Antibiotic Apprentice

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Game Overview

Antibiotic Apprentice is a digital role playing game (RPG) designed for medical students and intended to support memorization of appropriate antibiotic therapies for infection by a known causative agent. The player takes on the role of Logan, an apprentice disease-fighting warrior recruited by the King to help rid the countryside of rampaging disease monsters.

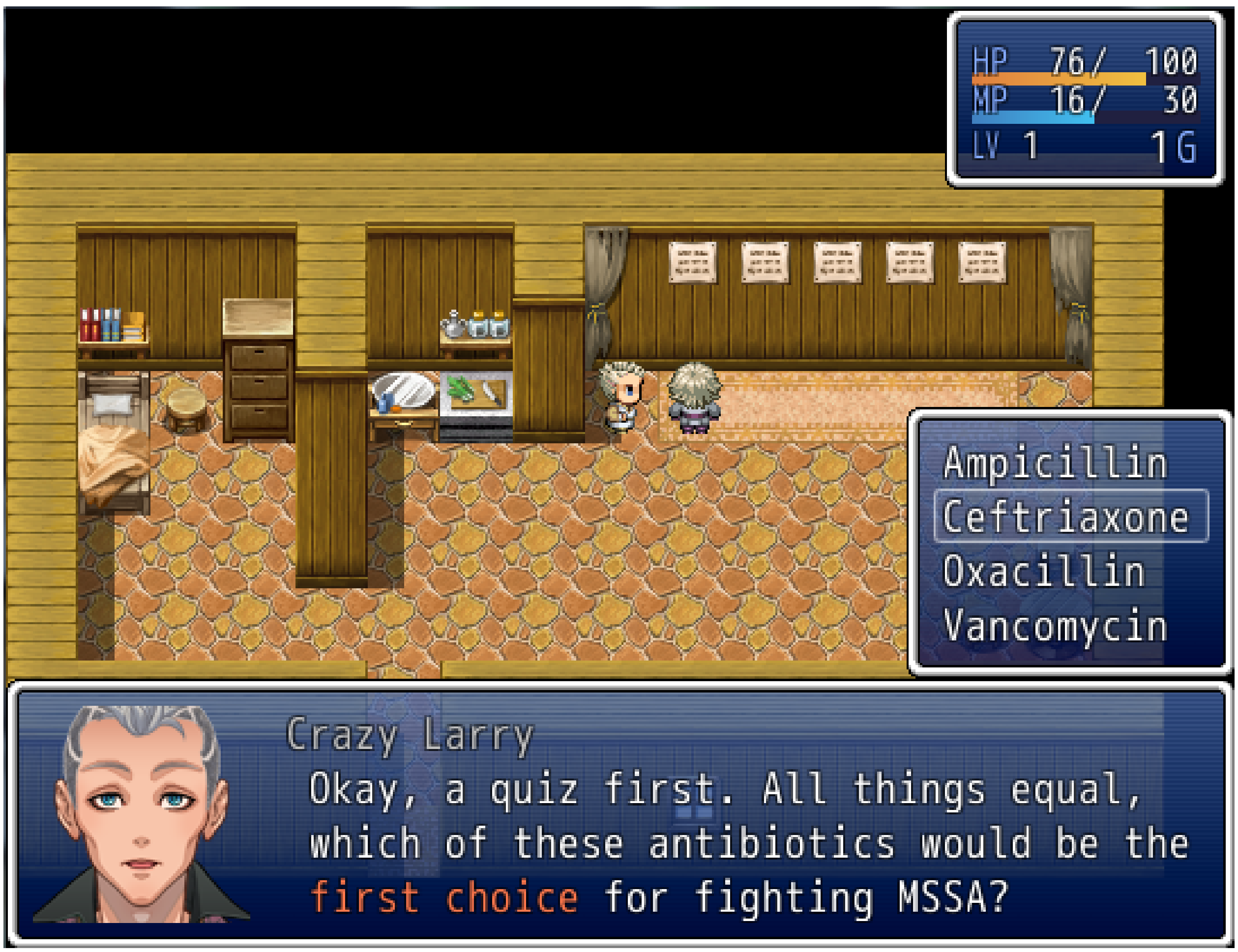
Narrative and fantasy are key aesthetics in our game. We have created a storyline in which our young apprentice, Logan, is given a mission by the King to save the outlying villages which have been devastated by the appearance of terrible monsters.

While Logan's primary job is to slay monsters (and gain experience points) by using his arsenal of antibiotics, he also has the opportunity to interact with the people of the village, and may uncover clues that point to a sinister plot at the center of the story. The most important of these interactions are automatically initiated to guide players through the narrative while other interactions are optional. During game play we noted that many players spent significant time wandering about the village, interacting with people and searching for treasure. During this time, they were frequently caught off-guard by horrible monsters that would appear and attack them. When players knew how to fight these enemies, they would do so and gain experience and collect loot. If players were unsure, they would sometimes experiment with a couple options, but would escape after repeated failure to kill the monster. Likewise, if a player knew how to attack a certain bug, but did not have the appropriate antibiotic, she also generally chose to escape rather than experiment with non-optimal antibiotics. Because we did not want players to lose the game because of lack of knowledge, we always allowed escape from monsters without penalty. However, in order to advance in the game, one must accumulate experience points, which only come from fighting monsters.

Examples of required (above) and optional interactions with NPCs in Antibiotic Apprentice.

Challenge is another essential aesthetic, largely implemented in the combat mechanic of the game. Players must select the appropriate antibiotic therapy given a particular enemy; while several drugs are acceptable, not all are first-line treatments, and so will be less effective against their target (they deal fewer damage points). Because players have many different choices for antibiotics (and a limited supply of each), and an array of different enemies, they must make their selections carefully. Poor choices will result in wasted antibiotics, and give the enemies the opportunity to deal a blow to the player. Abuse of the broadest spectrum antibiotics is discouraged by making these drugs costly to purchase (in terms of gold points), as well as costly to use (in terms of MP or "medicine power").

Because our players are learners of this material and not experts, we also created a more controlled training scenario in which to practice their knowledge. In these scenarios, they can check their knowledge with an NPC villager, Crazy Larry, before engaging in a battle. Furthermore, Larry provides them with extra antibiotics to use, so they do not need to deplete their own personal stash. Playtesters who were initially less comfortable with the material found these training scenarios compelling and were more confident fighting monsters "in the field" after they had gone through these structured scenarios.



