4F90 Honours Thesis

E-Brock Bugs: The Creation and Analysis of an Epistemic Mathematics Computer Game

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Abstract

While seriously underrepresented in our current education system, many (e.g., Devlin, 2011) argue that video games are an ideal medium for the teaching and learning of mathematics, and yet, very few 'good' mathematical video games exist currently. This, together with my own interest in video games and mathematics education, led me to take on the challenge of designing and implementing a 'good' mathematics computer game that would later be entitled *E-Brock Bugs*. Building on a board game that was created by Dr. Eric Muller in the early 1980s, my computer game prompts its players to learn through simulation and exploration several basic probability concepts, all of which are encountered in the Grade 12 Data Management course of the Ontario mathematics curriculum. In addition to taking inspiration from Muller's work, the design of E-Brock Bugs carefully stems from the principles of a good math video game outlined by mathematician Keith Devlin (2011); e.g., a strong storyline, the selection of an in-game avatar, and an environment where mathematics arises in a natural and meaningful way. Ultimately, after a long dynamic cycle of creation and analysis that still continues today, E-Brock Bugs has become an educational tool that, I suggest, doesn't just teach basic facts and skills, but rather, encourages the development of mathematical thinking; that is, I advance that E-Brock Bugs is one of the few mathematical computer games that we can call 'epistemic' (Offenholly, 2011).

Introduction

We live in a world where the use of technology is inevitable and most often than not, provides so many great benefits to us. These benefits, according to current leaders on the educational scene, surely extend into the realm of teaching and learning, as can be easily seen by simply flipping through the abundance of pages that make up the Ontario Ministry of Education's curriculum documents. However, although much progress has been made in integrating technology into mathematics education specifically, many would agree that there's still something missing: video games!

Many educators and parents can attest to the fact that most students today just aren't interested in mathematics, whether they think it's too boring, too difficult or too disconnected from the real world. And yet, at the same time, they will probably also be able to provide generous complaints about the fact that these same students choose to spend so much of their free time playing video games "instead of learning". The question then is: what better way to make math less boring, less difficult, and more applicable to the world of today's youth than to incorporate the use of good video games into our classrooms?

In the beginning, when creating E-Brock Bugs, my goal was to provide a new and unique resource for teachers that is easy to access and use in their mathematics classrooms. In addition, I sought to create a seriously good video game that goes beyond teaching basic recall of facts or skills, and actually focuses on encouraging youth to begin to see mathematics as worthwhile and meaningful, and to see themselves as mathematically-able people. As a result, I hope that E-Brock Bugs will promote future study regarding the use of computer games in teaching mathematics, and eventually encourage a positive movement for the increased creation, analysis and implementation of video games in mathematics education.

Context

Mathematician Keith Devlin (2011) spends his entire book, *Mathematics Education for a New Era: Video Games as a Medium for Learning*, explaining in great detail the numerous reasons why video games are ideal for teaching mathematics. For instance, he explains that, on one hand, "Teachers complain that many students appear uninterested in [mathematics] and are unmotivated to make the effort necessary to progress in developing computational skills, problem solving ability, or an understanding of basic mathematical concepts" (Devlin, 2011, p. 45). On the other hand, he refers to a study by the Pew Research Center (2007-08), which found that 97% of American teens aged 12-17 play video games. After making this extremely strong statement, he goes on to build his case through the use of several examples and ideas, many of which are explored in this paper as being linked to the design of E-Brock Bugs. Ultimately, after reading Devlin's (2011) book, I find it virtually impossible to dismiss the idea that the combination of video games with mathematics education is not only logical, but would also be extremely valuable.

On top of this, Devlin (2011) explains that he has been significantly underwhelmed by all of the mathematics computer games produced so far. He states that "What has left [him] unsatisfied is that those games [...], while succeeding in achieving their (modest) educational design goals, fall way short of the potential [he], and many others, are sure the medium offers" (2011, March). Reading this, I felt personally compelled to take on the challenge of designing a video game that would not be entirely underwhelming and would maybe even reach the point of teaching what he calls "mathematical thinking"; that is, "a whole way of looking at things, of stripping them down to their numerical, structural, or logical essentials, and of analyzing the underlying patterns", or, in other words, "think[ing] like a mathematician" (Devlin, 2011, p. 59). Hence, the creation of an epistemic computer game that would be known as E-Brock Bugs began.

