represent phosphates, very simply, as a ball (Figure 2 & 3). If our desire is to help game players understand static diagrams of protein interactions in textbooks, then it is important to use game pieces that mimic scientific illustrations. However, in the interest of designing an engaging game, object movements are being designed with unique approximations of the random motion seen in molecular movement. For instance, representations of ATP swim around the screen like tadpoles while extracellular ligands swing in extravagant arcing motions. As one CS student noted during the development process, if we developed a game that used true random movement, the game pieces would potential never come together.

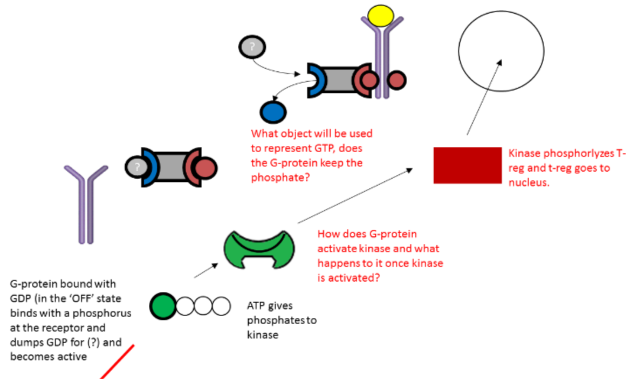

Figure 3: A CS student's workflow for protein interactions in BioRubeBot.

In order to induce feelings of flow in the player, the levels in BioRubeBot quickly become more difficult as game pieces are added, much in the same way as the game Angry Birds progresses. For instance, the first level introduces the idea of a signaling molecule activating a receptor. In the next level, players have to combine their new knowledge of receptor activation with the idea of phosphorylation. Notably, these five levels are produced from the assembly of just one simplified protein-signaling cascade. By adding proteins and changes to protein interactions we have, as one CS student noted, nearly limitless possibilities for the development of higher game levels that can incorporate the multiplicative effects of protein signaling cascades working synergistically and/or antagonistically.

In order to allow for repeated and unique capstone projects, we are developing a start screen where additional levels, such as those described above, can be added. Figure 4 shows the BioRubeBot start screen to the left and to the right is the main screen for the "Free Play Level" referenced on the start screen. Tapping the "Free Play Level" button places the player into the sandbox level, where they can experiment with the different proteins and small molecules to test different solutions. Currently, each regular level introduces a new puzzle and begins at the same main screen as the sandbox with different objects displayed. At this point, the player can then attempt to solve the puzzle by placing the game pieces in and around the cell. The player's potential solution is tested when they select the play button in the main screen. If the objects interact correctly, a reward screen appears and asks if the player would like to continue.

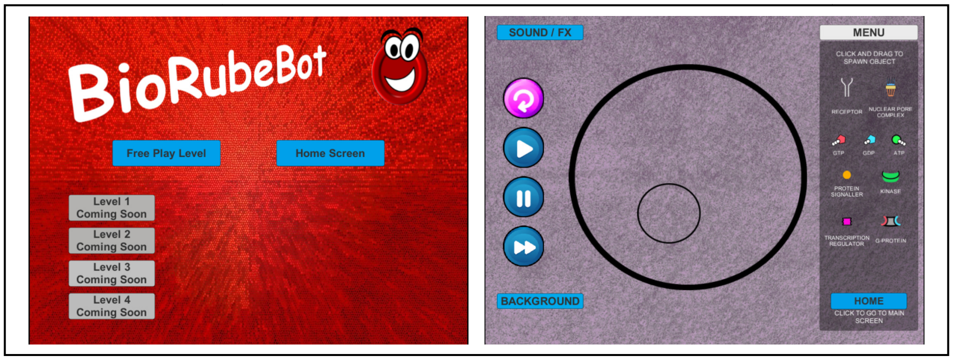

Figure 4: BioRubeBot start screen and main screen.

Methods

Three student teams from Athens State University's CS452 (Senior Software Engineering Project) course have participated in the development of BioRubeBot as of Fall 2015. This course is the capstone project experience for these students and is organized into self-managed teams that operate using principles of agile management and development.

CS Interviews

Student participants from the Athens State University's CS452 class were asked if they would be willing to take part in an interview related to educational research and were reassured that the

Table 1: STEM Preparation of Student Participants

College Level Natural Science	Spring 2015	Summer 2015	Fall 2015
Introductory Biology I	2	1	0
Introductory Biology II	2	0	0
Astronomy	1	0	0
Physics I	1	1	2
Physics II	1	0	1
Non-Major's Chemistry I	2	2	1
Non-Major's Chemistry II	2	0	1
Physical Science	0	1	1
Environmental Science	0	1	1

interview would have no impact on their final grade. The majority of the interviews were conducted prior to their final presentation for their CS452 class, although one took place afterward. The interviews lasted from 9 - 26 minutes, with the mean time being 15 minutes. At standard four year institutions, five would be considered non-traditional students and four would be considered traditional. All were senior CS majors in their ultimate or penultimate semester at

Athens State University. The number and types of courses that the students self-reported as having taken to fulfill their natural science lab requirements varied widely (*Table 1*).

