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DESIGNING DIGITAL GAMES AS LEARNING TOOLS FOR MATHEMATICS

Andry Chowanda, Yen Lina Prasetio, Nicodemus
and Naufal Rizdki Fadhlurrahman

Computer Science Department
School of Computer Science
Bina Nusantara University
Jl. K. H. Syahdan No. 9, Kemanggisan, Palmerah, Jakarta 11480, Indonesia
{ achowanda; yenlina }@binus.edu

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Abstract. *This paper aims to demonstrate the design of a digital game to be implemented as a learning tool for middle school students to learn mathematics. We argue that the game designed meticulously tailored with the learning subjects can increase the pupils' interest in learning, prevent boredom, and increase the curiosity of the students towards the learning subjects, in this case: Mathematics. The game design method proposed in this research is to combine the Six Facets of Serious Game Design and Ernest Adams' Game Design. The results show that the students that implement the serious game design as their learning tools were statistically performed better than the one who only use traditional learning tools.*
Keywords: Serious game design, Learning tools, Mathematics, Game design

1. **Introduction.** Technology has changed the way we live as humans. It changed the way we communicate with each other as well as the way we learn something. With the shifting wave of demography cohort from millennials to the Alpha cohort, who are the digital native, born in the Internet era, the conventional learning methods are no longer suitable for the new demography cohort. The Alpha (Z) generation is characterized as the most materially endowed and technologically literate cohort. Technology has been a satisfactory tool for them to enhance their skills and knowledge and love to collaborate both digitally and physically. With more than thirty percent of the world population and around 2.5 million Alpha generation born around the world in every week, we should start to change our conventional way of learning and teaching to adjust to the way of this new generation's learning style. Several technologies (e.g., e-learning, multimedia, and flashcards) have proved to be helpful to enhance the learning experience, thus resulting in satisfactory results in the learning processes. One of the state-of-the-art technologies used by this generation to enhance their knowledge is game. Game provides the opportunity to the learners to be able to actively engage with the content. Research has shown that games have been adequate tools to help in a learning or teaching process [1,2]. The element of game that creates interesting and unique experiences can be also applied and tailored to a learning or teaching process. Hence, create a unique experience in the learning or teaching process. This experience is empirically increasing the learner's retainment and engagements during the learning process in some subjects [1,3]. This paper demonstrates the design of a digital game to help middle school students, who are the Generation Alpha to learn a particular subject in their school. In this research, Mathematics subject was chosen to be the pilot case study as in the pilot research, and majority of students (83.33% from 108 respondents) choose it. We argue that the game we designed carefully to be

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tailored to the Mathematics subject can increase the pupils' interest in learning, prevent boredom, and increase the curiosity of the students towards Mathematics. The results empirically show that the game improves the student's Engagement, Understandability, Interest, and Curiosity in the learning process. This paper is organised as follows. Next section illustrates thoroughly the foundation of theories used in this research as well as the state-of-the-art games in education. The following section demonstrates our research and development methodology. Next section shows our game design for games as a learning tool for mathematics. The results and evaluation of the games are discussed in the following section. The last section demonstrates the discussion and future work direction of this research.

2. **Recent Work.** The way how we, humans think and learn has been evolving throughout generations. In this digital era, the existence of technology has empowered humans to learn new things. This also leads to the adjustment to our pedagogy methodology (i.e., the method or approach of teaching). The existing art of teaching needs to be reinvented in this digital era as digital technology has constituted new contexts for pedagogy [4-6]. The information overflowed in the Internet and cloud allows the equalization of the distribution and access to knowledge and information [5,6]. Moreover, the vast technology that is able to create a limitless and boundless virtual space for people to connect would create an endless way to interact leading to the enhancement of interaction [5,6]. Several methods have been proposed to enhance the quality of teaching such as using tools to help the teacher (or facilitator) and learner in the learning process. One of popular tools is multimedia and games. Multimedia and games have been claimed to increase the quality of learning and teaching [5,7-9].

