A case study in applying gamification techniques on mobile technology for mathematics high school students to learn polynomial functions

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***Abstract*— Teachers, schools and parents are continually looking for ways to make core subjects, such as mathematics, more stimulating for students from a wide variety of backgrounds and cultures. Recently, a technique that uses ideas from game design, often called gamification, is popular for its potential to increase students' engagement, retention rate and learning quality in the classroom. Therefore, in this paper authors present the application of game design into non-game context like mathematics in a topic of plotting polynomial functions. This is to investigate student's learning whether gamification techniques could make the class more enjoyable, interesting and help students in mastering their knowledge. A game for Android devices or tablets on the topic of plotting polynomial functions has been developed and published on Google Play Store under the name of "Astro Graphy" for anyone to download for free. The authors have also made some questionnaire for people who tested and played the application. Two surveys were undertaken as part of this case study, one on undergraduate students and another one on high school students. The results are discussed and the potential for gamification and mobile technology to be used more widely in education is examined.**

***Keywords*— gamification, high school, mathematics, mobile technology, polynomial functions**

I. INTRODUCTION

In the past decade, E-learning has mostly applied to desktop PCs at home and in the classroom, as teachers and students make use of the web as a platform for technology-enhanced learning. Although the web and desktop computing is highly successful, there are also some limitations for learners, e.g. internet access, fixed location, amount of time to set up. With the significant recent

increase in mobile device use [1], [2], together with the convenience anywhere and anytime access, mobile learning has become equally relevant to educational researchers and teachers. Mobile learning in classrooms can lead students to work individually, interdependently or in groups to learn, to solve problems or to work on projects [2]. It allows learners to access a variety of content and availability of applications anytime and anywhere, inside or outside classroom.

Gamification refers to the use of game mechanics in non-gaming contexts [3] or to the phenomenon of creating gameful experiences [4]. It is now an emerging trend in many different areas in particular education [5], [6]. Gamification technique has potential to influence three major areas: (i) cognitive - games provides complex systems of rules for players to explore through experiment [7], (ii) emotional - games evoke a range of emotions, from curiosity to frustration to joy [8] and (iii) social – games lead players to try on new roles and make in-game decision [9], [10]. Furthermore, it does enhance motivation and engagement in learning for students [11]. A good case study of how gamification helps at-risk student succeed is a mathematics class by Fanelli who makes her classroom to become a MathLand, she sets up each step of her teaching topics to be as a level for students to win through and fight for higher levels to be in a good position in a leader board. In addition, such a leading expert in educational game as David Dockterman [12], [13] also stated that four elements in the game that are required for students to learn are (i) the tasks must be about the content to be learned, (ii) feedback must be immediate and meaningful, (iii) progress must be transparent and (iv) the stakes must be low.

Mathematics is a core subject that is fundamental to all educational curriculums. Although there is a great attempt of both teachers and parents to improve their students'/children's mathematics skills, statistical data shows that mathematical literacy especially in Thailand is still poor. The data by Trends in International Mathematics and Science Study (TIMSS) shows that in 2011, Thai Prathom 4 and Matthayom 2 students were in the "poor" category in mathematics. Furthermore, the result of Ordinary National Educational Test (O-NET) for Matthayom 6 students in 2011 shows an average score in mathematics of 15%. This data supports the call for better techniques in teaching mathematics to improve the situation in schools not only in Thai education but worldwide.

As part of the search for new techniques, in this research we explore the possibility of applying gamification in mathematics. The topic of plotting polynomial function (linear and quadratic), which is a basic background to further study in higher level of mathematics, is selected as a case study for applying gamification techniques. The aim of the work is to create a game for high school students. The game itself is designed to aid the understanding of polynomial functions, in particular the connection between graph and function. The game is not designed to replace traditional classroom learning, but it is a possible tool for teachers to use in the classroom to reinforce understanding and to create higher levels of engagement.

II. GAMIFYING POLYNOMIAL FUNCTIONS

Astro Graphy is a mathematical game application for Android tablets, allowing learners to test their knowledge of graphing polynomial functions (linear and quadratic). The aim of the game is for the learner to match a given graph (in red) to a target graph (in blue) by adjusting the coefficients of a provided function. Learners adjust the coefficients by tapping buttons to increase or decrease their value as shown in Figure 1. The graph updates immediately giving learners instant feedback on the effect of changing the coefficients of the function. It is expected that this would make those who play learn the meaning of coefficient of each term of function and understand better what each term in the function represents.

Within the application, it contains 15 levels in total starting from easy (linear function) to difficult (quadratic function and mixed). Each level contains 5 randomly selected graph matching tasks with the time set of 20 seconds for each graph. The scores are calculated from the time the users have left in each question. The users are not allowed to play the next question unless they get the current question correct.