During the first interview in the Spring of 2015, the students were asked the following directive questions:

1) What classes have you taken in biology/science? Did you find that you applied the knowledge from these courses in designing this game?
2) What kinds of things did you do to help you better understand the biology content?
3) Do you feel confident in your ability to accurately design the game without knowing biology?
4) Are there differences in your approaches to learning the biology content of the game versus presenting the biology content in a way that would lead to learning? I.e. having correct content in the game vs. presenting the content to students.
5) Can you describe how you converted the biology concepts into executable code? How did this affect your understanding of those biology concepts?

In addition, each interview was initiated and concluded with a non-directive question: *we can start with - what you think of this project?* and ended with *Do you have anything else you wanted to add?* After formative evaluation following the Spring 2015 group, Question #3 was changed from "Do you feel confident in your ability…" to "How did you feel about your ability…" in order to avoid the interviewee being biased by the phrasing of the question. In addition, the following directive questions were included in Summer 2015 and Fall 2015:

6) What was your role in the project?
7) How did you feel about the group dynamics?

Biology Gameplay Interviews

The first beta test was completed on Version 1 with three randomly recruited Athens State senior biology students during the Summer of 2015. Students were asked to sign an informed consent and given no instructions on gameplay. As they explored the application for the first time, they were audio-recorded while they verbally described what they were doing. The educational backgrounds of the participants included one non-traditional student and two traditional students. The time since they had learned about cell signaling in a formal cell biology classroom ranged from 1-2 years.

YEA Gameplay observations

Observations of children interacting with Version 4 of BioRubeBot occurred in a semi-controlled environment on 04/09/2016 during the 2016 Athens-Limestone County (AL) Youth Education and Awareness (Y.E.A.) Conference. Attendees included families of all ages asked to sign a disclosure form upon participating. iPads were placed out on a table and the observer sat behind the table. Children were allowed to approach the table without observer engagement. Children then either engaged the observer by asking to play, asking to color, or were asked by the observer if they wanted to play. No one was cajoled to play, the question was asked only once. If children said they wanted to color, they were allowed to color. If they then decided they wanted to play, they were allowed to play. The amount of time that the children engaged with the game was noted and, because of the variable nature of the engagement, those times were rounded up or down to the nearest whole minute. Their gender, as perceived by the observer, was also noted. In addition, observations were made regarding whether or not the player triggered the congratulations screen 0, 1, or multiple times and if the child engaged in goal driven gameplay or not.

Results and Discussion

CS Interviews - Student Interest

Every CS student interviewed described the project as fun or enjoyable at some point during the interview. In addition, when asked question #3 above, they generally noted something along the lines of: *"My ability to code it, yes. ... and my ability to mathematically model it, yes. My ability to understand the actual things that these objects are supposed to be doing together, probably not so much."* Also some students did voice some concerns about the steep learning curve involved with learning the computing tools used to create BioRubeBot, for example: *"If I could get a better grip on the coding side of things, yes, I think I could do – […] I could probably offer a little more to the functionality of the success of the team."* This comment also reflects an opinion voiced by several of the team members which was they felt that, at the end of the semester, they were now in a position to work in a more effective manner. They also voiced the opinion that, from their perspective, the project was an effective learning experience: "*I learned a lot and uh it was fun to actually get in there and learn the Unity engine and the gaming aspect as well as the biology part."* and *"As a, someone who aspires to be a game programmer, I enjoy the – learning how to work with different objects and tools such as Unity, its – because its one of the major platforms among the frostbite engine and a bunch of others that are in modern use."*

CS Interviews - Group Dynamics

At times, some of the students mentioned team member task allocation, solving group dynamic issues, and awareness of their biology contact's essential role in the project. Nearly every student mentioned the fact that having a biology expert involved in the team was essential for the project. On the other hand, group dynamics varied greatly from semester to semester. An example of task allocation is described by this student: *"I guess I was one of the, guess me and [another student] were basically the developers and - So I kind of went on my own and did the - Some of the aspects that you wanted in the program on the coding side of it."* Meanwhile, a student from a different group noted how the group had to change the way it was functioning in order to obtain their goals: *"…once you realize the limits of the group then you start taking your own initiative as to what you need to do to better the group and so at that point in time, you know, I started like 'Alright. I've got to start watching more videos; I've got to start reading…'"*