Games have been prominent tools to help facilitator and students to increase their learning quality. Literature classifies two major game methods or tools for learning, serious games and gamification. Serious games are the games that are designed specifically for a peculiar purpose other than pure entertainment. The purpose of serious games is to leverage the advantages of games (e.g., the engagement, interaction, and fun) for training, advertising, education, or simulation [1-3,10]. It has been a long debate about the effect of games to society. Most people argue that games always have been contributing to the negative effects for the society (e.g., violence and addiction). However, there are groups who believe that we could take the advantages of games and blend them into learning mechanism. Literature has reported some positive effects in spatial motoric skills, education, social, and physiological aspects [10]. A number of researches have been done to use games for a specific purpose other than pure entertainment. The area of training and education has the greatest number of serious games implementation, compared to the other areas (for example, see [1-3,11,12]). The results show that serious games enhance the experience and interaction during the learning process, and this leads to the increase of the learning effectiveness [1,3,11,12]. Other than training and education, serious games have also been used in business simulation, as marketing toolkits, as well as companion tools for trainee. A number of researches in game also lead to the adjustment of the model (e.g., the difficulty) of the game to further increase the player's experiences [13]. In those scenarios, serious games are reported to increase the level of player's (or user's) engagements and retainment.

Compared to serious games, gamification is a technique that implements game design elements (e.g., game mechanics) to a non-game application or contexts. To emphasize, gamification is not a game application. It only uses some of the elements of game designs to increase the user's retainment and engagements. Both gamification and serious games are intended to increase the learner's retainment and engagements during the learning process [1,3]. This research contributes to the exploration of designing a game that can be tailored to the Mathematics subjects to increase the learners' interest in the learning

as well as to increase the curiosity of the students towards Mathematics. The results are empirically described in the results and evaluation section.

3. **Methodology.** The methodology for this research was divided into four major phases, which were analysis phase, design phase, development phase, and finally evaluation phase. The analysis phase aims to gather the potential users' requirements, such as which subject is the most difficult to students, what are the challenges, and what features should be implemented in the game. The initial user requirement analysis was conducted in more than 20 schools, from primary school to high school, in the Jakarta City with interview techniques. The respondents were the primary to high school teachers. The results lead to the perception that most of the 20 schools surveyed emphasized primary school students required more tools to help their study. Hence, the second user requirement analysis was conducted in the primary school. A questionnaire was designed to investigate more about which subject is the most difficult to students, what are the challenges, and what features should be implemented in the game. The target respondents were primary school students. 108 samples were chosen as the respondents. From the questionnaire, the most difficult subject to them was Mathematics (83.33%) with Algebra (49.10%) as the most challenging topic, followed by angle problems and solving equations topic (15.74%). The second most difficult subject chosen by the respondents was History (7.41%). Most of respondents also agreed that game would help them to study (92.60%) followed by animation (4.63%). Most of the respondents also preferred the game can be played in a mobile phone (80.56%) and in Indonesian language (71.30%).

The next phase was the design phase. The design phase aims to design the game and content based on the requirement analysis. The most challenging part in this phase was how to tailor the learning subject to the game. This research implements the Six Facets of Serious Game Design [14] blended with Ernest Adams' Game Design [15,16]. Detailed implementation and design are comprehensively described in the next section. The serious game design implemented in the proposed game thoroughly followed the design from Six Facets of Serious Game Design [14] blended with Adam Ernest's Game Design [15,16]. Next, in the development phase, the game was developed using Unity game engine with the devices target being Android. The next and final phase was the evaluation phase. In this phase, the game was played and evaluated with students from various schools. The students were evaluated with two learning systems, the traditional system that has been implemented in the school and with the learning system using proposed game. There are several questionnaires filled and analyzed in the evaluation phase. The results are comprehensively interpreted in the results & evaluation section.

