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USING SIMULATION GAMES FOR TEACHING AND LEARNING DISCRETE-EVENT SIMULATION

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ABSTRACT

Capturing and retaining the attention of students while learning complex topics like modeling and simulation is a critical task. In discrete-event simulation (DES), educators rely on examples like queueing systems in fast food restaurants or manufacturing organizations to provide the necessary context for learning. In many instances, these examples fall short in capturing the attention of students, especially at the middle and high school levels. One approach for learning complex topics, like creating simulations, is through gaming. This paper reports on the creative use of regular simulation tools to develop simulation games with entertainment content aimed towards engaging young learners. Two games are presented: one focuses on the use of decision nodes while the second focuses on the use of batch/separator nodes. As part of future work, we propose to use these games to evaluate how much knowledge transfers from an entertainment context to one using simulations for real-life situations.

1 INTRODUCTION

Let's consider the following situation where an instructor attempts to familiarize students with the notion of queues and discrete-event simulations:

> "We observe queuing systems wherever we go: at the fast food restaurant, at the coffee shop, at the movies, at the theme park. Moreover, what we learn from these systems we can extrapolate to systems in areas like manufacturing, banking and healthcare to mention a few. These systems can be characterized by people or things arriving for a service; if the server is busy then they wait. After being processed, they leave the system…"

If the situation above is presented to middle or high school students, it may present a challenge of keeping them engaged with the "next exercise." Their initial reaction might be positive. However, they lose

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interest quickly. Educators, today, compete with a large number of digital distractors that overload students' attention. As such, we are called upon to become more creative in the ways that we engage students for the long term and to gain their attention so that they further process what they are learning. Gaming is one way to accomplish this task.

Games are widely used to engage students in learning. PhET (Moore, Chamberlain, Parson, and Perkins 2014), for instance, uses simulation to teach/learn concepts in areas like biology, chemistry, and physics and engage students through intuitive games. Yet, while games are used for teaching/learning complicated concepts and have somehow proven to be successful, we do not have many options for teaching/learning simulation use and creation. System Dynamics has what is perhaps one of the best-known games to learn the concept of delay and feedback: the beer distribution game (Sterman 1989). However, this game is oriented to what could be considered motivated students, of appropriate age, who can grasp the positive implications of understanding the concepts of delay and feedback. Agent-based models have also been used under a game perspective with a similar goal of training older participants (Akhbari and Grigg 2013). In discrete-event simulations we can also consider the use of games for teaching/learning like logistics and supply chain. However, these topics are of less interest as the student/trainee gets younger. To provide an opportunity for scaffolding and to encourage students to moving into more realistic games, we propose the development of games focused on entertaining topics to later move onto more serious topics.

According to Schell (2005), entertainment, while considered frivolous, is important as it provides, among other important aspects, a cornerstone of discovery. As such, entertainment can and should be considered as a conduit to engage in learning. In this sense, we propose simulation games that first attempt to provide the idea of an entertaining learning activity, where the student can learn about discrete-event simulation concepts in a non or reduced jargon form, before moving onto a more serious game mode.

This paper presents two game examples and the learning objectives associated with each game. Game one (Dystopian City) focuses on the learning of the use of decision blocks. Game two (Medieval Wars) focuses on the use of batch, separators, and decision blocks. In addition, it allows the gamer to extend the game providing an option between a closed and an open simulation game (Kriz 2003). Both games are oriented towards discrete-event simulation. However, it is noted that similar approaches can be taken for teaching/learning any simulation paradigm with tools currently used by educators. No special tool was used in this case.

2 SIMULATIONS, GAMES AND LEARNING

Simulations provide an efficient and effective way to learn. According to Alessi (2000) "studying by using a simulation is quite different than studying a book, listening to a lecture, or doing a computer drill. In a scientific discovery simulation, for example, the learner is performing experiments, varying input variables in a systematic fashion, observing and recording output, and (if the simulation is designed well) reflecting on the results" (p. 185). Thus, simulation learning is more than a single activity and can be seen as a series of activities that move between *using* and *creating* simulations fulfilling different advantages in terms of learning efficiency and depth.

