Bridging the Gap Between the Derivatives And Graph Sketching in Calculus: An Innovative Game-Based Learning Approach

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https://doi.org/10.24191/ajue.v16i4.11962

Received: 15 November 2020
Accepted: 11 December 2020
Date Published Online: 24 January 2021
Published: 25 January 2021

Abstract: Sketching the graph of mathematical functions using derivatives is a challenging task for undergraduate students who enrol for the first level of calculus course. Before graph plotting, students are required to perform a thorough function analysis using the concepts learned in differentiation. They are then expected to solicit the results obtained to sketch the graph. Nevertheless, the students face great difficulties in achieving this goal; and fail to relate the results obtained in the analysis and their representation in a graph. Their performance is thus negatively affected eventually. To overcome this cognitive gap, an innovative board game named Graph Puzzle (GP) is developed. It is intended to function as a manipulator to facilitate students in comprehending the inter-related algebraic, symbolic, and graphic representation of a function under the applications of derivatives, forming the corresponding procedural and conceptual knowledge. To measure the effectiveness of this board game, 84 undergraduate students who took this calculus course were given pre- and post-test before and after the learning session. An ANCOVA test conducted reveals a significant difference ($F(1, 81) = 12.182$, $p = 0.001$) between pre and post-test score in solving polynomial functions, whereas students' performance in solving rational functions indicates no meaningful difference ($F(1, 81) = 0.04$, $p = 0.841$) of post-scores between control and treatment groups. From this standpoint, it is shown that GP has the potential to serve as a solution to the difficulties faced on graph sketching in calculus, particularly when dealing with polynomial functions.

Keywords: Visualization, Calculus, Embodied learning, Game-Based Learning, Graph Sketching

1. Introduction

Different mathematics courses covering the diverse fields of mathematics are generally among the core courses in the study plan of typical science, technology, engineering, and mathematics (STEM) related undergraduate programs. The students enrolled in these programmes are usually required to take at least one mathematics course in each of their first three or four semesters. Introductory and its subsequent advance calculus are among the main mathematics courses that these students across the STEM-related programmes are required to take. Nevertheless, calculus courses have been widely reported as challenging to the students. Mathematics incompetency was reported as the most important factor causing almost one-third of engineering students fail to complete their programs; with high school calculus course and the number of college calculus courses taken commented as the two strongest predictors of completion of an engineering undergraduate program (Hopkins, Lyle, Hieb, & Ralston, 2016); and merely over half of science and engineering students were successful in their calculus courses (Çetin, 2009).

The above alarming reports reflect the importance for students to master calculus, starting from the introductory or the first level course. Typical first-level calculus course focuses on the fundamental theorem of calculus and covers topics like limits, rules of derivative and integrations, and their applications. Most students are doing well for the topics like limits, and rules of derivative and integrations that are predominantly solvable procedurally; even if they fail to grasp the conceptual knowledge well (Zerr, 2010). Nonetheless, many of them have a hard time coping with questions related to the applications of these concepts. One of these application topics that particularly caught the attention of researchers is about sketching the graph of a function through the interpretation obtained from analysing the derivatives of the function (Hong & Thomas, 2015; Çetin, 2009).

Function in calculus is usually presented algebraically. Analysis of it using derivatives to denote its graphical representation entails mastering the conceptual understanding of the function derivatives. Students are required to solicit the interpretation from derivations in at least five aspects: i) slope at a point on the curve, ii) direction of the function (whether it is increasing and/or decreasing), iii) the relative extrema, iv) concavity of the function (whether it is concave upward or downward), and v) inflection points. They also need to identify the horizontal and vertical asymptotes for the graph of a function, applying the concept of the limits. Consolidating and interpreting this huge amount of information could be overwhelming for students who fail to possess the necessary concept, not to mention those who struggle with finding the derivatives. As a result, students with inadequate conceptual knowledge face problems of representing an algebraically given function graphically, even if they have no problems with finding the derivatives of the function procedurally (Çetin, 2009).

Students have difficulties to sketch, for example, an increasing function which has a downward curvature; maximum, minimum, and inflection points of the function; and behaviour of the function near the asymptotes. There seems to be a mental or cognitive gap that needs to be closed so the students could produce the graphical interpretation (sketch the graph) of a function by soliciting the results obtained from the algebraic derivatives and the numerical analyses that they have evaluated.

