Design of a Game-Based Intelligent Learning Environment for Elementary Geometry

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Abstract: Mathematics is a subject that is often stigmatized and avoided by students because of its uninteresting methods. Mathematics teaching prioritizes the improvement of basic skills as opposed to developing mathematical thinking. Yet, to achieve mathematical thinking, conceptual understanding must be first obtained. However, every individual may not have the same approach in learning a concept, thus individualized learning is important wherein each student has their own learning pathway. These methods can be translated into a video game which would make learning geometry, which is a branch of mathematics engaging and interesting. Video games can provide an immersive environment and can provide incentive for the player to keep playing thus, they keep on learning. A Game-based Intelligent Learning Environment (GILE) integrates the methods of intelligent tutoring system into a game environment, refining the learner's mastery of a topic by adjusting the problems in the game with reference to a learner model. This paper discusses the components of a GILE, the design of a geometry game on the domain of angles and triangles that would promote conceptual learning, and the game's preliminary evaluation of its mechanics and player enjoyment. Preliminary results indicate that the game has features that are both engaging and suitable for Geometry learning. This research offers insight into Game-based learning and the use of a learner model in educational games that make individualized learning possible and engaging.

Keywords: Game-based intelligent learning environment, game-based learning, educational games for elementary geometry

1. Introduction

Mathematics has usually been stigmatized as a subject that is often avoided by students because of its perceived difficult and uninteresting methods (Boaler, 2016, p. 65). This stigmatization negatively influences the students' motivation to succeed on the subject. Devlin (2011, p. 1) describes the state of mathematics teaching as prioritizing the improvement of basic skills (routinely performing computations in a subconscious manner) as opposed to developing analytical thinking through conceptual understanding.

Conceptual understanding, as described by Devlin (2011, pp. 107-115) is achieved when the learner has adequate comprehension to work efficiently on a concept while still allowing for the learner's growth and mastery of the topic. Conceptually understanding a topic allows for quick and total recollection without requiring much effort (Thurston, 1990). Contrarily, procedural skill is the ability to execute action sequences to solve a problem, i.e. problem drills schools use. The development of procedural skill and conceptual learning is an iterative process–that development of one contributes to the development of the other, which would then turn to further development of the first (Rittle-Johnson, Siegler, & Alibali, 2001). Consequently, the achievement of conceptual understanding benefits directly to the student's performance since developing conceptual understanding further improves the student's procedural or problem-solving skill. It is important to consider that every individual may not have the same approach in understanding a concept.

Boaler (2016, p.180) argues that it is very important that students are offered the opportunity to take mathematics to different levels and not give them closed math questions

suitable for only a small subset of the class. This can be done through "individualized learning" wherein each student has their own learning pathway (Boaler, pp. 183 - 185). Individualized learning is wherein a course, for example, has multiple variations that are adjusted for each student, to the fit needs of the learner more accordingly.

Given these considerations, the features of a videogame can be proven to be suitable for providing basic Mathematics education (Devlin, 2011). Games provide an immersive environment in which the user has a strong sense of being and acting in that world. Games can provide intrinsic motivation for the player, engaging them and allowing them to play longer (retention), which allows them to learn more. Games allow for mastery by making repetition of a skill meaningful and fun. Games also allow players to learn through failure, giving them an opportunity to learn without fearing heavy consequences. Games can also provide an opportunity for conceptual learning, which can be done by designing game mechanics with regards to the concepts of a learning outcome as seen in table 1.

The overall goal of this project is to develop a Game-based Intelligent Learning Environment (GILE), which integrates the methods of an intelligent tutoring system into a game environment that promotes individualized learning and conceptual learning while keeping the players engaged. We are developing a GILE for grade 4 geometry (angles and triangles) that could serve as a complement to the classroom sessions but also has the capability to be played independently. The GILE is developed following an outcome-based methodology (Sison, et al., 2018), in which special game mechanics are designed for each learning outcome. The game is developed using the Unity Engine for android devices to appeal to a younger audience of gamers which are on mobile devices. Design considerations were made for the GILE, which is also why two versions of the game exists and are to be tested: the time bound version, which challenges the player to finish quickly and the non-time bound version that gives the player enough time to think and act. It is important that the learner keeps playing for them to keep learning, thus it is important to know how engaging the game is and which of the two versions is more engaging.