In simulation use the learner is exposed to complex systems for which she does not need to build a simulation. In this case the simulation facilitates learning by providing a virtual environment in which the learner interacts safely, without the fear of damaging equipment or endangering people. In simulation creation the learner requires more depth when learning as this requires knowledge of the system or phenomenon of interest. Additionally, a student may build her representation of the system and actively change that representation towards creating new scenarios that allow her to answer different questions by capturing different levels of abstraction. Considering both simulation use (efficient learning) and simulation building (deep learning), each activity pushes students to higher levels of learning according to Bloom's Taxonomy (Bloom 1956).

Yet, while using and creating simulations facilitates learning of complex concepts, learning to use and create simulations is a challenging topic in itself. Training to become a modeler is like training for any other

STEM-related discipline. The proposed approach is to use games in an entertaining fashion to facilitate the transition to more realistic case scenarios.

Kapp (2012) makes a direct case of games as abstractions of reality where players, abstract thinking, and interactivity among others converge. Albeit directed, that abstraction of reality is not unlike the one provided by simulations. Simulations provide an advantage in addition to directed use: the ability to create your own game. In other words, instead of playing with puzzles, learners have the chance of creating puzzles or in this context, to create simulation games. This is an important difference to the way most of us use simulations: simulations are used as a conduit to learn topics that are not directly related to modeling and simulation (M&S), such as for learning chemistry concepts.

3 DISCRETE-EVENT SIMULATION

According to Robinson (2005), "Discrete-event simulation is one of the most commonly used modelling techniques" (p. 619). DES has been used in studying a wide range of queueing systems, including museums (Gunal and Sezen 2014), airport terminals (Guizzi, Murino, and Romano 2009), healthcare (Findlay and Grant 2011; Gunal and Pidd 2010), manufacturing (Semini, Fauske, and Strandhagen 2006) and road constructions (Lu 2003), among others, with the goal of optimizing system performance, diagnosing issues, and evaluating alternatives. Further, these systems are a topic of study across engineering programs like Manufacturing (ME), Industrial (IE), Systems (SE), Management (EM), and Aerospace (AE) to mention a few programs where learning about discrete-event simulations is not only relevant but also provides students with a great impact in preparation in STEM-related concepts.

A succinct description of queueing systems is presented by Diaz and Behr (2005):

"the three basic elements within a queuing system are entities, servers and queues. Entities can represent either customers or objects, servers can represent persons or production stations that treat or interact with the entity, and queues are the holding or waiting position of entities (…) the arrival process is characterized by the interarrival time, or the interval of time between successive customers or objects entering the system (…). Upon arrival, an entity enters into the system at which point the entity proceeds directly to either a server to receive service or to a queue if it is the case that all servers are busy."

As it can be surmised by this description, queueing systems are pervasive, observable, and have measurable variables. These characteristics make DES appropriate for K-12 students to learn STEM concepts through simulations and simulation modeling as they are familiar with these systems (fast food, amusement parks, and movies). Therefore, the amount of specific domain knowledge required to study these systems is minimal. In other words, students familiarize with a useful method that can have real impact on their daily lives and that they may encounter in college or at the work place in the future.

It is important to note that while DES tools exist they do not necessarily convey how to model. According to Robinson (2005), "although software vendors provide training in the use of their packages, in general they do not train their users to be simulation modellers" (p. 625). In other words, we want to train modelers that know how to use the tools of the trade. Games may provide both the context for learning how to model as well as help to familiarized students with the tools of the trade. It is important to note that while the case presented here focuses on DES, the same approach can and should be used for teaching/learning how to model under different paradigms or multi-paradigm.

4 LET THE GAMES BEGIN

According to Van Eck (2006), a game can be suitable for use in the classroom if the game aligns with the class content and the game is not so easy that it is not engaging. This is important as it requires a different game depending on the content. In this case, by focusing on DES (or any paradigm for that matter) would provide support not only for M&S practice, which is general in nature, but also as an introduction to topics that use DES like banking services, manufacturing, etc. Additionally, through games, users can arrive to an optimal learning state which is being in a state of "flow" (Csikszentmihalyi 1997) characterized by intense focus/concentration, distortion of temporal experience, and experience an activity as intensely rewarding among others.