CS Interviews - CS and Biology

This last quote reflects the fact that having access to a biology professor did not stop most of the participants from accessing additional information about the topic. Very few of the students had taken biology as their natural science elective, tending more towards physics and chemistry (*Table 1*). Therefore, they reported independent investigation of both general audience information, and, more rarely, peer reviewed scientific literature to enhance their understanding of the biological interactions. Some examples are YouTube Videos, Google Image Search, and various websites, including references found in the EBSCOhost (Elton B. Stephens Co.) online research databases. As a result, some CS students displayed an excellent grasp of biology vocabulary usage. For example, (Interviewer comments are bracketed.) *"I'd just research online after I learned the signaling process. I looked it up and a lot of the - I noticed that there was research going on for the cancer and how that may play a role in it and there's actually some other studies going on that, things like Parkinson's, that I believe they help. Things of that nature. But trying to understand it, it was, it's not something that's simple. It is very complex. Learning the different molecules… I know there's proteins and you've got… I don't know ATP and ADP, I don't know what the A stands for, but I'm guessing its triphosphate and diphosphate. {Yes, good.} And the GTP and GDP are nucleotides. Don't ask me what those are, but I know they're not proteins."*

CS Interviews - Long Term Engagement

As further evidence of their engagement with game design, participants displayed an intense interest in future directions. For instance, one student told the interviewer: *"I think the project is probably- after seeing what everyone else was doing I think this was by far the most important project we had. [...] how far I believe that it would be the sky's the limit on what you want to do."* Other comments related to future game development included more practical concerns, such as *"the extracellular proteins would kind of float around, they were like – like they were on speed or something or where they would just like, you know, shake and - It was affecting the rest of the program but it looked right, but then we had to make a functional change where […] you* *know, it looked odd. You know that was something that we couldn't do from a time standpoint, but that was something I would have corrected if I had been given more time."*

Biology Student Recorded Gameplay

All biology students involved in early testing were able to recognize relevant components of the game. It took them, on average, approximately 10 minutes to solve the puzzle. An example of a biology student describing gameplay demonstrates that the pieces were recognizable and that protein interactions were logical: *"I'm putting the ATP, the G-protein, the kinase, GTP, I mean GDP, and I'm putting the […] GTP and transcription regulator all within the cell membrane. […] And it's outside of the nucleus and now I'm going to hit play. So the signal protein comes. There's a conformational change, is that what it is? And now we're waiting for this. Oh so you can actually put more stuff in there to increase the likelihood of something attaching to the binding site. Just like a real cell. And then the cell wall actually contains everything. Yeah, this is cool! Now I get it! Nah, this is really cool. This'll help a lot. With uh, actually seeing how things really work with a bunch of random garble floating around and then they happen to attach in it bouncing around. The movement's clearly got that shaky, is that Brownian motion? I like it. […]"*

Brownian motion

The quote above also reveals an unexpected result from both the biology interviews and the CS interviews: the repeated theme of Brownian motion. In addition to the biology students noting the relevance of this type of random molecular motion to their understanding of protein interactions, the CS students seemed to agonize over this aspect of the game during their interviews. One of the more extreme examples of this type of considerations is shown below as a student discusses the movement of ATP. The tail is referring to the phosphates on the ATP: *"… and that's fine but for instance, when we got the game it was really erratic. You know the tail was like this and just going crazy. So I made it to where it would be very smooth and fluid it looked more like a living organism rather than - It's kinda an erratic object. If you generate an object. But then I started thinking. Is that really what it looks like, Should it be more like the other, should it be more erratic, or…"*

This concern on the part of the CS students is obvious upon reflection of the investigators: the majority of the coding requires the students to make the objects move. Therefore, the question for the coder becomes: how does a protein move? When the students realize that the answer to this question is that proteins move randomly, they are left with the technical hurdle of designing a game where the pieces appear to move randomly and yet still come into contact with one another. Over time, they have developed several solutions and improvements to this problem. One student describes the math involved in coding the general movement of ATP: *"…it moves randomly, it varies in speed and direction. I actually had to plot a path around the nucleus, like if the Receptors over here, the nucleus is here and the ATP's here, then it can't get to the - to the receptor. I had to make it to where it would ray cast here, detect the nucleus, and then plot a* *path around the nucleus, and then calculate the vector from the ATP to the receptor leg. And then, when it gets here, calculates the incident angle between the receptor and the ATP so it knows how far to rotate."*

The movement of the objects also tied in with their desire for improving the game and future challenges. For instance, one student lamented the approach that former students had adopted, noting that it will cause future problems for the movement of two interacting objects: *"because C# doesn't have the concept of pointers […] you can't keep an aesthetic reference to a variable in memory. You're creating a copy, for the most part, […] and so, if you keep referencing this copy, but the original is changing, it becomes a problem when you're trying to dynamically go to where an object is. So when we get around to having objects actually moving while they are trying to interact, this will become a problem because they'll be referencing a copy of the original that was over here, but the original is actually moving towards another location. So it's going to be a problem once we get to that point, but we haven't actually had any objects that are moving while interacting, so that will be something for the next semester, I think."*