The learner receives points for every graph that they are able to match within the given time limit. At the end, the points will be turned to the number of stars they can get in each level as a reward. In the same style as adventure games, the learner must complete levels to unlock another level, with each level presenting a new challenge.

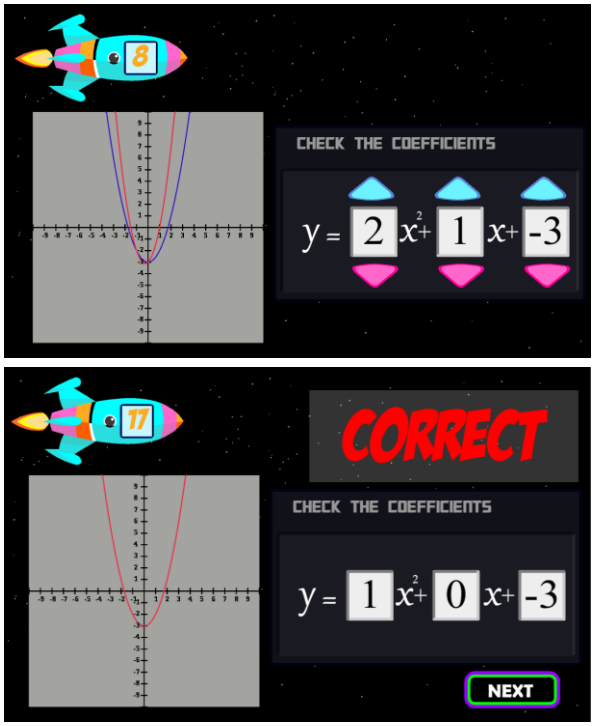

Fig. 1 Screenshots of the game (top) the game start (bottom) when the learners manage to get the question correct

For example, early levels contain only one linear coefficient and as the learner progresses, they are introduced to single quadratic coefficients and finally multiple coefficients such as $f(x)=ax^2+bx+c$ where a, b and c are coefficients of polynomial function. Figure 2 shows the progression through the game, the first three levels in green area focusing on simple linear function whereas the ones in red are more difficult linear function and simple quadratic function when the level is up, respectively.

III. IMPLEMENTATION

The application was developed by starting with the process of application design, creating storyboard, implementation, testing and publishing. The idea of the game within the application was written as the flow chart in Figure 3.

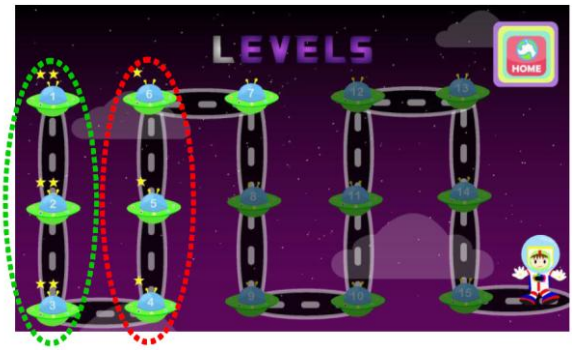

Fig. 2 Screenshot of the levels in the game

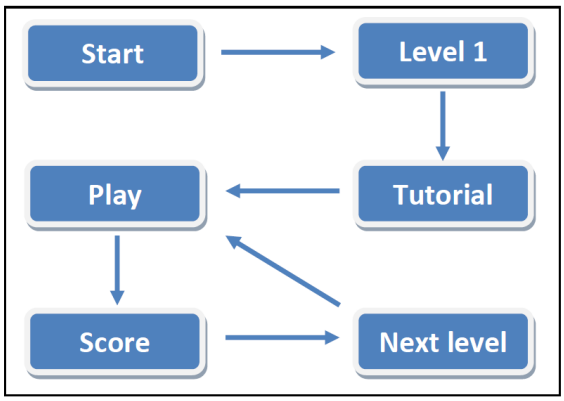

Fig. 3 Overall process of application

Once the idea was built, the storyboard of a whole application was then created. This is for choosing the best user experience for high school and undergraduate students. These storyboards were done in Microsoft Powerpoint. Some of the examples of storyboards within this project are shown in Figure 4.

In the next step, Adobe Flash Professional CS6 and ActionScript 3.0 were used for drawing the graphic designs and writing all

the game and interface logic. The algorithm for plotting the graph is achieved by an idea of drawing many tiny straight lines connecting points of the coordinates calculating from the function provided in the game starting from $x=-10$ up to $x=10$. This will give a graph that looks smooth to the user.