The various design elements within E-Brock Bugs, including the title, content, characters, organization of material and presentation of theory, take their inspiration from two previous works by Dr. Eric Muller and Dr. Chantal Buteau. According to Muller, probability has recently taken great importance in mathematics education due to its amazing and frequent applications in the real world (personal communication, November 6, 2012). It is no surprise then that in the early 1980s Muller designed and created a board game entitled Brock Bugs, which intends to

teach students from grades three through twelve basic probability concepts and is currently supported by the Ontario Association for Mathematics Education (OAME) as a resource for all schools in Ontario. Years after Muller had created Brock Bugs, he teamed up with Buteau, with the assistance of Sabrina Thomas and James Li, to develop and implement a trial version of a Brock Bugs learning object, which is currently available for use on Brock University's website, but never reached completion. In some sense, E-Brock Bugs is the continuation of this attempt to make Muller and Buteau's original vision come to life in electronic form.

Like the previous works outlined above, E-Brock Bugs is extremely versatile in the sense that it can be used effectively by pretty much anyone who knows how to read and has basic mathematical knowledge (e.g., of numbers, algebraic operations, etc.) due to the fact that it introduces what Devlin (2011) calls "everyday math" (p. 46). This being said, it is extremely difficult to design game elements such as dialogue, sound and graphics to meet the needs and interests of various different age groups. For this reason, E-Brock Bugs was specifically designed with high school students in mind, with a particular focus on those taking the Grade 12 Data Management course described in the Ontario mathematics curriculum. Nonetheless, with minimal changes to various different design aspects, E-Brock Bugs could easily be geared towards a much younger age group.

Description

Since the beginning of time, Bug City had been a peaceful place to live, where even the simplest of bugs felt right at home. Then, one day, the city was invaded by a band of Bullies, who used their intelligence to invoke a sense of fear in all. Each of the six districts that make up the city was quickly transformed into a wasteland; what was once lively and bright now stood cold in the darkest of shades. But, the situation is not entirely hopeless, for the player of E-Brock Bugs is the hero that Bug City has been waiting for! After viewing an introductory animation that sets up the storyline for the game and selecting one of six possible in-game identities, a player begins their quest to defeat the Bullies and restore Bug City to a peaceful state, one district at a time.

At the beginning of their journey, a player meets Bugzy, the somewhat simple, but extremely loyal bug who will guide him/her throughout the entire game. With no time to lose, Bugzy leads players into the city and helps them determine where to go and what to do. The player quickly learns that each Bully maintains his/her control through the use of a game of chance in a public place that appears to be way too difficult in the eyes of the regular bugs of the city. Upon entering a Bully's territory, the player is immediately challenged to play that Bully's game, with the Bully seeking to put the player in his/her place and continue to hold a position of power. To give the bugs of a specific district their voice back, all the player needs to do is defeat the corresponding Bully. There are two ways to do this: either the player needs to beat the Bully six times at his/her own game, or they need to successfully answer a challenge question the Bully poses only once they feel threatened enough to do so.

With each district comes a different environment, Bully, game and challenge. In District 1, players meet Mac the Mosquito, the oldest and crankiest of all the Bullies, who challenges them to play his "Sum of Two Dice" game. As the title suggests, Mac's game relates to the experiment of rolling two ordinary dice and recording their sum. Upon entering the next district, players are prompted to meet the most conniving and superficial of all the Bullies, Bash the Beetle, whose "Sum of Two Fibonacci Dice" game is almost identical to Mac's in terms of organization, but is entirely different from a theoretical perspective. Players are then introduced to the oddest of all the Bullies, Fitz the Fly, who challenges them to a game involving the experiment of drawing two balls without replacement and, once again, recording their sum. Trickz the Termite, the toughest Bully and the new leader of District 4, then exposes players to

the experiment of spinning two randomized asymmetrical spinners. Once in District 5, Crazee the Cockroach, the meanest of all the Bullies, persuades players to play his "Flipping Seven Cards" game, which involves randomized probabilities and introduces the concept of the Binomial distribution. And finally, in District 6, players are introduced to Wicked the Wasp, whose game also involves the rolling of two ordinary dice and the recording of their sum, but uses a randomized point value system that requires the player to use their knowledge of expected value in order to guarantee the best possible strategy for winning.