Finally, players experience the aesthetic of discovery, as they travel the world to new lands.

At the end of each level and each zone, players also learn new and more powerful skills, providing a motivation to level up.

Cognitive Task Analysis

We conducted three different versions of cognitive task analysis: an interview, a think aloud protocol, and a very simple difficulty factors assessment (effectively a short quiz). Because we have little to no content area expertise, we first needed to determine how experts structure and use their knowledge. To this end, we first spoke to Dr. Peter Veldkamp, a medical doctor and professor of infectious disease at the University of Pittsburgh School of Medicine. We sat down with him to learn about how drugs and bugs are organized, other possible learning objectives we might consider, and where students frequently had difficulty. For additional qualitative data, we conducted a think-aloud protocol with Dr. Michael Huijon, a 2nd year resident at UPMC using step 1 review questions.

In short, we learned that while there are many ways in which drugs and bugs are organized, these organizational schemes are often not useful for remembering mappings between infectious agents and appropriate treatments. The classes of bugs and drugs are, first of all, organized in different ways and do not map neatly onto one another. Dr. Veldkamp explains:

> *Austin: And where does that grouping come from? It is just based on which bacteria, or....?*
>
> *Veldkamp: No, the grouping of the antibiotics is purely pharmacological chemistry. And then the class of antibiotics is chemically somewhat related to each other and because of the chemical structure, they tend to be a little bit more active against some of these bugs more than others. But when they figured out the names and the structure, they did not link them any way shape or form to the bacteria. The bacteria were classified on sort of morphological criteria and now genetic analysis. That's why it's so hard to memorize, because it doesn't make any sense.*

While there is organization within classes of antibiotics and within classes of bacteria, there seemed to be little linking the two. For example, we probed as to antibiotic modes of action and bacterial morphology, but found that these clustering schemes had limited utility in the face of many exceptions to the rules:

> *Pavelko: Could you tell us which of these drugs has which mode of action, if it breaks down easily like that?*
>
> *Veldkamp: I can, it's just that the mode of action will not always predict which to use for bugs. I think you can deviate and make it almost more difficult.*
>
> *Pavelko: Is the morphology relevant to how the antibiotics attack these bacteria?*
>
> *Veldkamp: Yeah, some of them but not all. The gram-positive and gram-negative separation is based on cell wall, so antibiotics that are cell wall disruptors, you can*

derive that they are more or less active. But then, a lot of the other antibiotics are not really related to being gram-positive or gram-negative from a cell wall point of view.

Dr. Veldkamp was able to identify a few general rules for us. For example:

Veldkamp: The rough outline is that the first generations [cephalosporins] are good for gram-positives and the later generations are better for the gram-negatives.

We then saw evidence that Dr. Huijon made use of this very rule in his response to think-aloud question #9:

Listeria monocytogenes. And I know that because...why do I know that? Because Listeria is a gram positive rod and third generation cephalosporins wouldn't cover that.

We also saw that clusters within antibiotics were useful in helping to determine which drugs would be inappropriate given a potential for allergic reaction (Dr. Huijon, Q. #3):

So, if you're allergic to amox, that's a penicillin derivative, so you wouldn't use penicillin and you wouldn't use a cephalosporin because there's cross-reactivity.

However, we also saw evidence that information is memorized in a rather "brute force" manner or comes from experience with little to no sense-making involved:

Huijon (Q. #8): That's doxy. <<How do you know that?>> 'Cause I just know it. Because I treat a lot of gonorrhea and I know that that is the one.

Huijon (Q. #1 in syllabus): D, vancomycin. I know this because we're covering MRSA.

This technique may be necessary due to the history of antibiotic treatment. The most effective antibiotics are often widely used and hence are often precisely the drugs that are later rendered ineffective due to resistance. Pseudomonas, for example, is a bug that was identified as important by Dr. Veldkamp, and which students taking our quiz found very difficult. This bug is susceptible to certain antibiotic therapies, but there is no sensible pattern for students to follow. Exceptions due to resistant strains (and other reasons) render the rules virtually useless. To illustrate, these are three classes of drugs used to treat pseudomonas, and in parentheses are particular antibiotics within each class that can and cannot be used:

- aminoglycosides (gentamicin, amikacin, tobramycin, but *not* kanamycin)
- quinolones (ciprofloxacin, levofloxacin, but *not* moxifloxacin)
- carbapenems (meropenem, imipenem, doripenem, but *not* ertapenem)

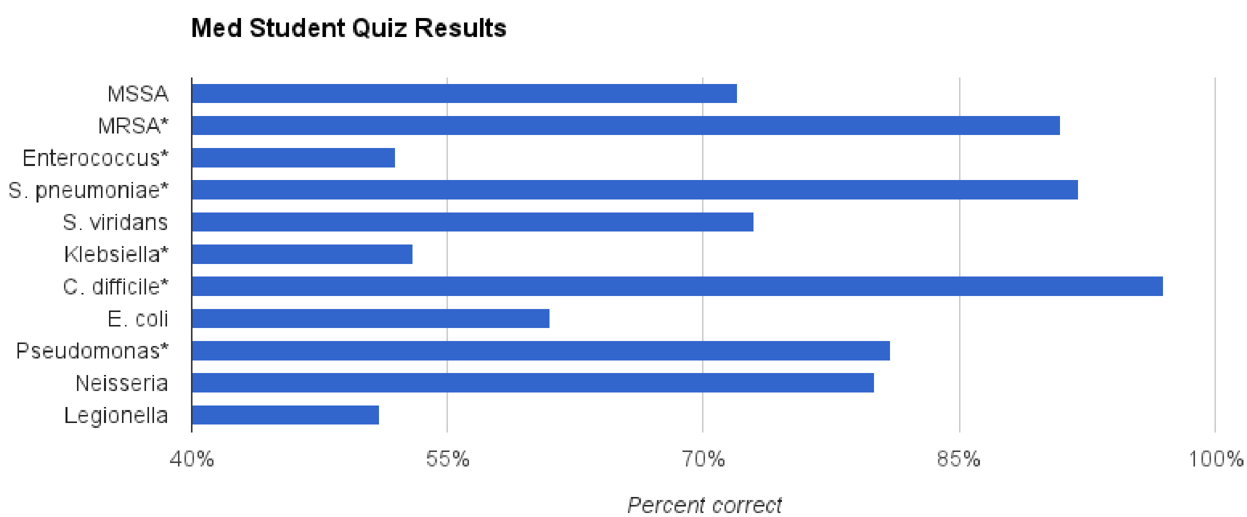
In addition to these interviews, we also conducted a short survey of current medical students. The goal of the survey was to answer the question, "Which bug/drug pairings are particularly difficult for medical students to remember?"

