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Toward an Outcome-Based Methodology for Developing Game-Based Learning Environments

Raymund SISON*, Candy ESPULGAR, Luis MADRIGAL, Jarl Brent OBEDOZA, Neil ROMBLON, Jazmine SACE, Maynard SI
College of Computer Studies, De La Salle University, Philippines
*raymund.sison@delasalle.ph

Abstract: The growing number of resources that offer advice on the development of effective game-based learning environments indicate a growing interest in effective methodologies. This paper describes a methodology for educational game design that begins with, and is based on, intended learning outcomes (LOs), with the game serving as a set of interlinked mechanics and other elements that support, directly as well as indirectly, the attainment of the LOs. Preliminary results suggest that due to the centrality of the LOs and LO mechanics in the methodology, the quality of the LO mechanics and the degree of their integration with the other game elements would determine the level of users' engagement.

Keywords: Game-based learning, educational game design methodology, learning outcomes

1. Introduction

Meta-analytic reviews of educational game studies seem to confirm the potential of video games to support learning and teaching processes (e.g., Wouters, et al., 2013). Meanwhile, the growing number of books that offer advice on the development of educational games indicate a growing interest in effective methodologies.

This paper describes a methodology for educational game design that begins with, and is based on, intended learning outcomes (LOs), with the game serving as a set of interlinked activities that support, directly as well as indirectly, the attainment of the LOs. In the next section, we list and discuss the steps of an outcome-based methodology for educational game development. In the third section, we then describe the use of the methodology in the design of two game-based learning environments (GBLEs) for elementary mathematics.

2. Outcome-Based Educational Game Design

Learning outcomes have become a major element of transnational education and qualification frameworks (e.g., Bologna Process, Washington Accord) and of entire national education frameworks (e.g., Malaysia, Hong Kong). There are several approaches to outcome-based teaching and learning (OBTL), one of which is Biggs' constructive alignment, which requires that teaching/learning activities (TLAs) and assessment tasks (ATs) be aligned with intended learning outcomes (LOs). It has four stages (Biggs and Tang, 2011, p. 100):

- Describe the intended LOs in the form of a verb (learning activity) and its object (the content);
- Determine TLAs that address the verb and therefore are likely to bring about the LOs;
- Use ATs that also contain the verb, thus enabling judgment, with the help of rubrics, if and how well students' performances meet the criteria; and
- Transform these judgments into standard grading criteria.

Based on these steps, and on incremental and iterative models of software engineering (e.g., Scrum), we propose the methodology in Figure 1 for developing a Game-based Learning Environment (GBLE). We define a GBLE as a digital game that facilitates the achievement of specified learning outcomes.