The objective of this paper is to evaluate the player's enjoyment for each of the two versions of the GILE prototype. It is to be evaluated using a variation of the GameFlow model (Sweetser, Johnson, Wyeth, & Ozdowska, 2012) for mobile adventure games (Sweetser, Johnson, Wyeth, Anwar, Meng, & Ozdowska, 2017) with educational purposes (Fu et al., 2009) by a different group of Educational Game Designers (EGD) and volunteer student playtesters. In the succeeding sections, the paper will discuss the GILE and its components, how the GILE was designed, how the GILE is evaluated, along with our findings and discussion. The results will indicate whether the game is properly designed to facilitate Geometry learning. This can ensure that significant learner performance improvements will be observed upon future testing of the GILE.

2. Computer-based Systems for Teaching

2.1   Intelligent Tutoring System and Intelligent Learning Environment

An Intelligent Tutoring System (ITS) is a computer program that supports learning by instruction, wherein the user is presented to a predetermined outline or a syllabus. An Intelligent Learning Environment (ILE) places the user in an environment and provides them a set of tools which the learner can manipulate or play with, so that the user could learn the target concept or skill (Sison, 2001). The intelligent constituent in both ILE and ITS is the system's ability to adapt to the learner's current understanding on the target concept, with the goal of fitting the needs of the learner more accordingly.

Woolf (2008, pp. 44-45) enumerates four components that are integral in building intelligent tutors, which are: domain knowledge, student knowledge, tutoring knowledge, and communication knowledge. The domain component represents the domain definitions, procedures, and skills (e.g. triangles are polygons that have three sides). The student component, refers to the learner's mastery of the domain, as well as other information such as the current student's possible misconceptions and their preferred learning style. The tutoring component or the pedagogical component represents teaching strategies, (examples, and analogies) and includes methods for

encoding reasoning about the feedback. Lastly, the communication component constitutes the methods for the communication between the learner and the tutoring device, to illustrate a point or to explain how conclusions were reached, for example. It can be argued that this component is encompassed by the tutoring component, because there is always some form of communication in tutoring (e.g. written, verbal, visual).

2.2   *Game-Based Intelligent Learning Environment*

A Game-based ILE benefits from a game's applicability as a medium for learning by exploration (Devlin, 2011) and provides an adaptive capability, wherein the game adjusts itself to suit the ability of the learner to improve their understanding of the domain. More formally, a Game-based Intelligent Learning Environment (GILE) integrates the methods of intelligent tutoring system (Woolf, 2008, pp. 44-45) into a game environment. The system has three components, namely: the game, the learner modelling component, and the pedagogical model. These components are devised with reference to an ITS's four components (i.e. domain knowledge, student knowledge, tutoring knowledge, communication knowledge).

2.2.1   *Game Component*

The game component contains the domain and communication knowledge. The domain knowledge is portrayed in the game through the game mechanics. The rules, definitions, procedures, and examples of the domain could be displayed through the means of puzzles, minigames, or general rules in exploring the world. The communication knowledge is portrayed through the game itself, serving as a communication medium by providing the learner with potential interactions.

2.2.2   *Learner Modelling Component*

The learner (or student) modelling component generates the learner model through the use of a statistical model. The learner model contains the student knowledge, an approximate qualitative representation of the learner knowledge on a domain that accounts (either partially or fully) for certain aspects of the student behavior (Sison & Shimura, 1998). The student behavior refers to the learner's observable responses to a stimulus from a given domain, which serves as the main input (along with the stimulus) for the learner modeling system. In the case of GILEs, the stimuli are obtained from the learner's interactions with the game component.

2.2.3   *Pedagogical Component*

The pedagogical component handles the adjustments to be made on the game component with reference to the learner model, and also contains the teaching strategies to be applied as the mechanics of the game. The pedagogical component makes use of pedagogical (or learning) theories in designing the game's problems and mechanics to effectively impact the learner's performance.