Another major theme in the student's concerns was improving the visual aspects of the game piece movement. This student also described improving the movement code of ATP: *"The code that was generated before, it was - was very static, it was - like for instance the ATP. It would just flip flip-flip-flip-flip. And what they were doing is they're just randomly generating a number telling it to move that far, move that far, move that far, and they were doing it all the time so it just - it didn't look - to me it just looked like it was freaking out all the time. What we did is we're like: OK, nothing looks like that. You know, all the things we saw online. Everything's very smooth. So we tried to give algorithms that would not be, uh, the ranges were smaller, the movements, so they couldn't do a one-eighty just like that, it would have to slowly turn itself."*

YEA Conference Observations

Conference attendees who solved the game averaged twelve minutes of playtime with BioRubeBot, which is comparable to the time that biology students required for solving the game. Notably, this average does not include individuals that did not solve the game nor does it account for the amount of time that individuals who played the game multiple times took to solve the game the first time. Furthermore, there appears to be no perceived gender disparity among the number of players, the amount of time played, or number of times the player solved the puzzle (*Table 2*). One interesting difference that may even out as more participants are observed was that two of the female participants appeared to be more interested in 'decorating' the cell in a non-goal directed engagement with the game, rather than solving the puzzle.

Table 2: Play times and Solve Rates for Perceived Gender

Males	Minutes Played	Average Minutes
Did not solve	3	
	2	2.5
Solved	7	
	5	6
Solved multiple	26	
	13	19.5

Females	Minutes Played	Average Minutes
Did not solve	11	
	3	7
Solved	6	
	4	
	20	10
Solved multiple	10	
	20	15

Mean	9.3
Median	6.0
Mode	N/A
Range	2 to 26

Mean	10.6
Median	10.0
Mode	20
Range	3 to 20

Preliminary Evidence for Informal Learning and Game Stickiness

Throughout the interview and observational processes involved with testing preliminary versions of this game, participants have volunteered information related to sharing the game with family and friends. For instance, one CS student developer noted: "*I work with someone who his first degree was in biology and I was explaining the project and he just got excited. He started talking about all these concepts. I'm like, yes, exactly, that's what we're trying to do. It was really neat. […] I think it's a great thing.*" Furthermore, informal discussions with beta testers led to one nontraditional student noting that he suspected his son would figure out the game faster than he would. Perhaps most encouraging was the fact that Y.E.A. conference participants asked if it were possible to download the game to their personal devices. All of these comments indicate that the Athens State University researchers and developers have created a sticky product that students want to share.

Conclusions

Here we have shown that our team has successfully built a cell biology game that is understood by biology undergraduates who have already had a course in cell biology, indicating that the biological concepts in the game are taught in a general cell biology course. In addition, we have demonstrated game stickiness, since both males and females between the ages of 8 and 16 will, on average, engage with BioRubeBot as long as undergraduate biology students. Furthermore, one out of thirteen young participants actively used advanced biology terminology, indicating that the technical terminology was not a barrier to gameplay. While the sample size is small, this still suggests a potential future success rate of 5-10% for biology vocabulary learning in truant students using an app in an informal environment. Finally, we have supported evidence in the literature showing that sandbox levels are important in the production of a sticky molecular biology game, as the participants engaged with the game in both goal directed and non-goal directed ways.

We also demonstrated that BioRubeBot game development as a CS capstone project worked to encourage students to integrate computer science concepts with concepts from a new subject area. The CS students demonstrated engagement with the project by seeking out additional information, voiced enjoyment of the project, and displayed awareness of the project's future development. They also demonstrated their ability to problem solve a solution to a novel problem, that of how to ensure that the game remained educational by coding proteins to move as if they were randomly floating in a cellular environment without losing the stickiness of gameplay. This indicates that the BioRubeBot project provides an opportunity for CS students to learn the skill of integrating computer science and new subject areas, an important aspect for capstone courses, since it helps the student transition to the continuous learning mindset required for software developers in industry [28].

From here, our next step is to test for learning gains in a formal classroom environment. In addition, we plan to help our CS students continue developing the game, focusing on wider dissemination of this product through mobile gaming stores and building the infrastructure to encourage other CS and biology departments to adopt BioRubeBot game level development and classroom utilization.

Acknowledgements

The authors thank the students of Athens State University's CS452 (Senior Software Engineering Project) and colleague Prof. Katia Mayfield for their effort and assistance in building the initial version of BioRubeBot. We also thank Dr. Quanda Stevenson of Athens State University's Criminal Justice program and the K-12 student participants in the 2016 YEA Conference for their assistance in the beta testing of BioRubeBot.

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