We created and utilized two games that seek to facilitate the teaching and learning of DES modeling: Dystopian City, and Medieval Wars. The goals of using these games includes the learning of the basic building blocks of simulation implementations: entity, arrival, resource, and processes. Three intermediate blocks are presented: decision, batch, and separator. Game descriptions will contain the rules of the game and what the player is supposed to observe. More importantly, the descriptions contain the learning objectives. These games are purposefully presented in an incomplete construction as part of the intended DES learning process as this pushes the students to get hands-on experience by completing the models in order to meet the defined objectives. In particular, the focus is on the learning to use some of DES blocks, like decision and batch, and on the use of simulation for experimentation via the varying of block parameters. Blocks are meant to be added to the simulation model and selection made of the appropriate block type based on the game description. This type of exercises fit into a curriculum mainly for learning simulation use, as the games require experimenting with the simulation of a system, and partly as learning simulation creation as learners need to complete the game in order to use it.

It is noted that metrics for evaluating whether the student learns through game completion relies on the instructor's session goals. However, two suggested metrics for measuring learning are: (1) correct selection of block type and (2) the appropriate variation of block parameters as to achieve the gaming objectives. Potential methods for evaluating the effectiveness of the learning vary from simple inspection to requesting an explanation how 1 and 2 were achieved.

Ultimately, it is expected that the games supports M&S education by providing an entertaining context for learning. Like simulations, games are abstractions that require abstract thinking and as previously mentioned, provide a cornerstone of discovery (Schell (2005). Unlike simulations, games are characterized by a higher level of interaction and engagement as "fun" is expected as part of the experience. In that sense, DES games are expected to provide fun-like experience while engaging students in M&S learning. What remains to be considered, is how much, if any, transfer of learning takes place. Moving from zombies to queues in an emergency room is not immediately obvious. To account for the potential confusions, the games rely on people queuing for accessing resources in a similar fashion to regular queuing scenarios. The variation, in this case, is the context where queuing is utilized.

Lastly, the games were implemented and made publicly available in the CLOUDES environment (Padilla et al. 2014).

4.1 Game One: Dystopian City

The Dystopian City game is based off the shooting and strategy game "Balloon in a Wasteland." A large group of people are stranded in a very dangerous city and need to get out. People need to navigate through the city along two paths: (1) dangerous; and (2) almost suicide. The dangerous path takes longer, but chances of demise are less compared to the almost suicide path which is faster but with higher chances of demise. The goal of the game is to set the decision points in a manner that allows (1) similar survivability levels (difference between survivals of less or equal than two), (2) more offensive survival (difference >= 3), and (3) more defensive survival (difference >=3) by (a) changing the decision block parameters and then by (b) also altering arrival and process block parameters.

The **almost suicide** path is taken by offensive players. The first step requires to get to D0 where each player is sent onto its path and then jumps into a taxi cab and drives to decision point 1 Offensive (D1-Offensive). The car keys are obtained from the crazy dog called Loko. It takes 10 minutes to get to D1-Offensive where the player plays a loaded coin with 30% chance of being eaten by aliens from the planet Empty and 70% chance of continue the game. If it survives the loaded coin, then it jumps onto the back of a truck and rides the truck for 15 minutes until reaching D2-Offensive where the player selects the shortest queue giving it the chance to move to the dangerous path. If it stays on the almost suicide path, then the player takes a bike from the Bike fixer. The bike allows the player to immediately arrive to D3-Offensive where it tosses a loaded coin with a 70% chance of being eaten by hungry, flesh eating cows. The cows have the same name: CowBellas. Otherwise, the player on the almost suicide path survives the city.