4. **The Serious Game Design.** General game design is specifically designed for entertainment by game designer. In a serious game, there are knowledge acquisition processes blended in the game. Hence, designing a serious game should be also looking for pedagogical aspects in the game design aspects by implementing Six Facets of Serious Game Design [14] and Ernest Adams' Game Design [15,16]. Six Facets of Serious Game Design ensures that the pedagogical aspects covered in the serious game proposed, while the Ernest Adams' Game Design covers the entertainment or fun aspects while learning. Figure 1 illustrates the proposed serious game design derived from the Six Facets of Serious Game Design [14] blended with Ernest Adams' Game Design [15,16]. There are six facets, namely Pedagogical Objectives, Domain Simulation, Interaction with the Simulation, Problem & Progression, Decorum, and Condition of Use. In this serious game design for the proposed game-based learning, Ernest Adams' Game Design was blended to several facets, namely, UI Design, Core Mechanics, and Balancing Design were blended into interaction with the simulation facet; Storytelling, Core Mechanics, and Balancing Design were blended into Problem & Progression; Rewards & Punishments system was

also blended into Decorum facet; Finally, all the facets' and game documentation was documented to high concept documents.

Table 1 demonstrates the proposed game-based learning design pattern using the Six Facets of Serious Game Design [14] blended with Ernest Adams' Game Design [15,16]. Left column represents the six facets, and the right column represents the design pattern of the facets combined with Ernest Adams' Game Design.

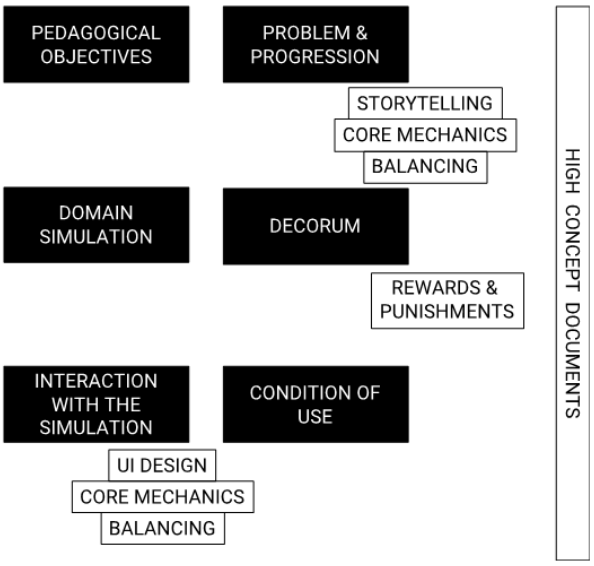

FIGURE 1. Serious game design proposed

TABLE 1. Proposed game-based learning design pattern

The facets	Design pattern blended with Ernest Adams' Game Design
Pedagogical Objectives	Mathematics Skills for Primary School based on National Curriculum Design
Domain Simulation	- Simulate specific Math cases - Simulate adventure games with Math cases
Interactions with the Simulation	- UI Design for 11-15 years old players - Simple core mechanics with puzzle - Balancing in every level. Each level represents Mathematics Skills for Primary School based on National Curriculum Design - Questions and answer system - Pedagogical Gameplay - Quick Feedbacks
Problems and Progression	- Achievements with Star based on Score (Time and Number of Correct Answer) - Storytelling with Spaceship and Alien Themes - Simple core mechanics with puzzle - Balancing in every level. Each level represents Mathematics Skills for Primary School based on National Curriculum Design
Decorum	- Rewards and punishment system with core mechanics of mathematic puzzle system - Rewards and object collections
Conditions of Use	- One player with mobile phone

To evaluate the proposed serious game design, a simple prototype was built with difficulty limited to only four level. However, the prototype is already representing all the minimum functions (minimum viable product) of the proposed serious game design. Figure 2 shows the level design of the game. Left side of the figure shows the level design for level 1 (upper side) and level 2 (lower side), while right side of the figure represents the level design for level 3 (upper side) and level 4 (lower side). The higher the level is, the more complicated the difficulty of the level, enemy, and puzzle are. The goal is to defeat several aliens, and search for the key to proceed to the next level. The character has 5 lives in every beginning of the level. If the player loses all the five lives of the characters, the player would need to retry the level from the beginning. The score is calculated based on the accuracy and the speed of the answer. Figure 3 illustrates the design of the character and the enemy.