Studies are conducted and subsequence strategies are suggested to tackle difficulties experienced in the teaching and learning processes of these topics in calculus. Undoubtedly, technological tools have been suggested to remedy the above graphic representation problems in this technologically advanced era. Mathematical software and graphing calculator (Chien, 2019; Sevimli, 2016) are among the technology tools that have been surveyed. Despite the positive results reported, some researchers have argued about its effectiveness to accommodate students of different learning styles, pace, and engagement levels (Borji, Alamolhodaei & Radmehr, 2018). Researchers commented that technology will never replace the role and effectiveness of hands-on learning approach, mainly due to the implementation difficulties in terms of the level of integrating the technology, and its didactical nature in terms of the usage (Hong & Thomas, 2015).

On the other hand, various intervention plans incorporating specially designed instructional approaches during regular teaching and learning sessions are found to be helpful. Findings from recent studies reiterated the effectiveness of employing a composite framework integrating the three worlds of mathematics (embodied, symbolic, and formal world), and the actions, processes, objects, and schemas (APOS) theory (Hong & Thomas, 2015). There appears a positive and long-lasting impact of designing an embodied learning environment (Duijzer, Heuvel-Panhuizen, Veldhuis, Doorman, & Leseman, 2019). When it comes to the teaching and learning of calculus, designing problem-based learning that focuses on the infinite concept that promotes capability of the students to think calculus conceptually (Zerr, 2010); and the importance of balanced emphasis among the algebraic, numeric, and graphic representations of functions under investigation (Çetin, 2009) is the emphasis for a meaningful learning process.

Apart from technological tools and intervention plans or programs, mathematics educators always come out with creative and innovative tools to be used as the teaching and learning aids, especially for topics with abstract concepts. They are created mainly as a manipulative during the instruction sessions for students to have hands-on activities physically, reporting improved mathematics performance of the students (Sulaiman, Subramaniam, & Kamarudin, 2019; Thuneberg, Salmi & Bogner, 2018; Ekwueme, Ekon & Ezenwa-Nebife, 2015). Many of these efforts have been designed for a game-based learning approach that integrates the game elements into a non-game context (Zimmerling, Höllig, Sandner, & Welpe, 2019). The approach is widely approved as capable of forming a student-centred, fun, and interesting atmosphere for an effective learning process to attain a learning outcome set (Pesare, Roselli, Corriero, & Rossano, 2016). Nevertheless, the great bulk of the tools and the successive hands-on activities were for the primary and secondary school students. Surveys about tools and the corresponding hands-on activities innovated for a game-based learning approach in the complex bodies of tertiary-education-level mathematical knowledge like calculus (Hopkins et al., 2016) are scarce. Furthermore, such surveys that focus exclusively on the analysis of a function for sketching its corresponding graph can hardly be found.

Consequently, an innovative tool is developed to aid the teaching and learning of the above topics under the introductory calculus course. The targeted students are those enrolled in typical STEM-related undergraduate programs. The tool designed is named Graph Puzzle (GP) (Liew, Chen, Tuh, Ling & Ahmad Bakri, 2019). GP is a type of board-game tool innovated for an embodied learning environment with a balanced emphasis among the algebraic, numeric and graphic presentations of functions and their derivatives so that capability of the students to think calculus conceptually could be promoted (Duijzer et al., 2019; Hong & Thomas, 2015; Zerr, 2010; Çetin, 2009). On top of this, the power of technology is also exploited to expand the capacity of the amount of content that could be included in it. This tool is meant to be a manipulator to bridge the cognitive gap mentioned earlier. The aim of this study is to evaluate the effectiveness of GP via interventions integrated within the level one calculus instructions in a local public university. Specifically, this study intends to look into the effect of Graph Puzzle on students' performance in obtaining the sketch of polynomial and rational functions by answering the following questions:

1. How does Graph Puzzle affect the students' performance in obtaining the sketch of a polynomial function?
2. How does Graph Puzzle affect the students' performance in obtaining the sketch of a rational function?

The flow of content of this paper is as follows: section one introduces the subject of interest of this study; section two expounds the background related to the study; section three explains about GP; section four illustrates the methodology and limitation of the study whilst findings and discussion are elaborated in section five. Finally, the paper ends with a conclusion where recommendations for future research are also suggested.