The survey was in the form of a Google Form, and was sent out to the 4th-year medical students at UIC Medical School and medical students from all four years at UPitt Medical School. We collected 70 responses in total.

The structure of the quiz was very simple. In consisted of a prompt:

> *For each organism listed, type in the name of an antibiotic that would be a good treatment choice. We know that absent any context, there may be multiple possibilities. Choose the one that first jumps to mind. If you don't know, make your best guess. We are looking for your immediate recall. You shouldn't spend more than 10 minutes and please DO NOT consult any resources.*

followed by a list of 11 bacteria. This list came from our discussion with Dr. Veldkamp, and included common bugs that he considered "easy" as well as bugs he considered "difficult". Grading was completed as follows: if the antibiotic the student provided could treat the given bug, *in at least some cases*, it was marked "correct", otherwise it was marked as incorrect. That meant that even if a student provided a less-than-ideal antibiotic as an answer (for example, one that was less effective than others against the bug, or a wide-spectrum antibiotic that is effective at the cost of possible future resistant strains), they still got full credit. If this criteria had been more restrictive--for example, only considering the "preferred" antibiotics to be correct--then the percentage of correct answers would have been much lower.



Results are given in the figure above. An asterisk next to a bug indicates that Dr. Veldkamp thought it was particularly difficult for med students to remember. Obviously, this did not always correlate with the actual difficulty for this group of med students. Still, based on this chart, we can scaffold our game by starting with "easy" bugs first, and more difficult bugs (as indicated by our quiz) at later stages.

The fill-in-the-blank style of the quiz also shed light into common mistakes made for particular bugs: for example, Klebsiella pneumoniae can be treated with 3rd generation Cephalosporins, however many students gave names of 1st, 2nd, and 4th generation Cephalosporins instead, indicating that Cephalosporin relationships are particularly difficult to keep straight. In addition to this, by comparing answers across bugs for a single student, it was obvious that many students have a “go-to” antibiotic in situations where multiple antibiotics would serve. While this is not necessarily a bad thing, in cases where there is a “preferred” antibiotic treatment for a particular infection, we want to guide the student to that treatment, rather than their “default”.

Learning Objectives

From our reading, and from our conversations with doctors, it is evident that the choice of appropriate antibiotic therapy given a particular clinical scenario is an immensely complex task. Even ignoring the expertise required to synthesize a suite of symptoms and a patient’s medical history into a diagnosis, there are multiple different agents which might cause a disease and multiple possible treatments. The treatment chosen will depend on a large set of factors, including patient allergies, the organ system affected, length of time the patient has been ill, and even geography, as local resistance patterns to certain antibiotics frequently occur. In some cases, detailed knowledge about a drug (e.g., it’s half-life or absorption patterns into different organ systems) is necessary to make a good clinical choice.

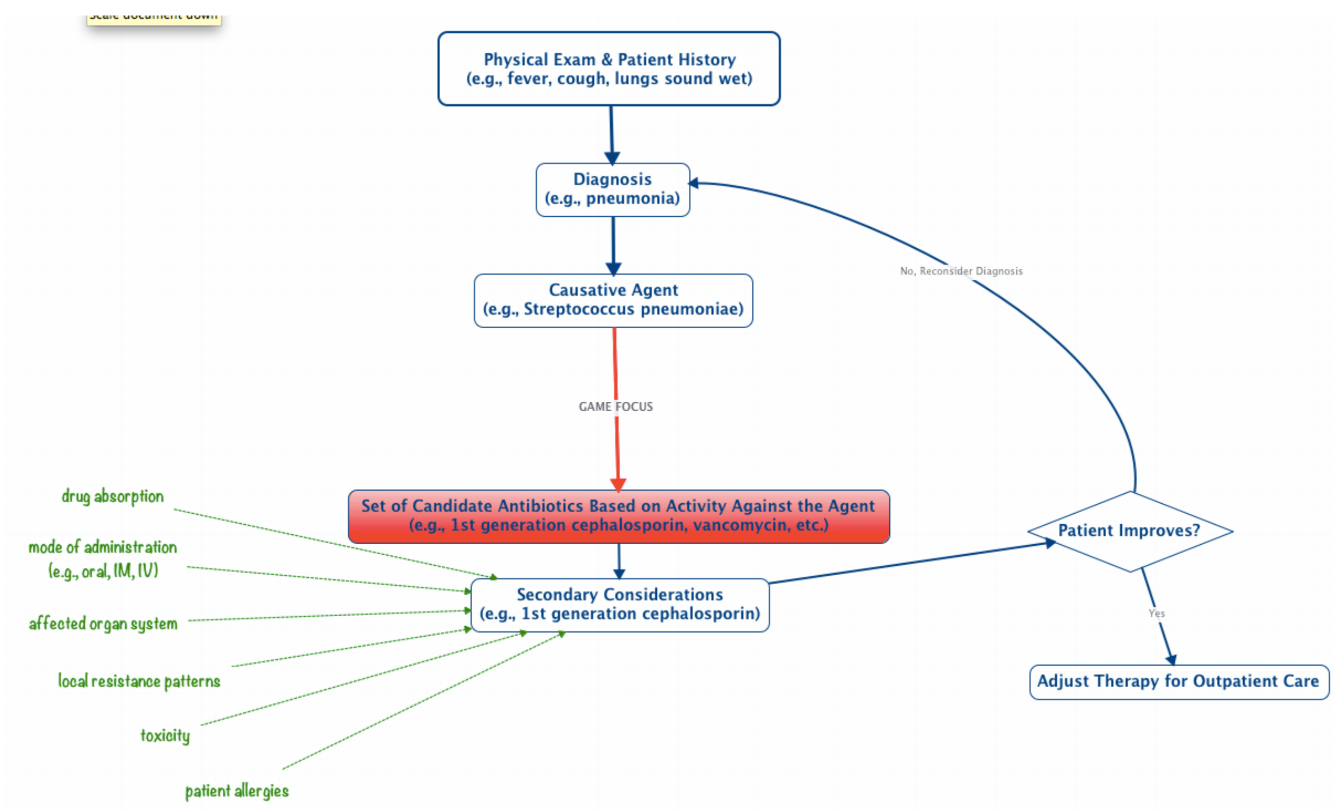


Figure: Outline of process for treating an infected patient. The main learning objective is highlighted in red.