The **dangerous** path is taken by defensive players. Like the offensive players, the first step requires reaching D0 where each player is sent onto its path and then drives to decision point 1 defensive (D1-Defensive). To do so, it takes a bus from the talking cat called TalCat. It takes 25 minutes to get to D1-Defensive at which point the player plays a fair coin: 50% chance of moving on or being eaten by the evil clown named NotFunny. If moving on, then the player rides a slow moving tractor for 20 minutes until reaching D2-defensive. On D2-defensive, the player has the option of jumping over to the almost suicide path if the queue (queue 19) is shorter and continues on that path. Otherwise, the player rides on the Lawnmower Man's lawnmowers. The ride takes five minutes to reach the D3-defensive point. Here, the player tosses a loaded coin with a 55% chance of being washed away by a huge WasherwithNoDryer device. Otherwise, the player on the dangerous path survives the city.

Figure 1 shows the portion of the simulation game where D1-Offensive is supposed to go. The simulation game can be accessed by the reader at http://cloudes.me.

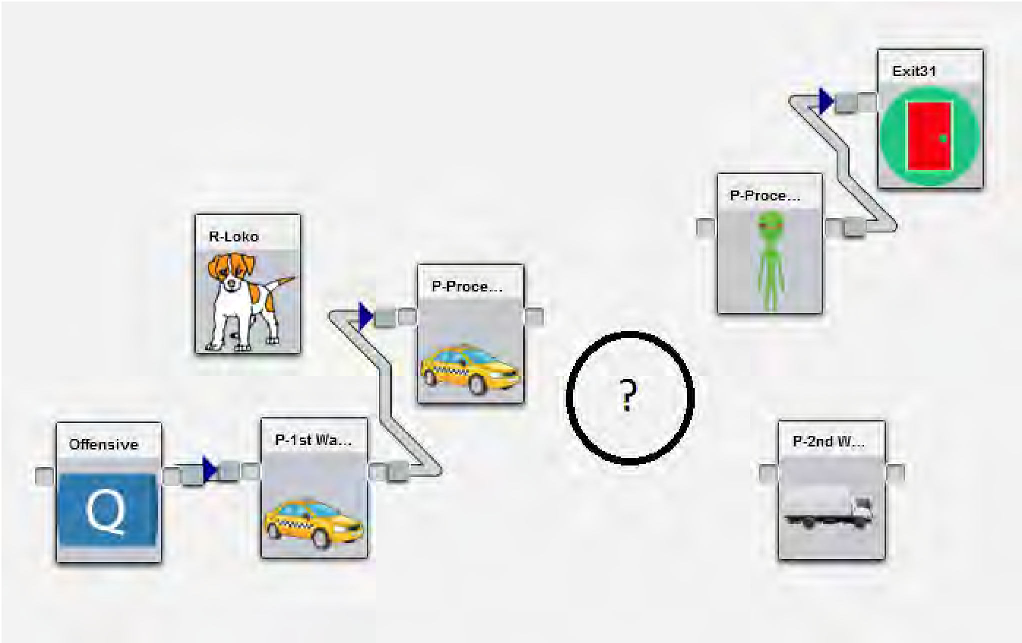

Figure 1: Snapshot of Dystopian City DES Game in CLOUDES.

The learning objectives of the game and the prerequisite needed for its completion are:

- *Learning objective 1:* the student/gamer will successfully apply the three decision block options (decision by entity type, by chance, and by shortest queue) based on the description of the model and the incomplete model available in CLOUDES.
- *Learning objective 2*: the student/gamer will successfully vary the decision blocks parameters in order to achieve the three gaming objectives.
- *Learning objective 3*: the student/gamer will successfully vary other block parameters (arrival, process, etc.), as well as decision bock parameters, to achieve the three gaming objectives.
- *Prerequisite:* understand the basis of DES implementation including entity, arrival, resource and process blocks and how they form a model.

It is important to note that the learning objectives are part of a larger ultimate learning objective: learning how to create DES. As such, this game needs to be complemented with others under a curriculum design. However, variations of the same game could move the gamer closer to the goal like grouping offensive and defensive teams to teach/learn about batch/separator functions.