IV. TESTING

Early prototypes of the application were tested by 10 users and the game dynamics were improved before finally publishing on the Google Play Store [14]. Two surveys were undertaken, one on undergraduate students and another one on high school students. The questionnaire was given out to 84 individuals.

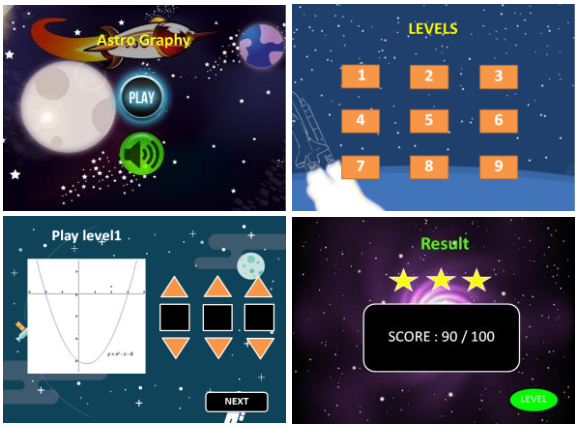

Fig. 4 Storyboard screens of application

IV. RESULTS AND DISCUSSION

In this research, Astro Graphy was developed to expand the learning experience of mathematics through game. The name Astro Graphy itself represents what are in the application, learning how to plot polynomial (linear and quadratic) function where the background scene and the sounds within the game relating to astronomy. The users of Astro Graphy can be ranged from Matthayom 1 (who start to learn about function) to Matthayom 6 students (who can use this game as a part of their revision for university admission exam). In addition, undergraduate students or higher can also use this game for obtaining better understanding and used in their further study.

By playing the games, users can learn how the graph relating to the written function and by adjusting the coefficient of each term in the function, users can learn the true meaning of each coefficient by experience, not memorizing it. Some of the screenshots of Astro Graphy application is shown in Figure 5.

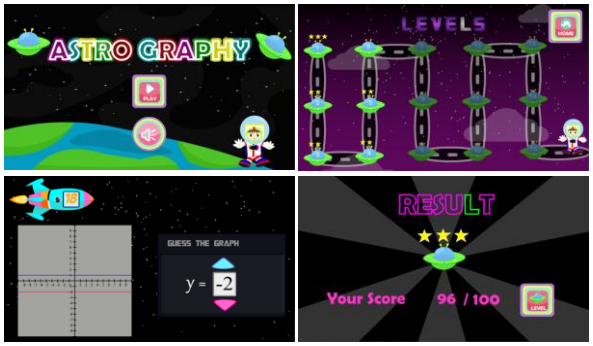

Fig. 5 Example of Astro Graphy screenshots

A questionnaire about Astro Graphy was given out to 84 people after they played the games in the application asking for the feedback. Most of them are high school students in Phitsanulok and undergraduate students in Naresuan University, Phitsanulok, Thailand. To evaluate the game, observation of the students was performed in addition to the collection of questionnaires.

Figure 6 shows 65% of the population who did the questionnaire are male and 35% are female, whereas 51% of the population are students at the high school level, 41% are undergraduate students and only 8% are either post graduate or above. The average satisfaction scores to the application in variety aspects, given by people who answered the questionnaire are shown in Table I. The score of each questionnaire is out of 5.0 and the score of 1.0 – 5.0 representing the level of satisfying, respectively where 5.0 is the most satisfied score.

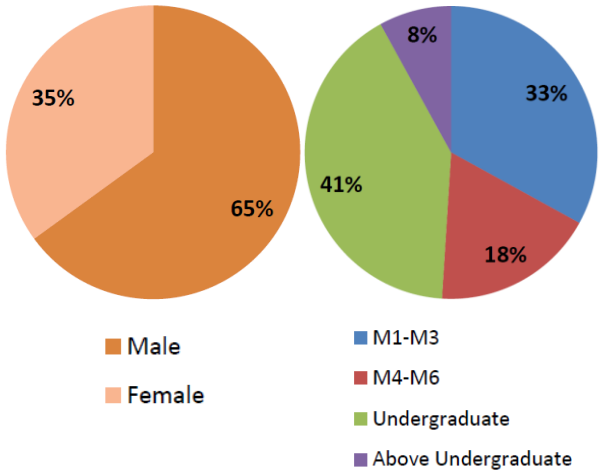

Fig 6. Percentage of number of people answering the questionnaire (left) by gender (right) by level of education

Table I
Average satisfaction scores of Astro Graphy

Title	Score out of 5
Content within application is clear	4.35
Graphic design within application is easy to understand	4.24
Tutorial within application is clear and easy to understand	4.15
Time required to spend in the game is appropriate	4.17
Users gain better understanding in "plotting polynomial function" graph	4.18
Users are interested in and enthusiastic to play game	4.20
Users like to play game in more difficult levels	4.33
The sound effect of the game is clear	4.04
This application is a modern material for teaching	4.49
This application should be further developed in the near future	4.56