2. Literature Review

In this section, discussion about studies in calculus education, embodied learning, student-centred interventions emphasizing visualization and hands-on approach, technology in conceptualization of mathematics knowledge and skills, and the role of play in education through game-based learning approach are presented.

2.1 Calculus Education

Plenty of studies have been conducted on calculus education and increased attention is putting on students' understanding of derivative concept in the context of mathematics and science (Dominguez, Barniol & Zavala, 2017; Steven, 2017; Hayfa & Ballout, 2015; Park, 2015; Siyepu, 2013). As presented in the first section of this paper, students are required to make use of the results obtained from the derivatives such as the direction, local or relative extrema, curvature, and inflection points of a function, to sketch a polynomial function; and the asymptotes of its graph to sketch a rational function. For this purpose, the prior and prerequisite knowledge required of the learners include manipulating limits and the first derivative of a function, evaluating the slope of a tangent line at a point of a curve, and the higher-order derivative techniques (Dominguez et al., 2017). It is closely related to the topic of rate of change which is about the local (or pointwise) and global understanding of a function; commented as one of the underlying main concepts that most students have difficulties with (Hong & Thomas, 2015). This has thus depreciated their skills for other topics in calculus, including the graphical interpretation of the derivatives.

Researchers revealed that students faced difficulties in graphical interpretation of the derivative which occurred on a straight line or complicated curves (Planinic, Ivanjek, Susac, & Milin-Sipus, 2013), computing the slope of a tangent line from the graphs (Dominguez et al., 2017), lack of visualization ability on the conceptual image of functions (Zerr, 2010), cognitively combining with the interval information of the derivatives and critical point(s) on graph (Borji et al., 2018; Hayfa & Ballout, 2015; Orhun, 2012). As a result, students experiencing these difficulties have problems to sketch the graph of a given (polynomial or rational) function even though they may be able to solve for its derivative and identify its direction, relative extrema, curvature, inflection points and/or asymptotes. Nonetheless, the embodied learning environment particularly stands out among the studies addressing these issues in calculus and their impact on the student's understanding and performance.

2.2 Embodied Learning

Embodied learning stresses the significance of learners' physical bodily experience with their physical surroundings towards learning, and the cognitive processes that happened at an instant. The advocacy of embodied learning evolves from the "concrete" learning that is limited at the first stage of cognitive development of a child – sensorimotor – that is purported by Jean Piaget (1964, p.177). However, embodied learning claims that the impact of learning involving sensorimotor is continual, lasting, and affects conceptualization even at higher stages (Oudgenoeg-Paz, Volman & Leseman, 2016). The embodied cognitive theory that based this learning approach emphasizes the important relationship between physical experience processes, a considerably lower-order cognitive stage, and abstract concept formation processes, a higher-order cognitive stage (Duijzer et al., 2019).

This theory goes well with the three worlds of mathematics (TWM), a mathematical thinking development framework that comprises the embodied world (conceptual embodiment), symbolic world (operational symbolism), and formal world (axiomatic formalism) (Tall, 2013). It provides a big picture of the full journey in the processes of developing mathematical thinking from birth to adulthood. Conceptual embodiment is emphasized as the result from the interaction between the learners' body and their physical world that give rise to the use of both static and dynamic mental images (Tall, 2013, p.12). The embodied world in TWM first uses the visual and physical attributes of a concept, then the enactive sensual experiences are combined to build the mental concepts (Hong & Thomas, 2015). The symbolic world is the situation where the symbolic representations of the concepts are manipulated. Hence, shifting between the embodied and symbolic worlds allows the learners to relate and to comprehend the relationship between the physical meaning of a concept and the properties of its symbols. In other words, it is bridging and eventually closing the cognitive gap among the algebraic, numeric, and graphic representations of functions. Lastly, the formal world is the stage where axioms are formalized from the properties of concepts and are used for the building and proving of theorems (Hong & Thomas, 2015) at a higher level of learning.