4.2 Game Two: Medieval Wars

During the Middle Ages various conquests occurred based on changing military might due to advances in technology and military tactics. Heavy cavalry and knights dominate the battlefield with their armor providing significant protection from enemy forces. However, the arrival of the English **Longbowmen** may swing the balance of power through the ability to pierce through armor and horses from a great distance. Sheer numbers give the advantage to Scandinavian **Viking**, Swiss **Pikemen**, and Asian **Mongol** troops: Vikings have their ships and naval advantage, Pikemen have a strong infantry with climbing tools giving them an advantage over mountainous terrain, and Mongols cunning knowledge of naval and terrain tactics giving them advantages on both environments. Who would be victorious at the end? Longbowmen, Vikings, Pikemen or Mongols? Who would vanquish the enemy troops in the area?

The goal of the game is for the player to select a team and minimize the number of casualties in that team at the end. The player does so by changing group sizes and casualty percentages. But first, the player needs to add batches, separators and decision blocks to tally the winners and losers.

Battles occur when enough soldiers arrive to form an army for each side. The battle process is captured through the use of batch and process blocks. Batches group specified numbers and types of entities together to form a representative entity, such as an army. The process following each batch represents the length of time that a battle lasts. A separator then breaks the armies back into their individual units and decision nodes tally the number of units that lived and died from each army. The decision nodes represent the presumed skill level of each army and represents the likelihood of casualties for each army. Survivors of each battle are redirected back to the batches so that they can reinforce and participate in additional battles. The number of English, Viking, Swiss, or Mongol troops killed are tracked in order to explore how the skill level of the troops effects the number of casualties at the conclusion of a four week campaign.

The Longbowmen entities branch into three identically-structured paths to fight against the three different forces. On each of these paths the game player needs to access the currently existing batch (Form_Armies_1, Form_Armies_2, and Form_Armies_3) and specify the number of each troop needed to qualify as a warring army. Next, a decision node needs to be added following each separator that splits the incoming entities by type in order to direct the divided entities towards the casualty-based decision nodes (note that a different casualty decision node exists along each path for the Longbowmen). The casualty nodes decide the path that incoming entities will choose based on the chance (1) that a unit dies and is sent to an exit node (Casualties_1, Casualties_2, or Casualties_3) or (2) that the unit survives and is redirected back to its path's batch to support its comrades in additional battles.

Figure 2 shows a snapshot of the simulation game. The simulation game can be accessed at http://cloudes.me.

The learning objectives of the game and the prerequisite needed for its completion are:

- *Learning objective 1*: the student/gamer will successfully apply batches, separators, and decision nodes based on the description of the model and the incomplete model available in CLOUDES.
- *Learning objective 2*: the student/gamer will vary the necessary parameters to achieve victory for the selected team.
- *Learning objective 3*: The student/gamer will extend the game by introducing horses and weapons, ships, climbing tools and both ships/climbing tools and batching them with Longbowmen, Vikings, Pikemen, and Mongols respectively. Extending the game brings an extra level of complexity to the task by adding new entities and new batching.
- *Prerequisite*: understand the basis of DES implementation including entity, arrival, resource and process blocks and how they form a model.