3. System Design and Development

The game-based intelligent learning system is comprised of three components as seen in figure 1, namely: (1) the game component, which is what the user would interact with, (2) the learner modelling component, which would generate the learner model, and (3) the pedagogical component which adjusts the game component with reference to the current learner model produced by the learner modelling component.
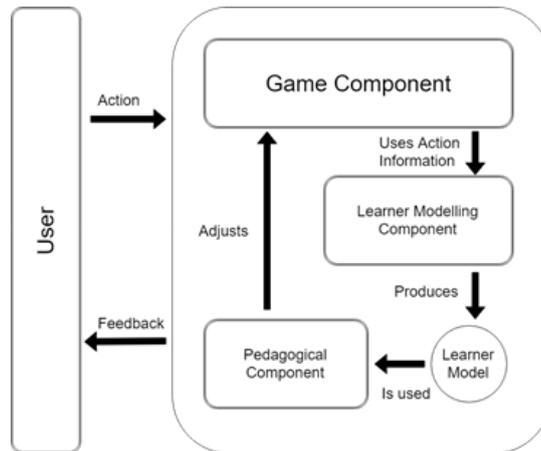
Figure 1. System Flow

3.1   *Game Component*

The game was created using Unity engine and is for android devices. The engine is responsible for the game's 2D graphics and audio, physics and the collision of objects, controlling the objects from scripts, animation, AI, memory management, and storage of user information (Arm Limited, 2018).

The game mechanic, its learning outcome and the concept, and the activity involved are based on the student model which can be found on table 1. The game revolves on two main activities: slashing and aiming (figures 2 and 3), which refers to measuring sides and angles respectively. The two main activities are extended to more complex triangle mechanics (figures 4 and 5). These mechanics had several variations during the development process. Design considerations (such as the game having two versions) made and issues encountered are described in the succeeding paragraphs.

Figure 2. Length Measure mechanic

Figure 3. Angle Measure mechanic

Figure 4. Triangle Angle Measure mechanic (left) measuring and (right) classification

Figure 5. Triangle Side Measure mechanic (left) measuring and (right) classification

The first version or the *Time-bound* (TB) version is where the enemies of the game constantly attack the player at a normal time pace. Although this version provides challenging gameplay, it may be at the cost of learner development due to its fast nature. Time-bound encounters could inhibit the player's conceptual learning since they would be less inclined to reflect and find the optimal solution as their survival would be the priority. On the other hand, the *Non Time-bound* (N-TB) version is where time is significantly slowed down during enemy encounters, resuming only when the player is creating a gesture. In this version, the player is now given ample time to find a solution for the problem presented to them. However, the time to defeat the enemy is still limited, thus preserving the challenging aspect of the game.

Table 1

GILE Mechanics for "A Samurai Fable"

Learning Outcome		
Draw angles using a protractor	Concept:	An angle is the space measured between two rays with a common starting point.
	Activity:	Illustrating an angle starting from the base arm, then the vertex, and finally the other arm of the angle with the guidance of a protractor for the angle opening.
	Game Mechanic:	Flying enemies are in the way of the player. The player is given two flames located on his left and right side which would allow them to conjure a spirit protractor. To defeat these enemies and avoid taking damage, the player has to shoot an arrow through them by drawing an angle. To accomplish this, the player has to first drag a flame towards the center, forming the base ray and revealing the protractor. From the center, the player drags their finger towards the direction of the enemy, forming another ray and completing the angle, as seen in Figure 3. During the previous sequence, the player can reposition their aim by dragging their finger either left or right. The arrow is fired by releasing the finger off the screen. These mechanics relate to the concept by tasking players to draw two lines with a common intersection point while having significance on the angle between the lines. This mechanic makes use of the knowledge of the different angle types by spawning acute/obtuse enemies on either side of the protractor.
Measure the length	Concept:	Measurement is recording the size, amount, or degree of an object using an instrument marked in standard units.