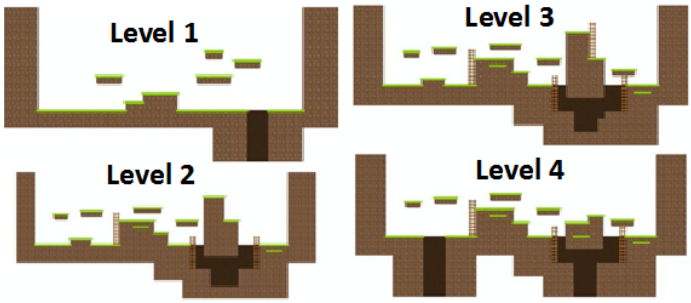

FIGURE 2. Level design (Left: Lv. 1-2; Right: Lv. 3-4)

FIGURE 3. Character design (Left: Player; Right: Enemy)

5. **Results & Evaluation.** A minimum viable product as a prototype is designed and developed to evaluate the proposed serious game design. Figure 4 illustrates the proposed game play. The game was implemented to an Android mobile phone and tested to two groups of students in the same level from various schools. Each group consists of 30 students with relatively similarity in their level of knowledge in the Mathematics (based on their teachers' testimony). One group implements the game as their learning tool (Group B), while the other group uses books as their learning tool (Group A). Each group will have the identical learning materials and quizzes. Each group had to answer 20 quizzes and fill out some questionnaires based on Abdellatif et al.'s framework [17], asking about the engagement, usability, and understandability. The results then are analyzed using ANOVA Test and statistic descriptive. Figure 5 illustrates the results of the evaluation. Up side of the figure shows total score for each student in both groups. Group A indicates the student's group that uses books as their learning tool, where Group B indicates the student's group that implements game as their learning tool. On the other hand, Figure 5 demonstrates the total of correct answer for each question.

As presented in the up side of Figure 5, students in the group B performed better than the one in the group A. An ANOVA test performed resulted in $F = 12.946$; $p = 0.0006$