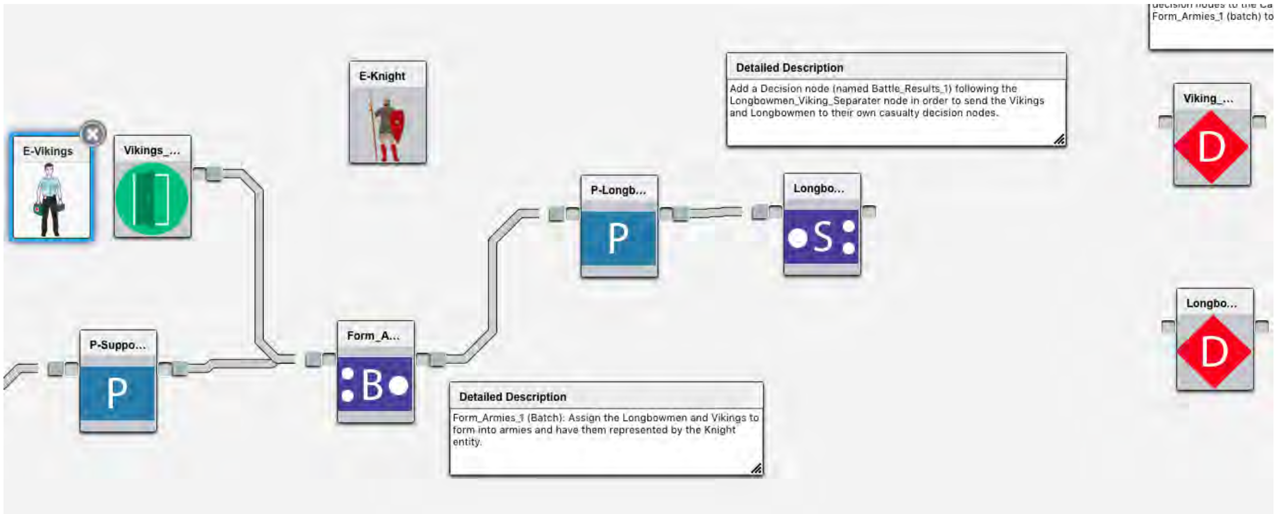

Figure 2: Snapshot of Medieval Wars DES Game in CLOUDES.

As mentioned before, the ultimate learning objective is the learning of discrete-event simulation so the game must contain conceptual elements that fulfill that goal. In other words, the games, while having an entertainment content, need to fulfill the learning objectives.

5 CONCLUSIONS AND FUTURE WORK

This paper explores the idea of using simulation games, with entertainment content, for learning/teaching discrete-event simulations. It is argued that while we can use realistic examples, even within a game format as in business decision making, games provide an entry point for non-experts especially for middle/high school students. Two games were proposed: Dystopian City and Medieval Wars. Dystopian City focuses on learning the use of different types of decision blocks. Medieval Wars focuses on the use of batch, separator, and decision blocks. Both games require knowledge of basic discrete-event simulation components like arrivals, processes, and resources to mention a few. In addition, it is encouraged on both games to further introduce new simulation components so the game can grow with the needs and skill levels of the gamers.

Future work includes the evaluation of these games in a class setting and measures (1) whether or not learning occurs, (2) whether or not games are advantageous to traditional examples, (3) whether there is transfer of learning, and (4) the level of engagement learning through games compared to traditional examples. We will make considerations for students of different ages. For instance, we hypothesize that younger users (middle and high school students) will be more engaged than older students (college) in learning about DES through games. Engagement in this case will be measured by: session length when learning using games; number of sessions dedicated to a game; amount of time dedicated until the gaming and learning objectives are achieved; as well as students' verbal statement of interest.

Lastly, we suggest that a similar approach be used for teaching/learning other simulation paradigms as the development of these games do not require special software beyond those already used by educators. It is suggested, however, to create games in easy to use tools in order to prevent the tool from becoming a distractor to the learning process.

6 DISCUSSION

Perhaps the major challenge for the development of games for teaching/learning simulation, at least for middle and high school students, is the lack of implemented curricula for M&S. Even if games were developed for this purpose, it would be a challenge for instructors to implement these games as part of their standardized coursework. This is of course under the assumption that schools and teachers are aware of the benefits of M&S for teaching simulation use and creation but also as a support for learning STEM related concepts and materials. One suggested approach is using simulation games, in this case, to teach/learn concepts in statistics. For instance, students/instructors could use the game as an experimental setting just like one would a simulation.

Having students change the frequency at which customers/warriors arrive and the frequency at which servers/game activities perform shows the impact on the outcome of the simulation (who survives for instance).

One aspect that became apparent before the development of the game is the reliance on the use of discrete-event simulation and queueing theory terms: batches, queues, or resources. Some of these terms are not of common use among non-experts generating another barrier for learning. We suggest exploring naming options for some of these terms that directly reflect the context of the game: instead of batch, use a term like "grouping" and instead of queue "do the line." The use of the appropriate term is important for rapid assimilation of concepts. As in the game case, the appropriate terms should be introduced at a later time.

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