Since we could not hope to tackle this complexity in the short time we had to develop the game (and with our very limited domain knowledge), our game supports the foundations of this more complex knowledge by helping students to gain fluency in matching particular bugs with one of several possible therapies. We fully recognize that this style of “flash card” learning objective is necessary, but not always sufficient for clinical practice or difficult case-based exam questions. We feel that this is useful knowledge, and Dr. Huijon agrees:

> *To be able to function, what you need to know is MRSA equals vanc. Strep pneumo equals penicillin. That’s what you need to know in order to function clinically. To answer why, you need to know all the other stuff. I’ve never been asked why except when I was a third year med student. And to pass my microbiology course. Since leaving preclinical medical education behind, I’ve never been asked why azithromycin covers atypicals. I don’t know. It just does. You come in with pneumonia, you get azithromycin.*

In other words, as illustrated in the chart above, matching drugs with bugs based on activity is a foundational element in treating patients and answering exam questions. While we initially considered many possible learning objectives, we have narrowed and refined our objectives as follows:

Main learning objective: Given a species of bacteria, which antibiotics are active against it? Choose the antibiotic with the narrowest coverage and lowest toxicity among possible options.

Secondary objective: In the case of resistant strains and/or patient allergies, what are alternative antibiotic treatments?

It was evident from our interviews that some knowledge, for example the mechanism of action of an antibiotic, was often not useful in helping doctors to select appropriate treatments for disease. Other hypothesized learning objectives, such as drug-drug interactions and drug half-life proved to be less important considerations when selecting treatment. As such, we removed these objectives in order to focus more narrowly on those identified above. We also refined the primary objective of the game to include the idea that a preferred antibiotic is one that has the narrowest coverage. We want students to increase their repertoire of drugs, rather than simply defaulting to the most powerful broad spectrum antibiotic available. Students should not use the nuclear option in each case, as this leads to the emergence of powerful drug-resistant strains of bacteria.

Below are two example tasks in which we expected to see performance improvement. The first task is a straightforward multiple choice question in which the learner must match a given bug with a preferred treatment. In this task, several choices would be effective in treating the infection, but the antibiotic with narrowest coverage is the best option. This kind of learning is explicitly supported in the game through training scenarios and combat with monsters.

All things being equal, which of these antibiotics would be the first choice for fighting an MSSA infection?

- Ampicillin
- Ceftriaxone
- Oxacillin
- Vancomycin
- None of these

The second type of task below is a transfer task. Here, we see a more realistic clinical scenario in which the causative agent is not explicitly stated. Students must distill the lab results to determine that the infection described is caused by VRE (Vancomycin-resistant Enterococcus). If students manage to do this, then our game will help them to determine that the appropriate treatment for this resistant bacterium is Linezolid.

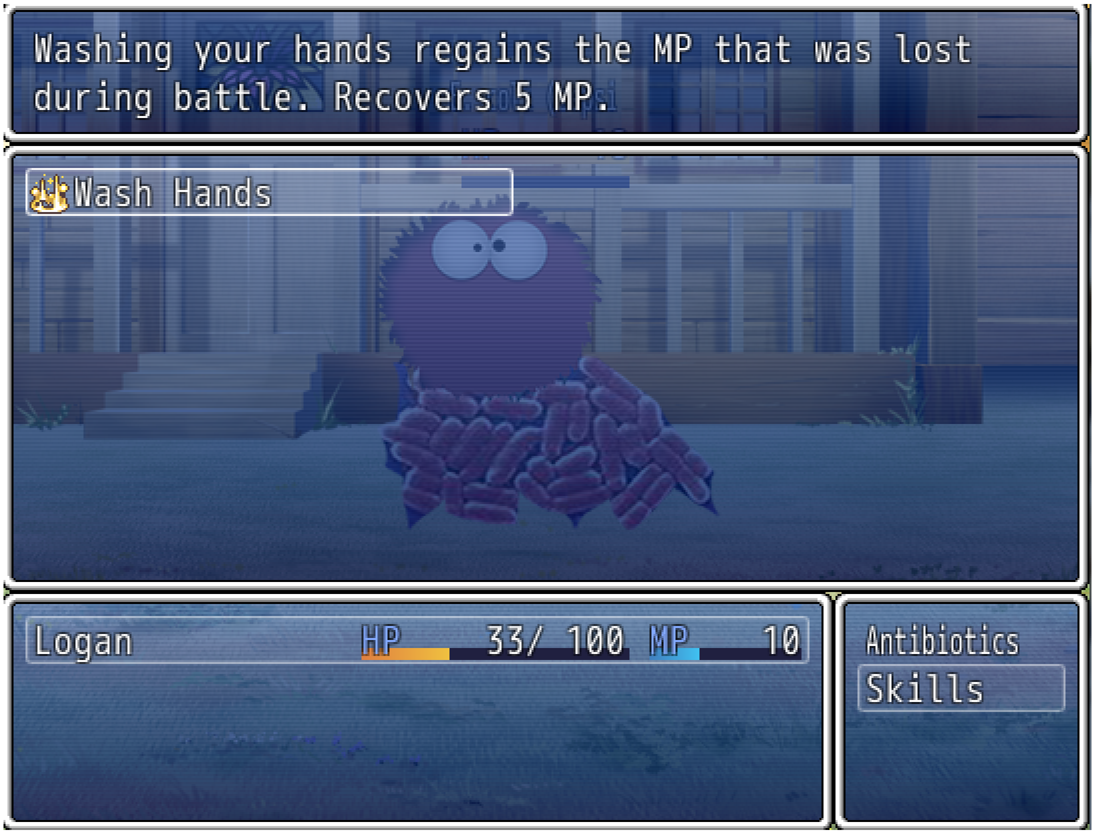
Gram stain of a clinical specimen reveals gram positive cocci in pairs and chains. Laboratory testing reveals resistance to bile, hydrolysis of esculin, and resistance to hypertonic saline. Susceptibility testing reveals resistance to penicillin and vancomycin. What antibiotic would you recommend for coverage?