FIGURE 4. Game play

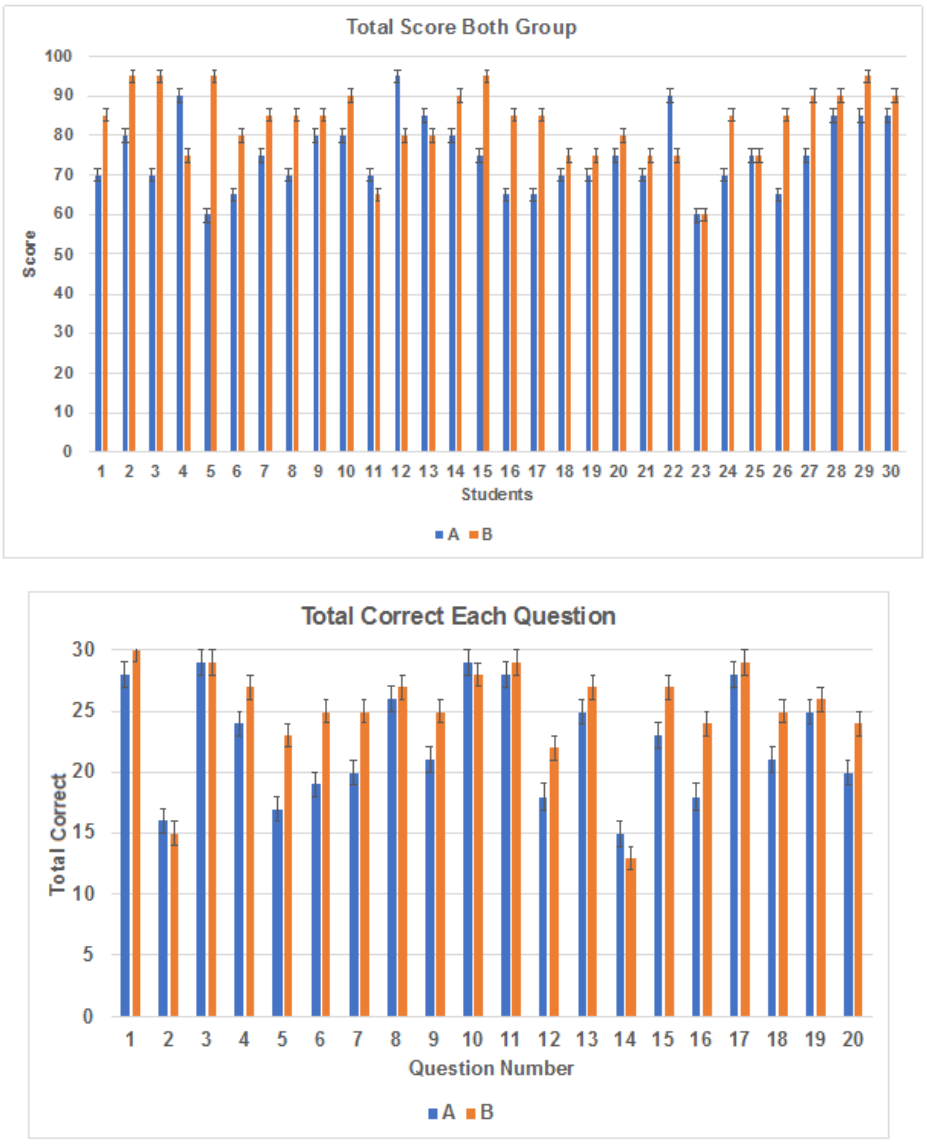

FIGURE 5. Total score of students both groups (up) and total number of correct questions (down)

($p < \alpha$); F-crit = 4.0068. Moreover, a descriptive statistic method shows that the average score in group A is 75 and B is 83.33; maximum score in both groups is 95 and minimum score in both groups is 60; and standard deviation in group A is 9.097 and B is 8.840. The results indicate that students in the group B (that implements the game as their learning tool) statistically performed better than group A (that uses books as their learning tool) with $p < \alpha$ and F > F-Crit. Moreover, as presented in the bottom side of Figure 5, most

of students in group B have higher correct number in most of questions. There are several question numbers (numbers 2, 10, 14) in which students in group A performed better that the one in group B. In addition, after the evaluation, a simple questionnaire is to evaluate 5 variables: Engagement, Usability, Understandability, Interest, and Curiosity to both groups. The results indicate that students in group B statistically show higher score in the Engagement ($F = 6.218$; $p = 0.015$; F-Crit = 4.006), Understandability ($F = 6.706$; $p = 0.012$; F-Crit = 4.006), Interest ($F = 73.384$; $p < 0.001$; F-Crit = 4.006), and Curiosity ($F = 19.852$; $p < 0.001$; F-Crit = 4.006) variables towards group A. While there are no statistical differences between both groups for variable Usability ($F = 2.004$; $p = 0.162$; F-Crit = 4.006872886).

6. **Discussion & Future Work.** This paper presents the exploration of a serious game design by using Six Facets of Serious Game Design [14] blended with Ernest Adams' Game Design [15,16] in Mathematics subject. The subject was chosen in this research project because majority of the respondents (i.e., students) choose Mathematics subject as the most difficult subject in the school (83.33% from 108 respondents). The proposed serious game design was implemented to a simple game that can be played in a smartphone to be evaluated by students. Two groups of students (30 students each group) who have similar knowledge and level of understanding in Mathematics subject were chosen to be respondents. Group A uses books as their learning tool, while Group B implements the mobile game as their learning tool. The results show that the students in group B performed statistically better than one in group A ($p < \alpha$ and $F >$ F-Crit). Moreover, the students whom the group used game as their learning tool achieved higher score in Engagement, Understandability, Interest, and Curiosity compared to group who used books as their learning tool. For the next research direction, a dynamic balancing [5,13,18,19] can be applied in the game to dynamically adjusting the subject's difficulty based on the student's performances during game. Hence, each student can have their own phase for learning the subject. Moreover, other subjects can also be explored to be implemented in a serious game as learning tool.

