Game based assessment in the mathematics classroom

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ARTICLE INFO	ABSTRACT
	The objective of this paper is to present a conceptualization and creation of a game-based assessment to address student anxiety and accelerate students' learning through the immediate feedback given in-game. We used a revised form of Computerized Adaptive Testing in order to adapt to the test-takers' ability and knowledge level. We adapted the Computerized Adaptive Testing to design our game-based assessment. Our design is guided by the existing education literature about student learning and the context of the game is based on the current trend of popular culture among school-going age children. We propose a game which incorporates the features of the three types of assessment: assessment for learning, assessment of learning and assessment as learning. The structure of the game-based assessment allows students to proceed as a pace which is suitable for the individuals. Through the use of a technology enhanced game-based assessment, we hope to reduce students' anxiety related to assessment, and that they are able to progress at a customized learning.

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1. INTRODUCTION

Recently in addressing the learning needs of the new generation of learners, educators have turned to innovative approaches in education to reach out to a wider group of learners, e.g. comics and video clips have been used for mathematics instruction to reach out to the less motivated (e.g. Chu & Toh, 2020; Toh, Cheng, Lim & Lim, 2019; Han & Toh, 2019) to In this paper we offer a proposal of how games can be used as a mode of assessment in the mathematics classrooms. Games are what children of school-going age look forward to after lessons. Most students dread assessment – in fact, it is a taboo word among many Singaporean students. Game and assessment seem to be incompatible. In this paper, we attempt to marry the two concepts together by presenting our idea of a Game Based Assessment (GBA) for mathematics lessons.

For many years, the Singapore Ministry of Education (MOE) and schools have placed much emphasis on the traditional paper-and-pencil assessment for Singapore's school level and national examinations. Paper-and-pencil assessment has proved to be a reliable means of identifying students' level of cognitive thinking (Dugan, 2016). However, some researchers such as Ruff and Boes (2014) believe that "reliance on timed tests and memorization has increased anxiety making math a high-risk activity" (p. 1). Studies have also shown that test anxiety can interfere with students' ability to perform well during a test (e.g. Blazer, 2011). High levels of test anxiety could result in students' development of academic avoidance behaviour, hence affecting their test performance.

2. GAME DESIGN

With alleviating students' test anxiety in mind and being more encouraging to students, underlying which is the belief in the importance of assessment for mathematics instruction, we present in this paper our conceptualisation of GBA for the mathematics classrooms. In particular, we cater our GBA to lower secondary school students (aged 13 to 14). We believe that this group of students is most attracted to games and movies based on our school experience.

2.1 Theme and Mode of GBA

The genre on dragon has captivated many Singaporeans, including the teenagers. The box office record of the movie "How to Train Your Dragon", which was released in 2010, and its two sequels released in 2014 and 2019, each hit more than $2 million record in Singapore. The three movies were ranked within the top twelve most popular movies of the year, as shown from the website (e.g., see **https://www.boxofficemojo.com/intl/singapore/yearly/**). Inspired by this, we decided on dragon as the theme for our conceptualising and designing of the game. We named the game 'Dragon Hero'.

The digital game 'Dragon Hero' that we conceptualised is a game with single-player mode, operated by using mouse controls. The game starts with the player's selection of the game character (known as the "hero"). The player can select either the "boy hero" or the "girl hero". The game begins with the selected hero being locked up in a dungeon with a fire-breathing dragon on guard duty. The hero's mission is to defeat the fire-breathing dragon in order to escape from the dungeon. Prior to that, the hero is required to complete all the quests to collect tools or power-ups at each quest to defeat the dragon. Each quest consists of five different levels of questions, starting from the easiest question at Level 1 to the most challenging at Level 5. At each quest, by default the player is presented with a Level 3 item so as for all players to take the "standardized" test. The player is only required to complete one question at each quest. Each quest must be completed within five minutes. The player wins when his hero has successfully collected all the tools and power-ups and defeated the dragon to escape the dungeon.

The genre of the game is action-adventure. The dungeon-battle setting of this game 'Dragon Hero' is inspired by the famous multiplayer online battle arena (MOBA) video game, Dota 2. Dota 2 was nominated as the Choice Video Game at the 2017 Teen Choice Award, which signifies its immense popularity amongst teenagers aged 13 to 19 (Vulpo, 2017). Hence, we intentionally modelled 'Dragon Hero' after Dota 2 in order to appeal to the popular demand of secondary school students, especially those who enjoy fighting games and levelling their resources.