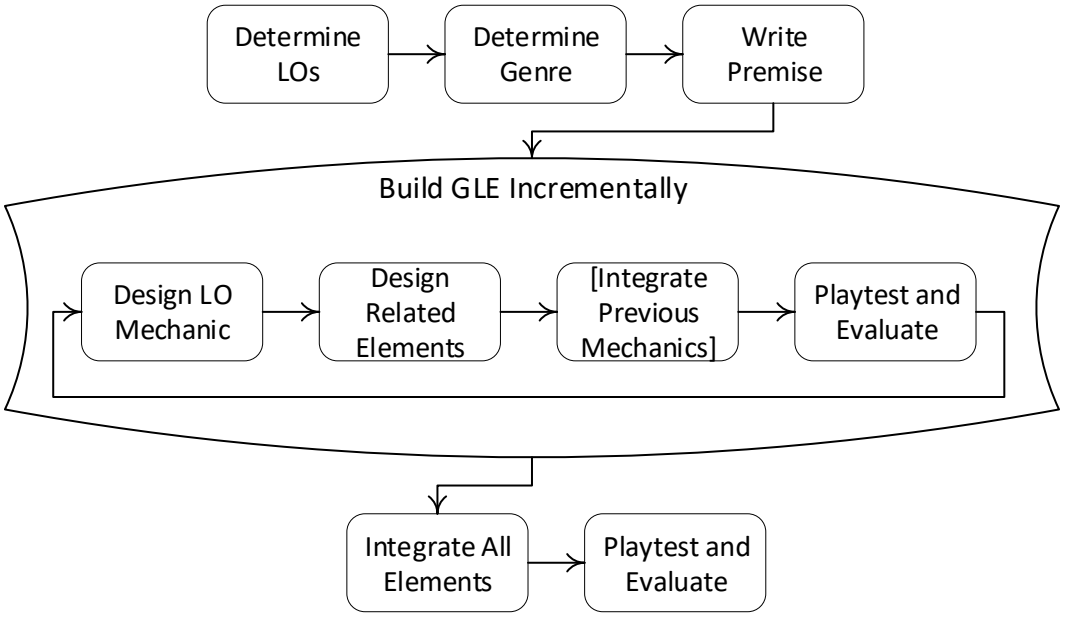

Figure 1. Outcome-Based Methodology for Game-Based Learning Environment Development

We now discuss the steps in Figure 1.

1. *Determine the Learning Outcomes (LOs).*
   An LO is usually expressed as a verb phrase (e.g., add fractions). Typically, the objects of these verb phrases denote concepts (e.g., fractions), while the verbs denote processes (e.g., the addition procedure). The source of LOs could be national, state, or institutional standards. The choice of which LOs to cover in a GBLE is determined by stakeholders (e.g., Grade-4 mathematics teachers, a funding agency).
2. *Determine the Game Genre.*
   The genre of a GBLE—whether action (e.g., Grand Theft Auto), adventure (e.g., Tomb Raider), role-playing (e.g., Final Fantasy), strategy (e.g., Civilization), or simulation (e.g., The Sims)—will depend on several factors. First would be the LOs, since a GBLE is supposed to lead to the achievement of the LOs. Second would be the genre that the target players might prefer. This could be determined through a survey or focus group discussion (FGD) of target players (e.g., Grade 4 students), or of stakeholders who understand the target players (e.g., Grade 4 mathematics teachers). The third factor would be the familiarity of the game designers with the genre.
3. *Write the Game Premise.*
   The premise of a game is what it is about. A good premise provides high-level answers to three questions (Mayer, 2016): What is the player's primary goal? How will the player achieve that goal? What is the environment/world within which the goal will be achieved? Premises provide a way of tying together what Fullerton (2014) calls a game's "formal" elements (goals, procedures, rules, resources, and boundaries) and "dramatic" elements (challenge, play, character, story, and world building), with what we call a GBLE's "learning" elements, embodied in the LO mechanics.

The next four steps (4-7) are implemented iteratively. Each cycle involves one LO mechanic.

4. *Design LO Mechanic.*
   An LO mechanic is a game mechanic that helps the learner-player: (1) achieve an LO, and (2) determine whether and to what extent the LO has been achieved. There are, therefore,

two types of LO mechanics: teaching/learning (TL) mechanics and assessment task (AT) mechanics.

A TL mechanic helps the learner-player achieve an LO without necessarily being aware of it. Specifically, it helps the learner-player understand an LO's content by getting him/her to perform the LO's verb. For example, a mechanic for "draw angle" could involve hitting an enemy character with a power blast by swiping one's finger left then right at an angle. There should be at least one LO mechanic per LO.

An AT mechanic, on the other hand, helps the GBLE determine whether and to what extent the learner-player has achieved an LO. An AT mechanic can involve several TL mechanics.

To be effective, LO mechanics and the other formal and dramatic elements of a GBLE must be designed with the help of established guidelines (e.g., Sweetser et al., 2017) as well as what the domain's literature suggests to be effective ways to teach the domain's contents (e.g., in mathematics education, it is now clear that conceptual understanding, and not just procedural skill, is important to develop in learners, and this can be done through visualization and the design of TL activities with multiple pathways).

5. *Design Other Elements Related to the LO Mechanic.*
   Other non-LO mechanics will, of course, have to be designed. For example, movement mechanics have to be designed for a player's character to be able to traverse the game space. There are also other game elements aside from mechanics that have to be designed, such as non-player characters (e.g., enemies), game objects (e.g., a sword), and the world within which the premise and LO mechanic are set.
6. *Implement the LO Mechanic and Other Related Elements, and Integrate Previous Mechanics.*
7. *Playtest and Evaluate.*
   One may integrate the newly implemented LO mechanic with all previously designed, implemented, and playtested LO mechanics (and associated game elements), and then playtest and evaluate the integrated mechanics together. Alternatively, one may playtest and evaluate one LO mechanic (and associated game elements) at a time.