of a side using a ruler	Activity:	Aligning the ruler to a starting point of a line and getting the whole number of the line's endpoint.
	Game Mechanic:	The cave-dwelling demon, "oni", is in the way of the player. The player must banish this demon back to its realm by slashing it the same number of times as the length of its spiritual form in whole numbers to open a portal where it fits perfectly. The player has a sword which can aid in measuring the height of the enemy's spirit form through the markings on its blade. The player can "slash" by sliding their finger across the enemy. They can use multiple fingers to quickly increment the counter, as seen in Figure 2.
Measure the length of triangle sides using a ruler	Concept:	Measurement is recording the size, amount, or degree of an object using an instrument marked in standard units
	Activity:	Aligning the ruler to the starting edge of a line and getting the whole number of the line's ending edge for all sides of the triangle.
	Game Mechanic:	The flaming wheel, "Wanyūdō", forbids the player to progress. Wanyudo has three chains linked together in a triangle. The player taps on one of the triangle's sides and slashes the chain by the same amount as the side length, as seen in Figure 5. Once the chain is broken, they have to repeat the process until all other chains are broken.
Identify triangles according to its sides	Concept:	A triangle with all three congruent sides is classified as equilateral. A triangle with two congruent sides is known as an isosceles triangle. A triangle with no congruent sides is called a scalene triangle.
	Activity:	After measuring the 3 sides, determine how they compare in length and categorize the triangle given the comparison made.
	Game Mechanic:	After all the chains of the Wanyudo are broken, it enters a weakened state. To completely banish the enemy, the player has to choose the correct cleansing card—which are abstract depictions of triangle types according to their side lengths (i.e. equilateral, isosceles, scalene), to be based from the measurements of the three broken chains, as seen in Figure 5.
Measure the degrees of triangle angles using a protractor	Concept:	Measurement is recording size, amount, or degree of an object using an instrument marked in standard units
	Activity:	Align the protractor to one of the sides of the triangle, placing the center mark at the vertex then measure the angle. Repeat for the remaining unmeasured angles.
	Game Mechanic:	The thunder god, Raijin, is in the way of the player. Raijin has three drums linked together forming a triangle. To stop the Raijin's control of lightning, the player must break the drums. The player taps on one of the drums and shoots an infused arrow which would refire itself towards the next drum. The player specifies the trajectory by drawing the angle at the current drum's vertex, as seen in Figure 4. This process is repeated until all drums are broken.
Identify triangles according to its angles	Concept:	A triangle is obtuse if an angle is greater than 90 degrees. A triangle is right if it possesses a right angle of 90 degrees. A triangle is acute if all 3 of its angles are less than 90 degrees. A triangle is equiangular if all 3 of its angles are equal.
	Activity:	After measuring the 3 angles, categorize the triangle given the angle types.
	Game Mechanic:	After all the drums of the Raijin are broken, it enters a weakened state. To banish the enemy, the player must choose the correct cleansing card to take full control of the drums and deal the final blow. The cleansing cards for the Raijin are abstract representations of the types of triangles according to their angles, as seen in Figure 4.

Originally, the player can drag their finger back and forth the enemy's body to emulate multiple slashes. The problem with this is that the player could quickly swipe the target until the ruler matches the height of the enemy which potentially does not let the learner understand measuring but instead would learn how to quickly match the ruler to the object's height. Our solution is to restrict one touch instance (the touch on the screen, without lifting the finger) to a

single slash count. To compensate for the loss of the player's potential to quickly complete the encounter, the mechanic allows for multiple touch instances at a single time, letting the player do a three-finger slash.

Another issue is the player's comprehension of the drawing angles activity. It is possible that the player will think of the activity as drawing a line between a point and a target rather than the action of drawing an angle itself. Our solution for this is to indicate through various visual feedbacks that the player is engaging in an activity related to drawing angles. Thus, the measure is of the angle they created and the angle measures of their targets are displayed.

3.2 Learner Modelling Component

An implementation for the learner modelling component, a Bayesian network is a specific type of graphical model, a directed acyclic graph, which means that all of the edges (or the connections) in the graph are directed towards a particular direction and does not create cycles–the edges does not direct in such a way that it is possible to return towards the starting point (Stephenson, 2000). In a study by Garcia, et. al (2007), Bayesian networks were used to model and detect students' learning styles. Factors such as whether the learner uses mail or not, how good their exam results were, and how fast they hand over exams were used to determine the students' learner style which is based on Felder's learning styles (Felder & Silverman, 1988). The study also evaluated the capability of Bayesian network to model the students' learning. The study concluded that the Bayesian network can determine the perception style (a part of Felder's learning styles) of a student with high precision (Stephenson, 2000).