Although they are given several hints throughout the game, little does the player know that there is actually more to the Bullies than it seems; that is, their every move is controlled by the evilest of all bugs and the real mastermind behind the fall of Bug City: the one and only Dr. P. This truth is finally revealed after the player defeats all of the Bullies. While standing in a newly refined district, they are suddenly captured by Dr. P's praying mantis minions and taken to face the final obstacle in their adventure: a simulation challenge based on the Binomial distribution and connected to the games played in each of the six districts.

Throughout their entire journey, users get to know another very important character: Smarty, the quiet and shy, but extremely smart bug who has been developing the mathematical theory behind the Bullies' schemes. When prompted by the user, Smarty leads him/her through a series of interactive activities with the goal of teaching how mathematical thinking can be used to develop the best strategy to win against each Bully and, eventually, Dr. P. She even prepares randomized "leaf"-sheets for the user to practice their knowledge before using her well-organized tunnel system to quickly get back to saving Bug City.

Whether in Smarty's Shack or through game play, a player of E-Brock Bugs has the opportunity to learn about a variety of different mathematical concepts, including the basic definition and properties of probability, theoretical and empirical distributions, the product and sum rules, independent and dependent events, equally and unequally likely events, expected value, and the Binomial distribution. Nonetheless, E-Brock Bugs has been designed in such a way that the greatest emphasis is placed on only a few of the most important concepts. For instance, within five of the six districts of Bug City, the main educational focus is the development of the frequency and relative frequency graphs for the corresponding experiments, and the use of the formula frequency/total number of outcomes for determining probabilities. In addition, throughout the entire game, players are constantly encouraged to make the distinction

between theoretical and empirical values through the comparison of Smarty's theory to what actually happens when playing against a Bully; that is, players are encouraged to see that while theory can tell us what the best strategy is, it cannot ensure success.

In summary, E-Brock Bugs is an educational computer game about basic probability concepts that seeks to provide its users with a personalized, interactive, animated and fun experience complete with an interesting storyline and cast of characters. While progressing throughout the dynamic game world of E-Brock Bugs through the use of exploration and experimentation, players are ultimately prompted to develop their ability to think mathematically.

Analysis

My design choices when creating E-Brock Bugs, while being influenced by a variety of factors, were solidified mainly by the principles of a good video game outlined in Devlin's book (2011). Most predictable perhaps is the eleventh principle of his "Eleven Principles of an Ideal Learning Environment", which states that "The learning environment should, if possible, provide an enjoyable and stimulating experience" (p. 31). Hence, E-Brock Bugs is complete with interactive games, interesting animations, colourful backgrounds, dynamic characters, challenging obstacles etc., as explained above; that is, as the word "game" so naturally implies, E-Brock Bugs was designed to be both fun and exciting for its players.

A much less obvious idea perhaps is that, "the back story is crucial to the success of a game" (Devlin, 2011, p. 134). Devlin explains how most game designers who do not think about the storyline of their game until late in the design process are often very unsuccessful. As a result, I spent a considerable amount of time developing the story behind E-Brock Bugs and its characters, creating an introductory animation to explain the initial details, and implementing various elements throughout the game to consistently and coherently build the story for the player. The aim of such a storyline construction is to motivate the player enough not only to want to play, but also to want to play successfully. In E-Brock Bugs, playing the game becomes about saving Bug City and not just about learning mathematics.

While building the back story for E-Brock Bugs, it was decided that some element of mystery could also be useful in encouraging users to continue playing, the idea being that if the storyline is interesting enough, but some of it is hidden from the user, then the user will want to keep playing in order to unveil these hidden parts. Thus, for example, the existence of Dr. P is not explicitly explained to the user, but rather, the villain makes subtle appearances at different points in the game to indicate that he has some role within the story, only to finally get involved once the user has defeated all six of the Bullies.

The first task a player really encounters in E-Brock Bugs, as in most other successful video games, is to select his/her in-game identity. As a result, the user's experience becomes more personalized right away; the player easily identifies with the character and therefore wants this character to succeed (Devlin, 2011, p. 126). However, since the character is often displayed on the screen in front of the player, he/she also has a sense of being outside the action taking place, which means that, "failure is not as personal as it is in real life; the player can mitigate

failure by saying 'It was my character who screwed up,' even though the character failed only because the player did" (Devlin, 2011, p. 88). Ultimately, the player will be more likely to take chances and less likely to be embarrassed by mistakes.