From Table I, it can be seen that the scores of all title are above 4.0 out of 5.0, which corresponds to more than "very satisfied". In particular the last two points in the table indicate that the application is modern, good for teaching and should be developed further. In the questionnaire, some users suggested not only that the topic within the application should be extended and involved other mathematical topics (e.g. circle equations, trigonometry), but also increase the difficulty of higher levels. Furthermore, 100% of the people who did the questionnaire support the researchers to develop this application further and agreed that learning mathematics through games on mobile is good idea for learning. Informal observations during the time users play the game positively indicated that the application caught students' interest. In particular, most students looked enthusiastic to play the game and continue deeper into the higher levels of the game.

With comments and feedback from 84 users who did the questionnaire after using the application, an improved version was further developed and is now available for free on Google Play. Higher degree of polynomial functions and other types of function/equations are planned for future versions of Astro Graphy.

V. CONCLUSIONS

As discussed at the beginning of the paper, making mathematics more engaging in the classroom is a global issue that is important to address. Furthermore, with the nature of the Thai educational system emphasizing a "memorize and recall" style of learning, a more interactive and exciting environment is required to improve mathematics classes. One approach is to utilize technology, and therefore Astro Graphy was developed to expand the learning experience of mathematics using game techniques. In this research, the topic plotting polynomial functions (linear and quadratic) has been chosen, since it is a fundamental knowledge for applying to other subjects. Eighty four questionnaires give us a promising result that the game is both fun and could extend education beyond the physical confines of the classroom. It is no doubt that gaming will be a part of students' lives for years to come, therefore, it is a great challenge for us to think how we can design game-play that could be meaningful to the students, and fruitful for their learning.

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REFERENCES

[1] S. S. Adkins, "The US market for mobile learning products and services: 2008-2013 forecast and analysis," *Ambient Insight Comprehensive Report*, Dec. 2008.

[2] D. M. West, "Mobile learning: transforming education, engaging students, and improving outcomes," *Centre for technology innovation at Brookings*, Sep. 2013.

[3] S. Deterding, D. Dixon, R. Khaled and L. Nacke, "From game design elements to gamefulness: defining gamification," in *Proc. the 15th international Academic MindTrek Conference: Envisioning Future Media Environments*, 2011, p. 9-15.

[4] J. Koivisto and J. Hamari, "Demographic differences in perceived benefits from gamification," *Computers in Human Behavior*, vol. 35, pp. 179-188, June. 2014.

[5] I. Caponetto, J. Earp and M. Ott, "Gamification and education: a literature review," 2014 [Online]. Available: http://www.gartner.com/newsroom/id/1629214

[6] A. Domínguez, J. Saenz-de-Navarrete, L. De-Marcos, L. Fernández-Sanz, C. Pagés and J. J. Martínez-Herráiz, "Gamifying learning experiences: practical implications and outcomes," *Computers & Education*, vol. 63, pp. 380-392, April. 2013.

[7] J. J. Lee and J. Hammer, "Gamification in education: what, how, why bother?," *Academic Exchange Quarterly*, vol. 15(2), pp. 1-5, April 2011.

[8] N. Lazzaro. (2004) Why we play games: four keys to more emotion without story. [Online]. Available: http://xeodesign.com/xeodesign_whyweplaygames.pdf

[9] K. Squire, "From content to context: videogames as designed experience," *Educational Researcher*, vol. 35(8), pp. 19-29, Nov. 2006.

[10] J. P. Gee, *The ecology of games: connecting youth, games, and learning (D. John and C. T. MacArthur Foundation series on digital media and learning)*, Katie Salen ed., Cambridge, MA, The MIT Press, 2008.

[11] M. Ott and M. Tavella, "A contribution to the understanding of what makes young students genuinely engaged in computer-based learning tasks," *Procedia-Social and behavioral Sciences*, vol. 1(1), pp. 184-188, Jan. 2009.

[12] D. Dockterman. (2012) Games help kids learn through failure. Educational article by Guest Blogger on March 5th, 2012. [Online] Available: http://attachments.aplus.agora.com/t13_live/P51AC2.handout.F1EFC.pdf

[13] A. Sarlin and D. Dockterman. (2013) The "Gamification" of math research, gaming theory and math instruction. [Online] Available: http://nctm.confex.com/nctm/2013AM/webprogram/Session15597.html

[14] Mobile Computing Lab. (2014) Astro Graphy. Android application published on Google Play. Available: http://www.mobcomlab.com/astrography/