2.2 The Quest and Battle with the Dragons

Each game corresponds to the assessment of one particular topic in the mathematics curriculum. The number of assessment objectives corresponds to the number of quests in the game. The goal of the game is for the player to complete all the quests. In each quest, the player has to answer at least one question at a particular level from 1 to 5. The higher the level, the more powerful will be the tools or the power-ups to battle the dragon. The scene of the game that we designed with 10 quests (or 10 assessment objectives) for the topic on Lower Secondary Geometry is shown in Figure 1.

Figure 1. Dungeon Game-Map for a game with 10 quests

The players is allowed to decide on the sequence of quest attempts, as the tasks are not hierarchical in nature. Each quest corresponds to a different assessment objective. The player is required to complete all the quests before he is allowed to move on to battle with the dragon as the final mission of the game. The players are allowed to use any tools or power-ups they have acquired in completing the quests. The completed quests are marked with a tick (Figure 1).

Upon entering a quest, the player will initially be presented with a Level 3 problem. Upon successful completion of the problem, they would either earn a tool or power-up (depending on the quest) in which players can utilise in his battle with the dragon (Figure 2).
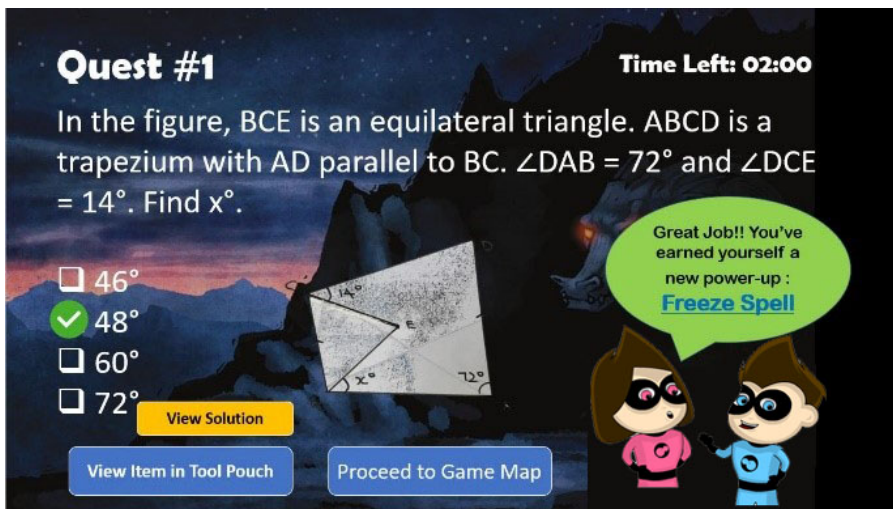

Figure 2. Successful Completion of Quest No. 1

If the player does not manage to solve the question correctly, he will be given an opportunity to either view the solution of the problem, or to proceed to the game map to proceed with the other quests (Figures 3 top and bottom). The player will need to start at that level in attempting this quest later.
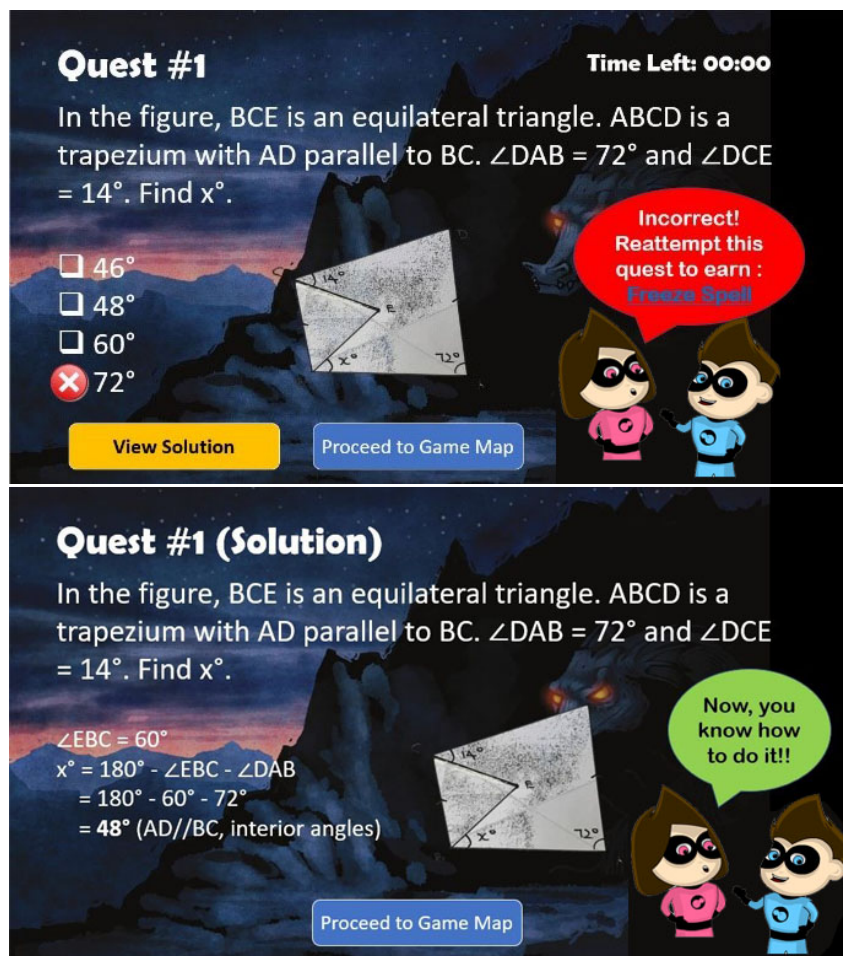
Figure 3. Incorrect attempt of Quest No. 1 (Top) and view of the solution (Bottom)