REFERENCES

[1] A. Chowanda and Y. L. Prasetio, Indonesian historical game design (Perancangan game edukasi bertemakan sejarah Indonesia), *Proceedings SEMANTICS*, pp.151-155, 2012.
[2] A. Chowanda and A. D. Chowanda, Gamification of learning: Can games motivate me to learn history?, *ComTech: Computer, Mathematics and Engineering Applications*, vol.7, no.3, pp.225-232, 2016.
[3] Y. L. Prasetio, S. Rambito, A. Yudhistira, S. F. Aulia and A. Chowanda, Teaching social critique to adults with a desktop horror myth game, *Procedia Computer Science*, vol.135, pp.624-631, 2018.
[4] H. Beetham and R. Sharpe, An introduction to rethinking pedagogy for a digital age, *Rethinking Pedagogy for a Digital Age*, pp.1-10, 2007.
[5] H. Beetham and R. Sharpe, *Rethinking Pedagogy for a Digital Age: Designing for 21st Century e-Learning*, Routledge, 2013.
[6] A. Loveless, Technology, pedagogy and education: Reflections on the accomplishment of what teachers know, do and believe in a digital age, *Technology, Pedagogy and Education*, vol.20, no.3, pp.301-316, 2011.
[7] K. D. Squire, Video games and education: Designing learning systems for an interactive age, *Educational Technology*, pp.17-26, 2008.
[8] D. B. Clark, E. E. Tanner-Smith and S. S. Killingsworth, Digital games, design, and learning: A systematic review and meta-analysis, *Review of Educational Research*, vol.86, no.1, pp.79-122, 2016.
[9] T. Hainey, T. M. Connolly, E. A. Boyle, A. Wilson and A. Razak, A systematic literature review of games-based learning empirical evidence in primary education, *Computers & Education*, vol.102, pp.202-223, 2016.
[10] T. Susi, M. Johannesson and P. Backlund, *Serious Games: An Overview*, 2007.

[11] S. Arnab, T. Lim, M. B. Carvalho, F. Bellotti, S. De Freitas, S. Louchart and A. De Gloria, Mapping learning and game mechanics for serious games analysis, *British Journal of Educational Technology*, vol.46, no.2, pp.391-411, 2015.
[12] F. Xu, D. Buhalis and J. Weber, Serious games and the gamification of tourism, *Tourism Management*, vol.60, pp.244-256, 2017.
[13] V. Vorachart and H. Takagi, Evolving fuzzy logic rule-based game player model for game development, *International Journal of Innovative Computing, Information and Control*, vol.13, no.6, pp.1941-1951, 2017.
[14] B. Marne, J. Wisdom, B. Huynh-Kim-Bang and J. M. Labat, The six facets of serious game design: A methodology enhanced by our design pattern library, *Proc. of the 7th European Conference on Technology Enhanced Learning*, pp.208-221, 2012.
[15] E. Adams and J. Dormans, *Game Mechanics: Advanced Game Design*, New Riders, 2012.
[16] E. Adams, *Fundamentals of Game Design*, Pearson Education, 2014.
[17] A. J. Abdellatif, B. McCollum and P. McMullan, Serious games: Quality characteristics evaluation framework and case study, *2018 IEEE Integrated STEM Education Conference (ISEC)*, pp.112-119, 2018.
[18] M. T. Akbar, M. N. Ilmi, I. V. Rumayar, J. Moniaga, T. K. Chen and A. Chowanda, Enhancing game experience with facial expression recognition as dynamic balancing, *Procedia Computer Science*, vol.157, pp.388-395, 2019.
[19] J. V. Moniaga, A. Chowanda, A. Prima and M. D. T. Rizqi, Facial expression recognition as dynamic game balancing system, *Procedia Computer Science*, vol.135, pp.361-368, 2018.