It is important to note that decisions related to failure at a task in E-Brock Bugs did not go without serious consideration. Devlin's (2011) tenth principle of his "Eleven Principles for an Ideal Learning Environment" says that "There should be sufficient 'cost' at getting something wrong to motivate correction, but not so great that it leads to the student losing heart and giving up" (p. 30). Throughout E-Brock Bugs, if a player loses against a Bully, they only get harassed by him/her (i.e. there is no additional loss of points, etc.). Therefore, players will likely not be too afraid or too frustrated to keep playing the game until they've mastered it, and at the same time, they will hopefully be motivated to defeat the Bully who is antagonizing them.

A different example of punishment in E-Brock Bugs relates to the alternative way Bullies can be defeated in the game. As explained previously, to avoid having to win a game six times to defeat a Bully, a user can opt to take the Bully's challenge, where answering a mathematical question correctly ensures instantaneous defeat. If a user provides an incorrect answer though, he/she must beat the Bully two times more than already required, a punishment that intends to encourage the user not only to think more carefully about the question and the mathematics involved, but also to want to come back and attempt the question again since it can lead to success much quicker and with much more certainty than playing the regular game. Because this punishment is much harsher than the simple heckling a user experiences after a regular loss, however, it is natural to question whether it has the right magnitude. Devlin (2011) explains that "[...] the greater the motivation to succeed in the overall endeavor, the more the student is likely to respond positively to greater losses resulting from failure" (p. 30). Since the challenge question allows for a much greater reward than simply playing the game, the harsher punishment is justified. Just how harsh the punishment should be can only be confirmed after the game goes through testing.

Quite expectedly, equally as difficult as the choices related to failure were those related to success in E-Brock Bugs. Devlin's ninth principle of his "Eleven Principles of an Ideal Learning Environment" demands that "The student should be given immediate positive (and ideally public) feedback for any success that is commensurate with that student's current level of attainment" (p. 30). Furthermore, there must be just the right amount of acknowledgement for the

user to feel as though his/her hard work was worthwhile and that he/she is deserving of the praise. Though this principle would have been much more efficiently and effectively met had E-Brock Bugs been designed as a multiplayer game with a more complex structure, the dialogue and events that occur after a user experiences success in the current game were carefully thought out. For instance, after defeating each Bully, the user finally gets to see the transformation of the corresponding district from sad and dark to happy and bright, full of new characters who have only good things to say, lively animations, and cheerful music.

A significant part of E-Brock Bugs, besides the game play, is the optional learning object component that can be found in Smarty's Shack. The gathering of all theoretical material in the game into one place was done strategically so to maintain its optional characteristic, for according to Devlin (2011), “Putting symbolic expressions in a math ed game environment is to confuse mathematical thinking with its static, symbolic representation on a sheet of paper ” (p.6). In other words, the more traditional teaching approach that is represented by Smarty and her theoretical lessons tailored to each Bully does not necessarily fit in the description of a good mathematics game in Devlin's view. Nonetheless, this does not mean that it is not useful, nor that it does not nicely complement the exploratory learning a player experiences throughout the game play in E-Brock Bugs; after all, some students may not learn through exploration as well as others, and teachers will likely be able to rely on Smarty as a sort of educational assistant in their classrooms, who can re-emphasize the concepts they teach.

Smarty's Shack also helps E-Brock Bugs meet several of the principles discussed in Devlin's (2011) book. For example, Gee's "Explicit Information On-Demand and Just-in-Time Principle" states that "The learner is given explicit information both on-demand and just-in-time, when the learner needs it or just at the point where the information can best be understood and used in practice" (p. 99). In order to allow for exploration, a player will likely play against a Bully at least twice before they are invited to Smarty's Shack. At this point, they are ready to learn about the theoretical concepts that can be used to help them defeat that specific Bully. Note that in many of the theoretical explanations given by Smarty, certain concepts are discussed that do not directly relate to the game play. As a result of the above principle, these parts are made optional to the user. After being led through Smarty's instruction, the user is able to immediately go back to play the Bully and use the information they've learned with purpose.