The next problem that will be posed to the player will be a problem that is one level lower (If the player is unable to solve a Level 3 problem, he will then be presented with a Level 2 problem with the same assessment objective in the quest).

Once the player has successfully completed all the quests, he will be invited to reattempt the selected quests at a higher level (assuming that the question that he has previously attempted has not reached Level 5). The player will have an opportunity to level up his tool or power-up so as to be better prepared to battle the dragon. The quests that the player can reattempt (if he has not answered the question at the highest Level 5) are marked with a yellow exclamation sign (see Figure 1 for example). The player will be informed of their outcome of the reattempt of the quest if they have managed to solve a question at a higher level (Figure 4).

Upon successfully completing all quests and earning all 10 tools and power-ups, players will then be invited to start battling with the dragon as the last mission of the game (Figure 5). The players will have a choice to utilise any acquired tool or power-up at any time of the battle. Each "hero" is granted with three lives and 1000 health points, which will be deducted if the dragon is successful in attacking the "hero" in any way. Once the hero's health is depleted completely, one "hero" life would be deducted and the player needs to restart the battle using his remaining lives. The game mission would be accomplished when the player has successfully defeated the dragon and escaped the dungeon (Figure 6). The player would have lost the game if the hero lost all three lives before the dragon is defeated.

Such an in-game reward system serves as a motivation for most modern-day students, who crave for instant gratification. Guthrie and Carlin (2004) believed that "modern students are

primarily active learners", for which modern technology can serve to satisfy their instant gratification. This will encourage them to move on to complete all the quests and achieve the higher possible level at each quest.
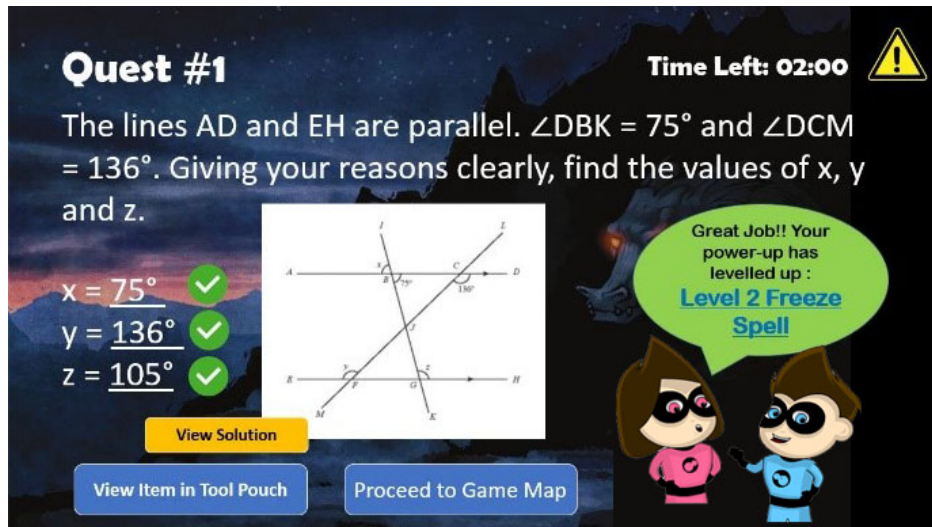

Figure 4. Interface showing the player has re-attempted Quest 1 at Level 2 and managed to solve it correctly.

Figure 5. Interface showing the battle with the dragon and the available tools and power-ups.