The loop in Figure 1 from "Playtest and Evaluate" (in "Build GBLE Incrementally") back to "Design LO Mechanic" could involve either redesigning an LO mechanic based on the results of playtesting and evaluation, or the design of another LO mechanic, whether TL or AT mechanic.

8. *Integrate All Elements.*
9. *Playtest and Evaluate.*

These last two steps would involve integrating all other game elements or components, such as tutorials, that are not directly related or crucial to the LO mechanics, and playtesting and evaluating the game-based learning environment as a whole.

The methodology in Figure 1 is incremental in that it builds the GBLE one LO mechanic at a time. It is also iterative in that building the GBLE involves several cycles of LO mechanic design, other-elements design, implementation, integration, playtesting, and evaluation.

3. Using the Outcome-Based Methodology in the Design of Game-Based Learning Environments for Elementary Mathematics

We used the outcome-based methodology described in Figure 1 in the design of two GBLEs for elementary mathematics, which we will describe in a short while. These GBLEs are actually game-based *intelligent* learning environments (GILEs), which use artificial intelligence (AI) techniques for learning modeling and pedagogically adaptive interaction, but this paper will not discuss their AI components. Interested readers are referred instead to (Espulgar et al., 2018) and (Madrigal et al., 2018). Both games were developed using Unity for use on PCs as well as Android devices.

3.1 A GBLE for Fractions

Discord is a GILE that aims to promote conceptual understanding of Grade 4-level fraction number sense. Specifically it aims to help its players achieve the following learning outcomes:

- Add and subtract similar fractions (also known as fractions with like denominators)
- Change dissimilar fractions to similar fractions (using LCD)
- Add and subtract dissimilar fractions (also known as fractions with unlike denominators)

These correspond to the fraction LOs in the textbook used by the Grade 4 students of the De La Salle University Integrated School. They also correspond to LOs 30-36 of the Department of Education's Curriculum Guide for K-12 Mathematics.

Discord revolves around Yuni, a discarded theater puppet that gained awareness when the sky broke, and resolves to return the world to its proper state by attempting to fix the fractured sky.

3.1.1 LO Mechanic 1: Needle

Throughout the game, the player encounters *partitionable objects*, which are semi-transparent, rectangular objects of different sizes. These are incomplete objects that remain intangible to the player character until they become whole. Once whole and tangible, these objects can be used by the player character to navigate the world. The player can make these objects whole through the *needle* mechanic. Once hit by the needle, a partitionable object's segments will be shown to the player (see the bottom rectangular object in Figure 2a) and a second box of the same size then appears above the partitionable object. The player must then get segments from the second box to make the partitionable object whole. This mechanic follows the part-whole concept of fractions, and partitionable objects are used to visualize fractions as parts of a whole.

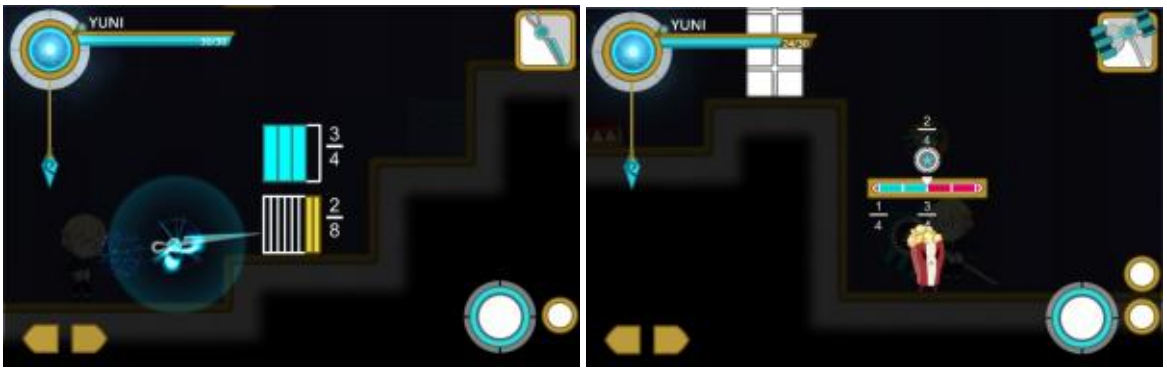

Figure 2. Needle and Hammer Mechanics

3.1.2 LO Mechanic 2: Hammer

The player character can also encounter hostile characters, each of which has a number line as life gauge. Each such number line has: (1) an *initial pointer* (the small pointer seen on the upper edge of the number line in Figure 2b), which tells where the enemy's life is currently at; (2) the *target value* (indicated by the star above the number line), which tells the player what value to set the initial pointer to; and (3) the numerical fraction labels of these pointers. To pacify these hostile characters, Yuni must use a *hammer* to bring the pointer of the number line to the target value.