- Ampicillin
- Ampicillin + sulbactam
- Gentamicin
- Imipenem
- Linezolid

Game Analysis

The core game mechanic is combat. Learners spend time exploring the village to interact with villagers and collect treasure. As they meander about, they are frequently ambushed by bacteria monsters who attack them. In fighting back, players exercise their knowledge of drug activities in order to try and kill their enemy. One of our aims was to help students identify ideal treatments for a particular infection, as opposed to merely any plausible treatment. One mechanic that supports learning this distinction is the number of damage points a particular antibiotic scores against an enemy. We painstakingly compiled a matrix of bug-drug combinations and assigned, with expert input, damage points to each pairing. Using the preferred antibiotic scores 10 damage points, killing the enemy on the first try, whereas using an applicable but not preferred drug scores only 5 or 8 points. Drugs to which a particular organism was resistant inflict no damage.

We also implemented different costs for various drugs. Those that were relatively narrow-spectrum were less costly than broader-spectrum drugs, or drugs with high toxicity levels. In addition to cost in terms of gold, drugs also had differing “medical power” requirements according to toxicity and breadth of coverage. By imposing a scarcity of money, the player must be strategic in selecting the quantities of each kind of drug in his arsenal. Medical power or “MP” is a kind of magic the player has, which is depleted each time she uses an antibiotic to attack a monster. Players are only able to replenish their MP during combat by using the “Wash Hands” skill. While good infection control through hygiene was not a primary learning objective, we nevertheless felt that reminders about this were appropriate.



When a student goes to purchase antibiotics, we also provide a short description of each drug's class, spectrum of action, and other relevant information, including whether it is *generally* (though far from always!) effective against gram-positive or gram-negative bugs. The gram-staining test is one of the most common laboratory assays, and virtually all the resources we consulted organized bugs in this manner. While initially did not include this information, feedback we received from our resident and medical student playtesters indicated that such reminders would be useful.

Learning Principles

The application principle (aka practice principle) is certainly supported in our game. Players spend most of their time engaged in combat and so receive frequent and varied practice selecting appropriate treatments to kill a vanquish their enemy. We ensure that students receive sufficient practice by tying progress in the game directly to successful combat outcomes. The player cannot complete an area in the game without reaching a certain level of experience. Since players only gain experience through defeating monsters, they cannot progress if they do not practice applying their knowledge. Additionally, players will be motivated to collect treasure and items (usually gold and more antibiotic supplies). By activating a battle near the treasure (noted by sparkly pixels), we ensure that players will encounter enemies and have the opportunity to fight and enhance their memory for the bug-drug pairings. Since players are encouraged to travel all over town, they encounter a variety of different bugs, as opposed to just one bug or even a single category of bug. This kind of spaced practice has been shown to improve long-term retention of information.[1]

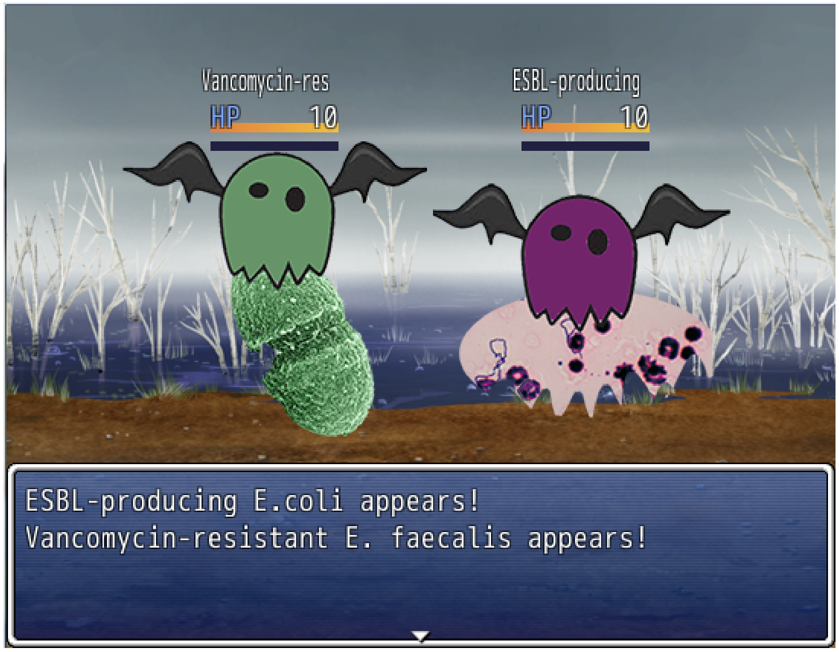
In all battles, the game provides players with immediate feedback in the form of information about the damage done to the monsters. As described above, the amount of damage inflicted is tied to the effectiveness of a particular drug against a given enemy. Since bugs have hit points equal to ten, and the optimal drug choice always inflicts ten damage, an enemy can be killed in a single round. Suboptimal choices, while effective, will require more than one round to slay a monster. In-game comments from our playtesters demonstrate that they noticed these differences and inferred correctly that 5 and 8 points of damage meant that those drugs were okay, but not the best choices.

In addition to battling monsters “in the wild,” players also have the option to engage in training scenarios, which provide significantly more guidance and feedback. Players can visit Crazy Larry’s home, a villager who is very knowledgeable about the monsters. Here, players can train with each of the five bugs in that particular zone. Before engaging in battle, Larry first quizzes each player as to an appropriate treatment for a given bug. Since players do not immediately battle the bugs, this is a low-stakes way to make mistakes, and players incur no costs in terms of MP points or antibiotic resources. In fact, Larry actually provides extra antibiotics for these scenarios. If players make a correct selection on the quiz, Larry congratulates them and provides an explanation as to why this is the best choice. If they make a mistake, Larry gives error-specific (as opposed to simply correctness) feedback and additionally provides the correct answer. In either case, the players immediately apply the knowledge in a battle against that same monster and so gain experience while reinforcing their memory and improving fluency.