This component is implemented as a Bayesian network where the nodes specify the topics in grade 4 geometry and each edge is accompanied with a conditional probability table for the probabilities of the learner knowing the child node given their knowledge on its parent nodes. The network consists of three nodes: (1) Draw Angles, (2) Measure Triangles, and (3) Identify Triangles. The nodes correspond from the learning outcomes which are mentioned above in Table 1. The nodes' relation with one another is portrayed in Figure 6 below.
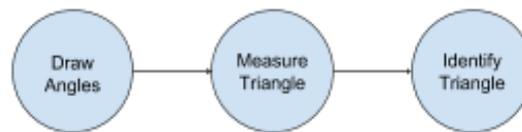

Figure 6. Bayesian Network Implementation Structure

3.3 Pedagogical Component

The pedagogical component communicates with the game component on what game elements are to be adjusted to fit the user's current state of knowledge. The game is altered during level progression, with reference to the current extent of the user's performance.

With regards to difficulty, the game is adjusting itself depending on how the player performs in the mechanics. Levels are procedurally generated in such a way that the mechanics of the concepts that the player is having trouble with are more prevalent. The gameplay is split into runs, where each run has a more difficult set of encounters depending on the player's previous performance. The bayesian network, which represents the learner's current state of knowledge, is updated between runs. The difficulty of the mechanics increases and the spawn rate decreases as the probabilities of the learner model's nodes increases. The updated bayesian network then informs the pedagogical component to decide on the difficulty of the next encounters for the next run. Aside from optimizing the game's performance (framerate), this design was made so that the learner would have a clear sense of progress as the encounters become more difficult.

4. Experimental Design

One of the goals of this project and the objective of this paper is to evaluate player engagement which can be measured using the GameFlow model (Sweetser, Johnson, Wyeth, & Ozdowska, 2012). The GameFlow model is a model of player enjoyment, structured into eight elements:

- *Concentration* is the player's inclination to concentrate on the game.
- *Challenge* refers to the capability of the game to be sufficiently challenging, matching the player's skill level.
- *Player skills* is about the game's active involvement in supporting the player towards skill development and mastery.
- *Control* refers to the player's sense of control over the actions they make on the game.
- *Clear goals* refer to the awareness of the players regarding the task given.
- *Feedback* is the appropriateness of the feedback the game is providing the player.
- *Immersion* speaks of the player's involvement to the game, in regard to the level of involvement (how deep it is) and the amount of effort they put in to be immersed.
- *Social interaction* refers to capability of the game to support and create opportunities for social interaction.

All of these elements are given multiple heuristics, which are scored based on how much the game incorporates a specific concept. The scores are then averaged to produce the enjoyment score of the game.

A derived model from the original GameFlow model is the EGameFlow (EGF) model (Fu et al., 2009). The EGF model evaluates the enjoyment of e-learning games. The *knowledge improvement* element, which refers to the game's capability to improve the player's knowledge and skills while meeting the curriculum's goal, replaces the *player skills* element. The study (Fu et al., 2009) concludes that the EGameFlow model is reliable and valid enough for evaluating player enjoyment in e-learning games. However, removing the player skills element may not fit the study's aim for the GILE to have the capability to be played independently of supervision. Despite this incompatibility, the knowledge improvement element is a fine addition for a game that aims to educate players.

Along with an addition from the EGF model, the modified GameFlow model is based on a modern variation of Sweetser's GameFlow for mobile adventure games (Sweetser, Johnson, Wyeth, Anwar, Meng, & Ozdowska, 2017). The social interaction section was also omitted as the GILE is a single player experience with no online functionality such as leaderboards. The two versions of the game are to be evaluated using the modified model by two groups: a group of educational game designers (EGDs), and students ranging from grade 6 to grade 10.

For the first group, three volunteers that are around the age of 11 to 15 which are currently studying at Caritas Don Bosco school. Observations during the playtesting sessions were also noted, and an interview was conducted afterwards to probe further into their experience playing the game.

The second group is made up of three EGDs who volunteer to playtest the GILE. The developers are around the ages of 19 to 21 and are working on their own GILE for fractions and number sense. The developers were given a copy of the game which they played at their own time and with the freedom to play the as long as they want. Playtesters were made to fill a questionnaire based on the GameFlow model, wherein each item is rated from 1 (strongly disagree) to 5 (strongly agree).