3.1.3 LO Mechanic 3: Yarnball

Appearing throughout each stage of the game are yarnballs, which a player can either pick up or hit with the hammer. Picking up the yarnball changes the denominator of the player's needle and hammer. Hitting the yarnball propels it in a specified direction. Once it hits an enemy with a

number line, a mini game begins, in which the player solves the LCD of the number line's target value and the yarnball's value. This is done by aligning the bars corresponding to the two values.

3.2 A GBLE for Elementary Geometry

A Samurai's Fable is a GILE that aims to promote conceptual understanding of Grade 4-level geometry, particularly angles and triangles. Specifically it aims to help its players achieve the following learning outcomes:

- Draw different angles
- Measure triangle sides and angles
- Identify triangles according to sides and angles

These correspond to the angle and triangle-related LOs in the textbook used by the Grade 4 students of the De La Salle University Integrated School. They also correspond to LOs 47-49 of the Department of Education's Curriculum Guide for K-12 Mathematics.

A Samurai's Fable revolves around a red panda samurai, who is tasked to save what was once a prosperous land overtaken by the evil Yōkai—monsters that bring sorrow to the lives of the peaceful animals in the land.

3.2.1 LO Mechanic 1: Bow and Arrow

The *bow-and-arrow* mechanic is used when the player has to draw an angle (to hit a flying beetle spirit in Figure 3a) or measure the angles of a triangle (to destroy the flying drums of the Raijin thunder god in Figure 3b). When the player clicks on a red flame or drum, a semicircular aura with markings (a protractor actually) appears. To draw or measure an angle, the player drags the red flame toward the center of the aura, forming a base ray, and then drags his/her finger in a particular direction (toward a beetle spirit, or toward a drum of the thunder god), thereby forming an angle. When the player releases his/her finger, an arrow is fired at the angle specified, hitting (or missing) the target.

Figure 3. Bow-and-Arrow Mechanic

3.2.2 LO Mechanic 2: Sword

The *sword* mechanic is used to measure length (e.g., the height of the Oni land monster in Figure 4a, or the length of the sides of a triangle of chains that protect the Wanyūdō in Figure 4b). The player quickly slashes at an Oni or a protective chain to lengthen the sword. The sword must be of the right length for it to break an Oni or chain.

3.2.3 LO Mechanic 3: Ritual

Once all of a Raijin's drums or Wanyūdō's protective chains have been destroyed, the player can finally defeat the Raijin or Wanyūdō itself by selecting the correct card corresponding to the type of triangle (e.g., acute, scalene) that used to protect the enemy.

Figure 4. Sword Mechanic

4. Preliminary Results

The GBLEs were evaluated using a variant of Sweetser et al.'s (2017) GameFlow model, which identifies eight elements of player enjoyment. The averages of the GameFlow-based evaluation scores of three educational game designers were 4.38 for Discord and 4.04 for A Samurai's Fable, which denote "well done" in the model. The highest scoring element or criterion for both GBLEs was Player Concentration, which could be due to the tight integration of the game elements with the LO mechanics. The lowest scoring criterion for Discord was Control, mainly because users could not pause the game. The lowest scoring criterion for Samurai was Clear Goals, because the introduction apparently did not provide enough background and motivation, and there were no in-game cutscenes that furthered the story.

5. Concluding Remarks

In this paper, we have described an outcome-based methodology for the design of game-based learning environments. The methodology begins with, and is based on, intended learning outcomes. We have also described the use of the methodology in the design of two GBLEs for elementary mathematics. Preliminary results suggest that due to the centrality of the LOs and LO mechanics in the methodology, the quality of the LO mechanics and their integration with the rest of the game elements would determine, more than any other game element, the level of users' engagement.

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