The algorithm of completing each quest and the points awarded is summarized in Figure 7.

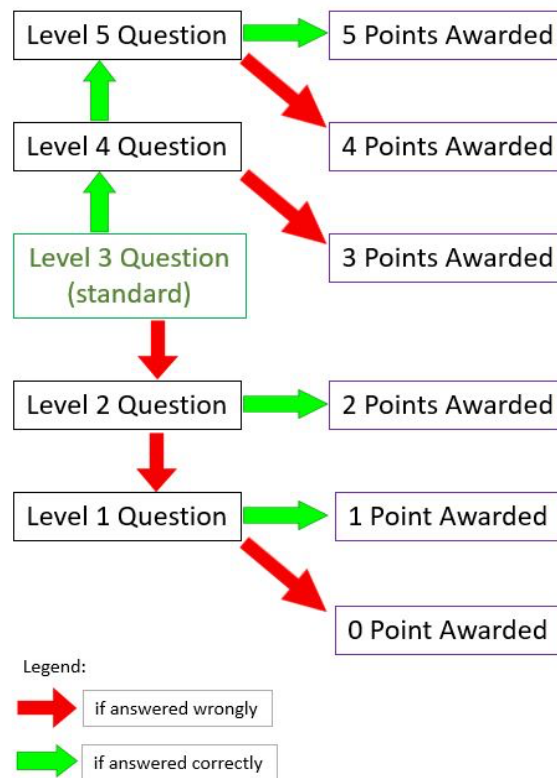**Figure 6.** Interface showing the battle won.

Figure 7. The algorithm of completing each quest and the points awarded.
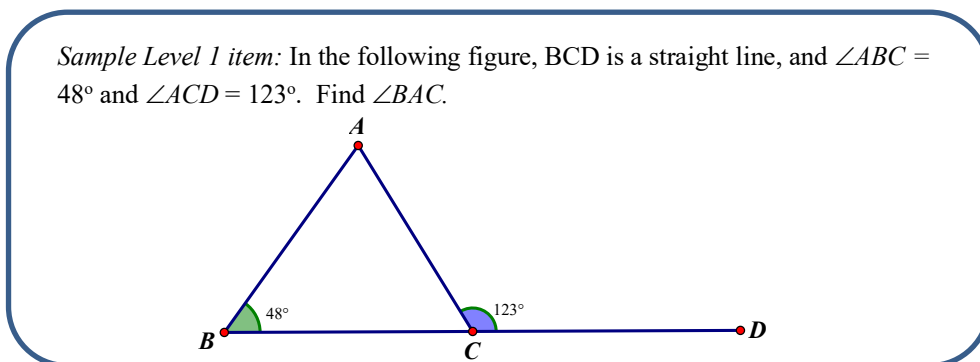
3. GAME FEATURES

3.1 Adaptive Testing

The proposed GBA is modelled after Computerized Adaptive Testing (CAT), which is a computerized test which adapts to the test-taker's knowledge level (Yoshioka & Ishitani, 2018, p. 381-404). Meijer and Nering (1999) asserted that in comparison with traditional paper-and-pencil assessments, CAT evaluates the students' competencies more accurately and "it is the most efficient and the most secure form" (p. 187–194). Unlike the CAT, all the players are first presented with a Level 3 question, which is taken as the 'standard question'. As suggested by Sireci (2005), implementing this "standard" question in the GBA allows for efficient and objective comparison of the players' level of the content knowledge across all the players, since all of them required to complete "the same set of questions" on their first attempt at each quest (p. 111–122). The adaptive testing in our GBA is implemented for each quest, rather than throughout all 10 quests. Thus, an individual may attain the highest Level 5 in one quest but at a slightly lower level in another quest. This information on the students' level of competency for each assessment objective will be very useful for the teachers in planning the subsequent activities in the mathematics classroom.

3.2 Design of the Test Items in the Quest

Each quest, which serves to assess one assessment objective within a particular mathematics topic, contains mathematics problems from Level 1 to Level 5 pertaining to the assessment objective. Level 1 consists of items that require lower order thinking skills while Level 5 consists of items requiring higher order thinking skills (according to Bloom's taxanomy of educational objectives, e.g. see Bloom, Engelhart, Eurst, Hill and Krathwohl (1956)). The questions progress in increasing level of difficulty from Level 1 to Level 5 in each quest. Several questions that are non-identical but of similar level of difficulty are available at each level.

We shall illustrate how the items of Quest 1 are developed in our conceptualization of the game. The objective of Quest 1 is to assess the ability to apply the facts about angle sum of a triangle.