The performance is categorized as follows. Games with scores below 1 is categorized as "bad", scores below 2 is categorized as "below average", scores below 3 is categorized as "average", scores below 4 is categorized as "above average", and scores 5 and below is categorized as "well done". Sweetser et al. stated examples of games that are considered "high-rating" with 76% as the lowest GameFlow score from high-rating group (Sweetser, Johnson, Wyeth, Anwar, Meng, & Ozdowska, 2017).

5. Preliminary Results

Both versions of the game yielded high player enjoyment scores. The *time-bound* version is categorized as "above average" having a lower score of 3.92 (78%) and the *non-time-bound* version having a score of 4.04 (80%) and is categorized as "well done". The *non-time-bound* version has a score of 80% and the time bound version falls slightly behind at 78%. Both versions of the game have scores slightly higher than the lowest GameFlow score from high-rating group from Sweetser's example, which was 76%. Table 2 reports the overall mean scores, its percentage, and category for each GameFlow element for each version of the game.

GameFlow mean results of the EGDs' group

Element	TB	N-TB	Difference
Concentration	4.17	4.50	**0.33**
Challenge	3.61	3.83	**0.22**
Player Skills	4.05	4.11	0.06
Control	3.78	4	**0.22**
Clear Goals	3.67	3.67	0
Feedback	4.08	4.08	0
Immersion	4	4.07	0.07
Knowledge Improvement	3.95	4.02	0.07
Overall Mean Score	3.92	4.04	0.12
Percentage	78%	80%	
Category	Above Average	Well done	

Table 2 also reports the mean of each GameFlow element for the two versions of the game. Aside from the "clear goals" and "feedback" elements, the non-time-bound version scored consistently higher across all GameFlow elements. The "clear goals" element across both versions remained consistent as there is no difference in the way the goals were presented. The same can be said for the "feedback" element, as there is no difference in the way the players receive feedback. The elements that yielded the highest differences are concentration, challenge, and control.

In addition to the questionnaire given, we also asked the participants their rationale for their scores per element. We found out that for concentration, the time bound version was too "overwhelming" as the enemy approaches the player too fast. For challenge, the participants felt anxious while playing the time-bound version and both version lacked hints to help the player. For player skills, they noted that across both versions, the tutorial is lacking. For control, they noted that it is hard to recover from mistakes in the time-bound version. For clear goals, they noted that the lack of narrative and context doesn't give the player an idea of why they are doing the tasks and as far as they know, they are just tasked with defeating the enemies. They added that during the "mini-boss" they had difficulty in knowing what to do. Feedback was well received by the participants. For immersion, they noted that a narrative may help the player be emotionally involved in the game. For knowledge improvement, they felt that they were simply "matching" for both measurement mechanics and not using knowledge about the topic.

6. Discussion and Conclusion

We presented to the participants two versions of "A Samurai Fable", the *Time-bound* (TB) version and the *Non Time-bound* (N-TB). We then asked the participants to evaluate the game's enjoyment factor through a series of questions based on Sweetser's GameFlow model modified for casual single player mobile adventure e-learning games. The N-TB version scored higher than the TB version, this is because players find the TB version "overwhelming" and too "fast-paced".

Table 3

Overall GameFlow mean results

	Version	Overall Mean	Percentage	Category
EGD Group	Time Bound	3.92	78%	Above Average
	Non-Time Bound	4.04	80%	Well Done

Aside from this group, we also gathered and analyzed the results from the playtests of students from Caritas Don Bosco school. As compared to the EGD group, their results were significantly higher. This could be due to the expertise of the EGDs with regards to game development. Their knowledge in this field allows them to form better alternatives in mind when seeing the various parts of our game. This leads them to lower their scores because they know that there is a better way to achieve a certain item listed in the questionnaire. For example, most of the EGDs remarked that our tutorials were unintuitive and lacking. As compared to the student playtesters where they were satisfied with the provided tutorials, thus leading to relatively high scores.

The findings from this study would enable us to improve our GILE's game component and develop a definitive, more enjoyable version of the game. We plan to conduct further study with a larger sample size and using the definitive version of our GILE to find out whether it improves learner performance and to evaluate the player enjoyment. We would also like to compare if the utilization of a student model improves learner performance when compared to a version that without one.

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