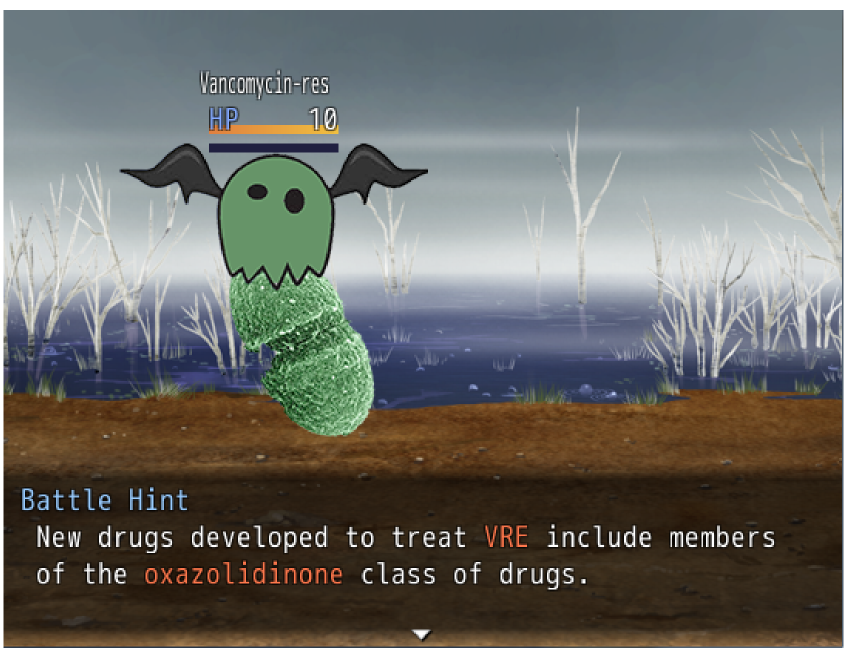
[1] Clark, Ruth C.; Mayer, Richard E. (2011). e-Learning and the Science of Instruction: Proven Guidelines for Consumers and Designers of Multimedia Learning (Essential Knowledge Resource) (p. 268). Wiley. Kindle Edition.

Example of error-specific feedback

We also took inspiration from intelligent tutors and included hints in our game during the boss fight. This is particularly challenging for players, as it involves not only one enemy, but two at once. Furthermore, both enemies are resistant strains of bugs they've already encountered elsewhere in the game.



Since the bad guy is resistant to many formerly effective antibiotic weapons, we chose to offer support to players in the form of hints. Once a player goes two rounds against the boss monsters without killing them, we automatically provide a series of hints which eventually bottom-out and indicate the correct answer.



Finally, we also implement the pre-training principle. While learners who are familiar with RPGs demonstrate a good intuition as to what one does in the game and which keys to press, not all our learners are hard-core video gamers. To make their game experience as smooth as possible and to facilitate their learning, we include an optional training at the start of the game. Players are walked through the game interface and receive guidance using basic navigation functions.

Development Platform

The RPG-style of gameplay is very common and we did not want to reinvent the wheel, so early in our development we researched possible tools that focused on the RPG genre. In the end, we chose to develop our game with RPG Maker[2] as it has a robust and extensible set of features along with a large community of fellow developers.

Like GameMaker, RPG Maker does not require any programming to develop games, so things like characters, battles, maps and events can all be created via an easy-to-use GUI. Importantly, however, RPG Maker also allows the user to modify any aspect of the game engine via scripts. This meant we were able to both quickly add the bugs and drugs to the game as "Enemies" and "Items", while at the same time modifying the battle engine to encode desired behavior from our bug-drug table.

The only downside to using RPG Maker is that it only runs on Windows, and only exports games to Windows format. While this is not an issue for this initial prototype in class, being able to export games to mobile platforms like iOS and Android will be critical if we wish to complete and distribute this game.

Playtesting

Round 1: In-class playtesting

The first version of our game had the basic narrative—Logan, a medical apprentice, is called before the king to fight the Squalorton Plague—as well as the initial training session with Master Telan in Logan's house. It contained the Squalorton level with a boss, though due to time constraints none of the participants were able to play more than a few minutes in Squalorton.

We had two participants: a CMU professor with no experience playing RPGs, and a student who was very familiar with RPGs. This was helpful because it gave us both ends of the spectrum, and we expect most medical students to fall somewhere in between. Neither participant was familiar with using antibiotics to treat infections, so the purpose of this playtest was to mostly to determine a) is the narrative engaging, and b) is the game interface intuitive?

Some major observations:

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[2] http://www.rpgmakerweb.com/ -- Note that we also used the provided sample game, *Crysalis*, as a starting point for our game maps

- The initial tutorial with Master Telan is useful—players had no issue understanding the mechanic of fighting bugs with drugs
- The initial narrative is too long, which is frustrating because it takes a while to start fighting bugs
- It was very confusing when Logan ran out of HP or MP, as the players were not paying attention to this metric

Major changes as a result of playtesting:

- We shortened the initial narrative so players got to the action as quickly as possible
- We added a heads-up display to the screen which always shows the players MP, HP, Gold, and current level. In addition, we added warning messages for low HP and MP

Round 2: UIC 4th-year medical student

This playtesting session was conducted over Skype with a 4th-year student from UIC medical school with no RPG experience, and little video game experience in general. In the email for our original antibiotics quiz, we asked people to email us if they were interested in playtesting, and she was one of the respondents. The main goals of this playtest were: a) how does a medical student, who has knowledge of antibiotics, respond to the game, and b) what changes (if any) should we make to the game feedback to ensure learning? That is, is losing or winning a battle enough feedback?

Some major observations:

- She failed to understand the Squalorton narrative, and thus just wandered around town fairly aimlessly.
- She enjoyed fighting the monsters, but felt that she was often guessing at which drug to use. In her words, she “spent a lot of time wandering around and fighting, but not really learning about antibiotics”.
- As she was largely unfamiliar with video games, it was unclear to her what she could and could not interact with. For example, she completely ignored the “sparkles” that indicated hidden treasure.

Major changes as a result of playtesting:

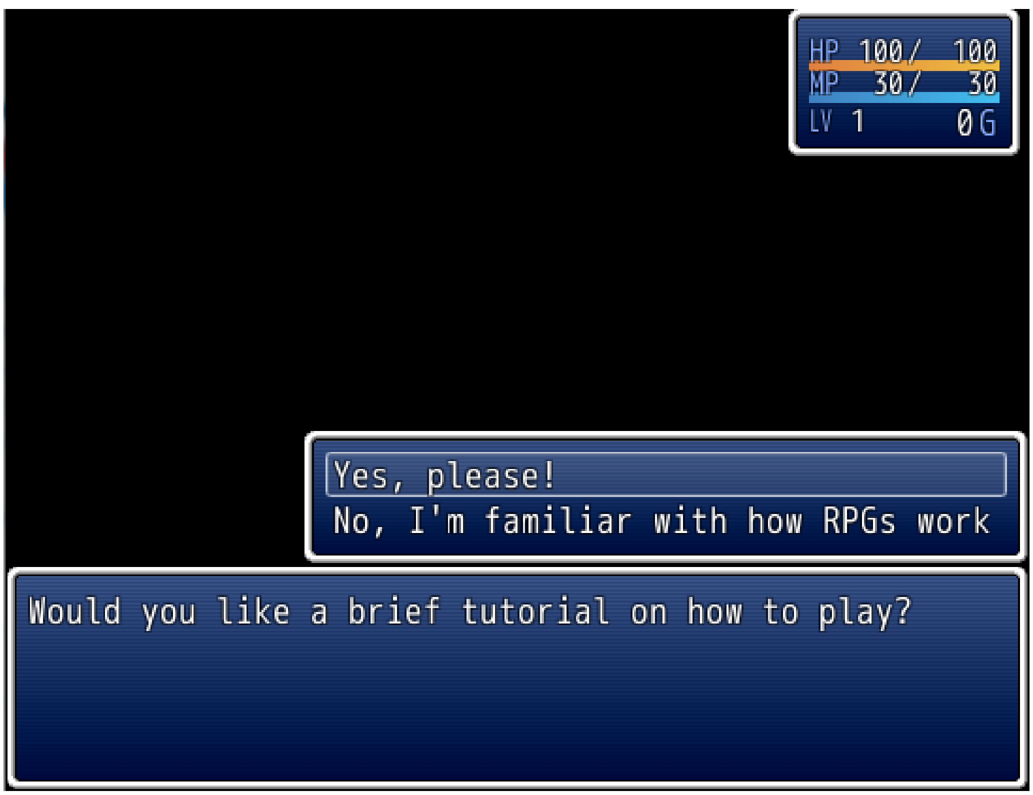
- We added the “Crazy Larry” training session in Squalorton. This introduces each bug, and describes which drug is the preferred choice for fighting it
- We added an optional “tutorial” at the beginning of the game, which introduces players unfamiliar with RPGs to the basic commands and interactions
- We updated the dialogue for all of the Squalorton characters, to make it obvious where the final boss lay, and how the player might reach it
- In addition, we added a lot of “color” to the game to make it more enjoyable to play. For example, we made animals interactive in the game, and added a “regeneration scene” after the player defeats the Squalorton Boss.

Round 3: UPitt medical residents

This round of playtesting was with two residents at UPitt: a psychiatry resident with little recent experience treating infections, and a pharmacology resident. We primarily wished to learn if the previous changes made we sufficient to solve our issues. Also, during the session the pharmacology resident reviewed our Crazy Larry training session dialogue and the Bug-Drug interaction table to ensure it was correct.

Some major observations:

- The Crazy Larry training session was very well received, and the added interaction with animals and NPCs was appreciated.
- While our bug-drug table and training session dialogue was largely correct, there were some redundant drugs as well as missing drugs, and our entry for one antibiotic was incorrect. Furthermore, we neglected to add information about Gram+ and Gram- aspects of the bugs and drugs, which is common and useful information.
- Replenishing MP was still confusing, and players ran out of Gold to buy more antibiotics, which left them stranded.



Optional "RPG Tutorial" at the beginning of the game

Major changes as a result of playtesting:

- We made fixes to our bug-drug table, updated the dialogue, added information about G+ and G- bugs, and changed the Squalorton Boss to a more realistic and problematic bug at the suggestion of the pharmacology resident.
- We added more MP hints, and updated the battles so that bugs would drop Gold when defeated

Round 4: Evaluations

Detailed information about this playtest is given in the following section.

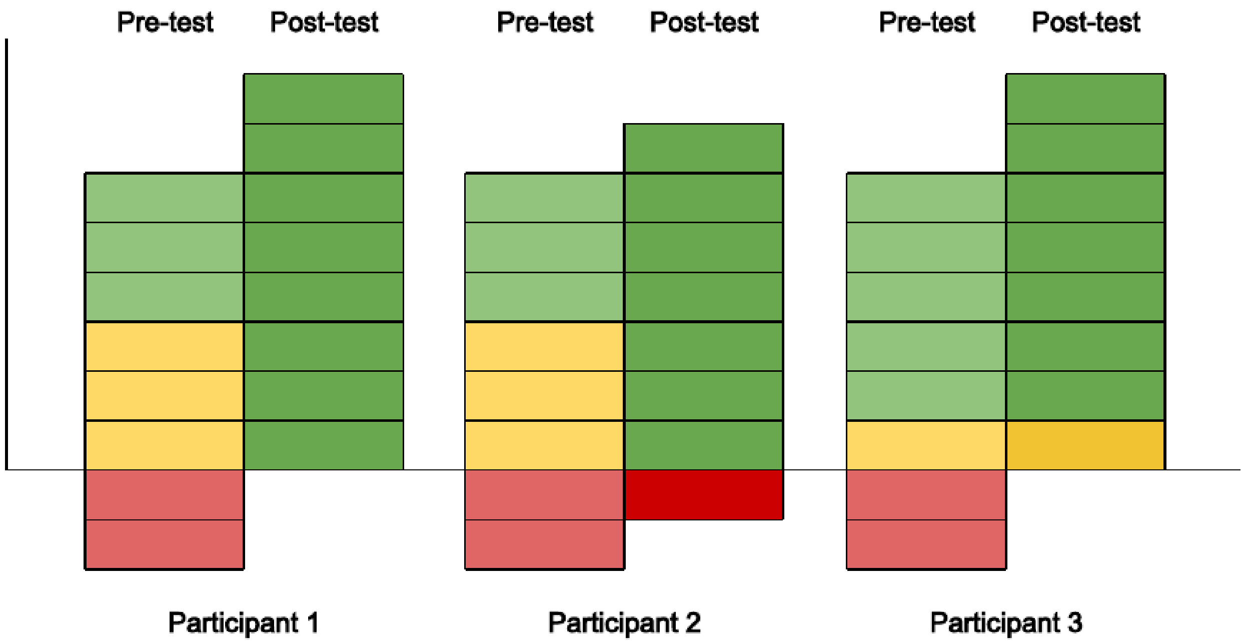
Evaluation of Learning Gains

After all of our playtesting sessions, we conducted one round of evaluations. We had three participants, two who are finishing up their fourth year of medical school at University of Illinois at Chicago, and one who will be starting medical school in the fall.