Smarty also helps E-Brock Bugs meet Gee's "Transfer Principle"; that is, "Learners are given ample opportunity to practice and support for, transferring what they have learned earlier to later problems, including problems that require adapting and transforming that earlier learning" (p. 99). Each of the Bullies' games is closely related to one another in various ways, and in most cases there is only one or two characteristics separating any two of the games. For example, the only difference between Mac and Bash's games is the type of dice used, while the only difference between Mac and Trickz's games is that the former involves equally likely events and the latter entails events that are unequally likely. In particular, all of the games build on the knowledge a learner gains through playing against Mac, which is why the mosquito finds himself in District 1. Thus, as the player moves throughout each of the five districts, the similarities between the games naturally encourages them to transfer what they learned previously and try to adapt this learning to the new situation. This transfer and adaptation is made explicit and much more easy for the player through the guidance and support of Smarty, who constantly refers back to previously learned concepts throughout her lessons.

Much of the overall game navigation and organization can also find its foundation in Devlin's (2011) theories. For instance, one will notice that the player is given the choice most often than not to direct his/her own path in the game, therefore making the game experience much more personalized, which is consistent with Gee's Multiple Routes Principle (Devlin, 2011, p. 95) and Principle 5 of Devlin's "Eleven Principles for an Ideal Learning Environment" (Devlin, 2011, p. 25). However, the user is still directed towards "pre-planned learning experiences, some of them in a particular order" (Principle 7, Devlin, 2011, p. 29). For instance, the districts are numbered and placed in such a way that the concepts build on one another, and in many situations, such as in Smarty's Shack, flashers and pointers indicate the ideal place to click on next. This way, without being forced into a certain path, the user can still be aware of the route that is suggested in order to achieve the best results.

Furthermore, a player of E-Brock Bugs may choose and may even be successful at beating each Bully using only his/her intuition, mathematical or not. As Devlin (2011) suggests, "while conceptual understanding is a goal that educators should definitely strive for, we need to accept that it cannot be guaranteed, and accordingly we should allow for the learner to make progress without fully understanding the concepts" (p.115). After all, if a game puts a player in a position where they cannot move forward because they are stumped by a problem that is just too

difficult, then the game fails at everything it is trying to accomplish in the first place. This being said, in order to discourage players from avoiding the use of mathematics altogether, E-Brock Bugs was designed in such a way that if a user decides to make the effort to think mathematically, then they can progress much more quickly. For instance, a player who looks for patterns and determines the best strategy when playing against each Bully is more likely to win and therefore much more likely to progress faster than a player who plays without any mathematical thought. In addition, the challenge question of each Bully, which gives a user the opportunity to win in an instant, also requires players to use mathematical thinking. Either way, in E-Brock Bugs, even after a player beats a Bully, they still have access to the game and the accompanying theoretical explanations, activities and practice questions. Hence, even if they beat a Bully by sheer luck (it is a game based on probability after all), they can always go back on their own will or on the advice of a teacher to learn and practice the intended material.

According to both Devlin and Gee, the encouragement of such practice is crucial in a good mathematics computer game. Devlin explains, for example, that "In mathematics as in most other walks of life, practice makes perfect. In fact, practice not only makes perfect, it's what it takes to become competent " (p. 92). Though the practice of mathematical thinking, as explained above, is not necessarily forced upon a user, it is certainly encouraged, especially within the final three districts of Bug City, where games are characterized by randomized elements. For instance, in District 4, Trickz uses different asymmetric spinners for his game every time a player loses, which means that a player who wants to play strategically must develop the strategy for the game over and over again. Similarly, Wicked randomizes the point values used at the beginning of each of her games, and Crazee generates new probabilities to be used at the start of each of his. The expectation would be that by the time a player reaches these last three districts, they will have already been persuaded to want to succeed in the game and, by extension, play strategically, thanks to aspects such as the storyline and the confidence boost of facing and accomplishing easier tasks in the earlier districts. Therefore, they will be more likely to participate in the act of practicing that is naturally embedded in the game itself, on top of the constant practice that available in Smarty's Shack, but is somewhat isolated from game play.

What is so interesting about the embedded practice described above is that it would require even the best of statisticians to work outside of the game with pencil and paper if they want to progress as fast as possible in the game; that is, the games and challenges users meet in

Districts 4 through 6 can be solved much more efficiently if the player stops playing and works on their own for a few moments. In the end, as Devlin (2011) explains, "The player who takes time out to consider and solve the math problem not only advances faster or further in the game, she or he also learns the valuable lesson that it is sometimes better in the long run to stop for a while and reflect than to continually press forward in an exploratory mode." (p. 81).