Level 1 consists of items that require the player to only recall or demonstrate understanding of the angle sum of triangles.

Sample Level 1 item: In the following figure, BCD is a straight line, and $\angle ABC = 48°$ and $\angle ACD = 123°$. Find $\angle BAC$.

Level 2 items require the player to recognise and apply the angle sum of a triangle, and in the presence of extraneous information (not required to solve the problem).

Sample Level 2 item: BCE is an equilateral triangle and *ABCD* is a trapezium with *AD* parallel to *BC*. If ∠*DAB* = 72º and ∠*DCE* = 14º, find *x*.
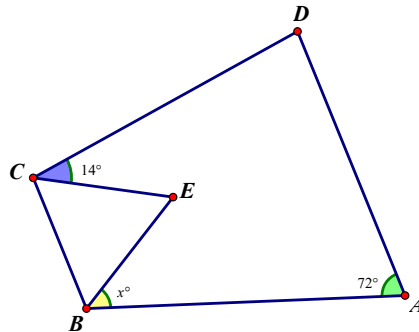

Level 3 items involve direct application of the angle sum of triangles, in addition to combining other angle properties (of parallel lines).

Sample Level 3 item: The lines *AD* and *EH* are parallel. ∠*DBK* = 45º and ∠*DCM* = 136º. Find the values of *x, y* and *z*.
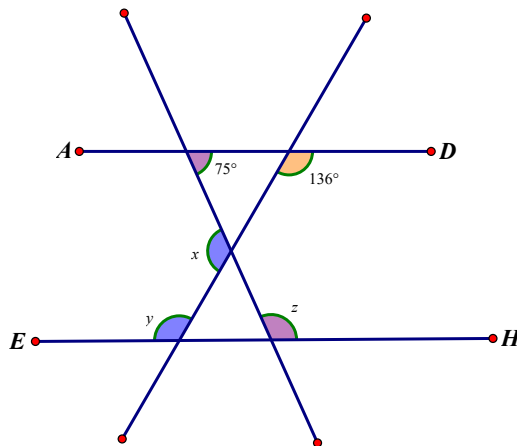
Level 4 items involve multiple application of the property of angle sum of a triangle, together with other properties of triangles (e.g. base angles of an isosceles triangle are equal).

Sample Level 4 item: In the following triangle *ABC*, *AB* = *AC* and *BD* = *BC*. If ∠*ABD* = 36⁰, what is the size of ∠*ABC*?
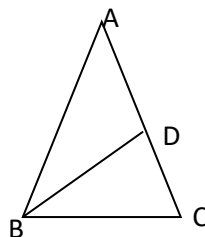
The solution of Level 4 items will also require the use of algebra to solve them completely.

Level 5 items involve the player to transform the angles and to synthesize additional construction lines to solve the problems.

> *Sample Level 5 item:* Calculate the sum of the shaded angles in the star below.
>
>
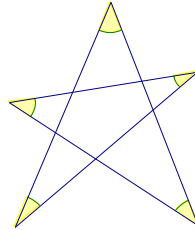
In designing the items for the quest, we relied on Bloom's taxanomy (Bloom et al., 1956) in general, and interpreted what each of the five levels will manifest in relation to the specific assessment objectives.

One advantage of computerized testing is that immediate feedback is possible (Benjamin & Pashler, 2015, p. 13-23). The players will know immediately if their attempt is correct. Not only that, the players can progress at the level that they are comfortable, but will be encouraged to move on to the next higher level if they are capable of doing so. Our design of the GBA taps on these two advantages.

4. DISCUSSION AND CONCLUSION

We believe that implementing a GBA as a tool of assessment to take prominence over the traditional paper-and-pencil assessment for mathematics instruction could be advantageous. Such a form of assessment, which incorporates excitement in the process of assessment, can potentially reduce students' anxiety about assessment and mathematics. Immediate feedback for the students about their performance is another advantage for such form of computerised testing (Benjamin & Pashler, 2015, pp. 13 – 23). The player can progress at the level that he is comfortable. Not only that, in our design, we made a conscious effort to constantly encourage the player to achieve each quest at the next higher level; in the case that a student has difficulty with one particular problem, he has the opportunity to learn, reflect and attempt a problem with a similar level of difficulty.

Though this GBA is primarily designed to assess students' mathematics knowledge and competencies, the action-adventure setting of the game makes the assessment engaging to the students. We believe that it could promote their intrinsic motivation to complete and advance in the game, and develop their sense of perseverance. GBA is a promising approach to assessment.

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