Before playing the game, these participants took an online pre-test consisting of some brief background information, plus 8 antibiotics quiz questions similar to those from the *Learning Objectives* section. Six of these were straightforward bug/drug matching, and two of them were short case studies, intended to evaluate out-of-game transfer. After playing the game for a time of their choosing (all participants reached the same point in the game, the end of the first level), they completed an online post-test. The post-test contained the 8 quiz questions, reordered, plus several questions about how they felt about the game. Possible answers to these questions were given on a five-point Likert scale. Also, it should be emphasized that since these participants were friends of the authors, their answers are most likely skewed towards a positive review. Further testing with randomly-chosen participants would be necessary to remove this bias.

	Where are you in your medical career?	**Have you ever played RPGs before?**	**How much time did you spend playing Antibiotic Apprentice?**
Participant 1	Med school	What's an RPG?	15-30 minutes
Participant 2	Pre-med	Yes	30-60 minutes
Participant 3	Med school	Yes	15-30 minutes

	I enjoyed playing Antibiotic Apprentice	**Someone who doesn't play video games could easily learn how to play Antibiotic Apprentice on their own**	**Playing Antibiotic Apprentice before a USMLE exam would improve my score**	**Playing Antibiotic Apprentice would improve my ability to treat patients**	**I would recommend Antibiotic Apprentice to a friend**
Participant 1	Agree	Strongly Agree	Agree	Agree	Agree
Participant 2	Agree	Agree	Neither agree nor disagree	Neither agree nor disagree	Agree
Participant 3	Strongly Agree	Agree	Agree	Neither agree nor disagree	Strongly Agree



Results from the pre- and post-test quiz. Green indicates a correct answer (the preferred antibiotic was given), Yellow indicates a semi-correct answer (the chosen antibiotic has activity, but is not preferred because it has over-broad applicability or high toxicity), and Red indicates an incorrect answer (the drug has no activity against the given bacteria).

These results clearly show that these participants enjoyed playing the game, thought that it would be easy to pick up for a non-gamer, and would recommend it to their friends. There was some agreement that the game would improve scores on an exam, however the respondents were more ambivalent when it came to using *Antibiotic Apprentice* to help treat patients. This may be due to the narrow scope of the game which, while appropriate for an exam, does not capture the level of detail necessary for treating patients in a clinical setting. For example, the game does not take into account regional variances in antibiotic resistance: as one participant noted, while TMP-SMZ is an acceptable answer on an exam to treat *E. coli* due to a urinary tract infection, it is no longer prescribed for UTIs in Chicago due to high resistance.

As for the antibiotics quiz results, while the sample size is obviously not large enough to indicate a definitive result, the results are very promising. All participants improved on both the number of incorrect answers, as well as the semi-correct answers. The incorrect answer on the post-test for Participant 2 was for which drug would best treat an *Enteroccocus faecalis* infection, and in this case the participant got the answer correct on the first quiz but incorrect on the second quiz. So either they had a lucky guess on the first quiz, or the game was confusing for some reason on this particular bug. A larger sample size would give insight on these types of results and eliminate skew due to guessing. As for Participant 3, their semi-correct answer for the post-test was the same as the pre-test, indicating that *Antibiotic Apprentice* did not override their previous feelings in this case.

Reflection

Designing this game was a significant challenge, in no small part due to our lack of subject area expertise. This was also, however, very interesting, and it was fun to learn about a new area of knowledge. With a great deal of research and significant input from experts, we feel confident that our game helps learners to memorize correct bug-drug pairings. As a core mechanic, combat was an effective way for students to practice this knowledge and receive feedback on their choices. Players seemed to find game play enjoyable; collecting sparkly items was fun, and experiencing victory over their enemies was satisfying.

There are certainly aspects of the game which did not work as well as others. For example, regeneration of medicine power (MP) can only be accomplished during combat by hand-washing. Players often found this confusing. We added a message to address this confusion, which certainly helped, but players seemed to find handwashing tedious. Our initial intention in assigning varying MP cost to different drugs was to drive home the point that narrow spectrum drugs, when effective, are a better choice than broader spectrum drugs. However, we did not see evidence that our players were considering the MP cost when selecting a drug to fight an enemy, and handwashing seemed a distraction. It may be that the tutorial sequence, as well as the differential damage done by first vs. second line drugs is sufficient to communicate this learning objective.

Striking a good balance as to monetary resources was also difficult. We wanted to impose a scarcity to some extent, as we wanted to force players to be somewhat strategic in their selections of antibiotics. However, if players had insufficient funds, it would be very difficult to progress in the game, as money is collected as loot from monsters, and monsters can only be killed with antibiotics, which must generally be purchased (or occasionally found). Crazy Larry gives extra antibiotics to players, but finding yet another alternate mechanism for making money or obtaining antibiotics might be advisable to deal with this balance issue.

We would also have liked to make the game more adaptive to players' decisions. For example, we would have liked to make the appearance of antibiotic-resistant bacterial strains contingent on a player's choice of drugs. if a player overuses Vancomycin, for example, then Enterococcus might transform into Vancomycin-resistant Enterococcus (VRE). However, we could not find a way to do this easily within the RPG Maker engine.

Other potential improvements to the game might include a more structured way of keeping track of game goals. Many RPG's have a quest log in which players are assigned several tasks but have the flexibility to choose which tasks they wish to complete. This gives players the option to explore the game in a relatively open-ended way while simultaneously providing some structure so that the player behaves in the manner intended by the designer. We would also be interested in creating an Activity Log which would allow the player to review important events, such as purchases and combat information.

One surprise was the popularity and effectiveness of the Crazy Larry tutorial section of the game. We were initially skeptical and worried that this would “break” the flow of the game by making it feel too much like a tutor. However, it was clear that this was effective, and players preferred this to randomly guessing when they did not know how to kill a particular bug. Given this outcome, perhaps one important lesson is that attempts to “hide” the education within an game may be misguided.

We have tentative plans to continue developing this game during the summer. However, we would start from scratch using another maker platform. While we enjoyed RPG Maker and found it to be an easy to use system, the games created will only run on Windows computers and are not compatible with mobile operating systems. We initially conceived of this game as something that medical students might play while on the bus or during their breaks. One of our playtesters also specifically suggested that the game would be much better on a smartphone. He explained that most medical and pharmacy students do not have their own computers at the hospital during the day, and they spend a great deal of time on their feet. However, virtually everyone has a smartphone, and he says he could imagine playing the game during a lunch break, or even in between patients during medical rounds.