This being said, perhaps the most interesting part of E-Brock Bugs is the fact that users are prompted to learn through exploration and experimentation, and are gradually given more guidance as they go. In other words, the traditional presentation of mathematical concepts has been reversed so that practice comes before theory and therefore, students can build their own ideas of what is happening. Even the more theoretical activities in Smarty's Shack are built in such a way that students are given space to develop the concepts themselves. Hence, the organization of Brock Bugs has been inspired by the Constructivist theorists, who believe that "regardless of how clearly a teacher explains a concept, students will understand the material only after they have constructed their own meaning" (Mills, 2002, p. 3). This style of learning through exploration is also supported by Devlin's (2011) theories. For instance, he suggests that a student who learns by exploration has more fun, gains more powerful, usable and durable knowledge, and takes more ownership of such knowledge (Devlin, 2011). Ultimately, he sums up his ideas by recalling the saying: "You tell me, I forget; you show me, I remember; you let me discover, and I know." (Devlin, 2011, p.99).

E-Brock Bugs: An Epistemic Mathematics Computer Game

Offenholly (2011) describes an epistemic mathematical computer game as one in which "The player becomes a mathematician and problem solver within the context of the game" (p. 45). Many of the features of E-Brock Bugs make it worthy of falling into this category.

First and foremost, since a player of E-Brock Bugs is able to select his/her own character at the beginning of the game, all activity in the game is presented not to the player themselves, but to their character identity. As Devlin (2011) explains, the game is no longer about learning how to do math; it is about learning how to be a (better) mathematician (p. 126). Yet, Devlin (2011) also points out that it can still be quite difficult to get a player to actually adopt the identity of a mathematically-able person in the game world, let alone in the real world. The best solution, he claims, is

> To build the entire game world and game around key mathematical learning experiences [...] Thinking mathematically should simply be part of what [the] character does in that world. The mathematics should not be hidden; the players should know they are doing math! But that math should arise naturally in the game, it should have meaning in the game, and it should make sense in the game. (2011, p. 127).

In E-Brock Bugs, the user's experience is based entirely on having to learn to think mathematically (whether through experience or theoretical explanations) in order to defeat the Bullies, who are using their own mathematical knowledge to dominate the more "simple" bugs of Bug City. It is therefore perfectly natural and almost necessary that the character thinks mathematically. Supported by the storyline, game elements and theoretical activities, mathematics definitely makes sense in E-Brock Bugs.

In addition to ensuring that the mathematics arises naturally within the game, Devlin (2011) discusses five key features of a good video game that are crucial in assisting players, especially those who are particularly math averse, in seeing themselves as mathematical thinkers: learning by doing, self-paced learning, exploration, immediate use, and regular tests. As can probably already be seen through the analysis of E-Brock Bugs discussed in the previous section of this paper, the game certainly satisfies each one of these characteristics.

For instance, as suggested by Devlin (2011), a player of E-Brock Bugs, "is never put in a position of having to 'learn something' prior to playing the game in order to play the game" (p. 128). In fact, as explained previously, a player of E-Brock Bugs is initially prompted to learn

through play and is only given more guidance when necessary. Furthermore, the first three districts within the game are kept quite simple in comparison to the final three, with the goal of supporting a player during his/her initial stages of learning.

Secondly, though a player of E-Brock Bugs is encouraged to progress in the game, he/she is never forced to do anything. This means that a more hesitant player can take as much time as he/she needs to complete a task and more bold players can advance as far ahead as they please, only to realize that they need to step back a bit when the games start to get too hard for them. In other words, players of E-Brock Bugs can definitely go at their own pace.

Thirdly, Devlin explains that by allowing players to go at their own pace, they can therefore, "take time to explore, try things out, and become familiar with new ideas and skills" (p. 129). As already mentioned, the rearrangement of practice and theory in E-Brock Bugs also contributes to encouraging the player to learn through exploration. In fact, most often than not, a player will not be urged to access the optional learning object component of the game until they have played a Bully at least twice. And even then, they still have the power to decide how their exploration will proceed.

Devlin's fourth key feature demands that "when a player learns a new fact or skill it is put to immediate use" (p.130). In E-Brock Bugs, the appearance and organization of Smarty's theoretical explanations satisfy this characteristic since they coincide with the user's position in the game; that is, a user must play a Bully at least once before they can access the corresponding theory and then, once they have been instructed by Smarty on how to use mathematics to defeat this particular Bully, they are encouraged to go back to the game and are able to put the knowledge they learned to immediate use. As a result, a view of mathematics as useful, worthwhile and applicable in the game world is encouraged.

Lastly, Devlin says that in order to help build a mathematical in-game identity, it is crucial that the "video [game] present[s] the players with frequent tests to see how well they have mastered the latest facts or skills" (p. 130). In E-Brock Bugs, a player is given the impression that he/she must win against each Bully at least 6 times in order to defeat him/her entirely. What this means is that a player is given the opportunity to go through a repeating cycle of testing (through the game play) and learning to see if they have either discovered or understood the best strategy for each game, and possibly the mathematics involved. This process is magnified greatly in the final three districts, where users should determine a new strategy with each new game

thanks to randomized game elements. Furthermore, the challenge question corresponding to each Bully, though it may reduce the amount of game play a user experiences (recall that it leads to instantaneous defeat of the Bully), also acts as a testing mechanism for a player of E-Brock Bugs, as it involves a mathematical question relating to the best strategy in each game. According to Devlin (2011), "it's the *enjoyment* of taking and passing the 'tests,' often after several failures, that *motivates* players to learn" (p. 130), and ultimately come to see themselves as being a mathematically-able person.

In the end, we see that there are many characteristics of E-Brock Bugs that give it the potential to be called what Offenholly (2011) refers to as an *epistemic* computer game. Whether or not mathematical thinking will actually be observed in its players will of course require further study of empirical nature.

Conclusion

Looking back now, it is hard to believe that I was able to accomplish all that I did over the past eight months; that is, the design, implementation and analysis of a mathematics computer game about basic probability concepts that involves over six levels of game play within a personalized, dynamic, interesting and fun game world. On top of having to learn how to use Flash Professional and the accompany programming language pretty much from scratch, I also personally designed virtually every part of E-Brock Bugs as it currently stands. The theoretical sections and games took their inspiration principally from Muller and Buteau's previous works. However, from the writing of the storyline to the drawing and colouring of the many graphics, the development of the game world, the recording and manipulation of the sounds, and in particular, the entire creation of the final simulation challenge a player faces, E-Brock Bugs is an original work that certainly required the use of both sides of my brain.

During the production of E-Brock Bugs, I went through a constant cycle of creation and analysis driven by a combination of my own experience with video games, feedback from others, and of course, Devlin's principles. I met several obstacles, such as narrowing the target audience and trying to find the right balance between the characteristics of a computer game and the learning object component. And though such a development process will likely continue in the future, and surely many more challenges will be faced, I am very proud of the current state of E-Brock Bugs, as I truly believe that it is a good mathematics computer game. Only time will tell if my opinion is shared by others.

Throughout my work, it has been confirmed that creating an educational video game, let alone one that actually teaches mathematical thinking, is not at all easy, which would likely explain why there are so few good ones on the market today. It is no secret that modern students certainly like video games; but, they don't just like any video games. They like the ones that have advanced graphics, faced-paced and exciting animations, intricate storylines and complex worlds. While reading Devlin's (2011) book, it was evident that he was attempting to move people to create these kinds of games, especially seeing as he constantly refers to one of the most successful games of all time (precisely, World of Warcraft (WoW)) when exploring his principles. There are numerous aspects of a great video game like WoW that I unfortunately was not able to accomplish in E-Brock Bugs due to time restrictions and/or my own limited technical abilities. For instance, I would have liked to make the game graphics more 3-dimensional so that

the world appeared to be more realistic. I also would have liked to give the user the ability to move their character and save their progress upon exiting the game. It would have also been interesting to figure out a way to make the game a multiplayer environment considering the great emphasis Devlin (2011) puts on the benefits of this type of game world. This is not to say, however, that I do not think E-Brock Bugs would and possibly will serve as a very useful resource for teachers, students and researchers alike.

In the near future, E-Brock Bugs will serve as a free online resource for educational professionals, parents and students. In addition, my game will likely be involved in several studies with respect to epistemic video games and the teaching and learning of mathematics. In the farther future, I hope that E-Brock Bugs will provide us with some of the insight we need to continue to develop our education system to use technology to its greatest potential. And, maybe one day, it will even have assisted in encouraging video games to become recognized on a more official level, in Ontario's curriculum documents, right beside graphing calculators and computer algebra systems.

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