The emergence of embodied mathematics activities has its basis in the embodied cognition theory and is closely related to Tall's TWM (2013). One example of interest to this study on embodied activities is about expressing both static and dynamic representations of functions and its graphs either on a piece of paper or in one's mind or using a computer application (Tall, 2013). Both contribute to the mental images and thus the mental model formed in the learners. The cognitive movement shifting among the algebraic, symbolic, and graphic representation assists the procedural and conceptual formation within learners. Many embodied mathematics studies have been carried out and more are called forth into interventions for the teaching and learning of mathematics within the STEM education community (Duijzer et al., 2019).

Consequently, it is beneficial to take advantage of the embodied learning for the teaching and learning of the applications of derivatives in analysing a function for the sketching of its graph.

It is obvious that the embodied mathematics learning environment is learner-centred. It should comprise of interventions that make use of manipulation with physical objects the students have (hands-on work), empower the visualization ability, allows students of the opportunity to observe or watch the manipulation of concept, relate the symbolic or algebraic representation of a concept of interest, and incorporates the element of enjoyment.

2.3 Learner-centred Interventions with Visualization and Hands-on Approach

Visualization in mathematics is the image forming process, either mentally (cognitively), physically (pencil and paper), or through the use of technology; where these images are then used for improved and effective mathematical understanding (Borji et al., 2018; Mendezabal & Tindowen, 2018). The ability to visualize enables meaningful graphical interpretation in mathematics education of which well-developed cognitive skills are required (Orhun, 2012). These cognitive or thinking skills could be fully trained through an on-going hands-on approach, particularly when its execution involves active mental or cognitive engagement (Rohaenah, Ngadiyem, Hasbudin, Fauzi, & Dewie, 2019; Rondina, 2019).

The main principle of hands-on approach is "learning by doing" by Dewey (1938). It is supported by a famous ancient Chinese proverb of "I hear and I forget, I see and I remember, I do then I understand" (Leal-Rodriguez & Albort-Morant, 2019), which encourage students to learn through experimentation and observation (Thuneberg et al., 2018) and to build new ideas by creative and critical thinking (Sulaiman et al., 2019; Mehmood, Anwer & Tatlah, 2017; Dhanapal & Wan Zi Shan, 2013). Researchers reported that hands-on approach has significantly and positively impacted student's academic performance in mathematics (Sulaiman et al., 2019; Ekwueme et al., 2015) and science (Ekwueme et al., 2015).

Recently, a hands-on approach that explicitly emphasizes cognitive engagement is gaining attention among the education research community. It is defined as the instance where learners involved actively in manipulating objects (hands-on) to gain knowledge and at the same time developed constructive knowledge conception cognitively (Rohaenah et al., 2019). Research findings showed that it built the learners' physical and mental learning (Rohaenah et al., 2019). Studies reveal this approach that actively engages cognitive processes in teaching and learning motivates and cultivates the learning nature of learners, and is very effective for the teaching and learning of abstract subjects like mathematics (Rohaenah et al., 2019; Rondina, 2019; Ekwueme et al., 2015; Dhanapal & Wan Zi Shan, 2013). Being the graphic representation of a function that is presented algebraically, hands-on activities that enable students to visualize the graph of a function (through the applications of derivatives) help the students to comprehend the abstract concept of this topic in calculus. On top of that, the impact of using technology as a tool to aid meaningful teaching and learning sessions, particularly for abstract mathematics concepts, plays a contributing factor for successful calculus lessons.

2.4 Technology for Conceptualization of Mathematics Knowledge

Education researchers recommended the use of technology to remedy the graphical interpretation and visualisation in calculus context. Its computing power particularly enables users' to further analyse and inquire the mathematical numeric and graphic knowledge. One category of technology tools widely used across the mathematics field is mathematical software. Some well-established tools include MAPLE (Borji et al., 2018; Salleh & Zakaria, 2016); MATHEMATICA (Ayub, Sembok & Luan, 2008); MATrix LABoratory or MATLAB (Ayub et al., 2008); GeoGebra (Öçal, 2017); and Microsoft Mathematics (Mendezabal & Tindowen, 2018; Oktaviyanthi & Supriani, 2015). Other popular tools are Computer Algebra System (Sevimli, 2016); and also, the graphing calculator (Chien, 2019; Sevimli, 2016). Many educators and researches revealed that the use of such technology helps learner visualize the mathematics content (Borji et al., 2018; Mendezabal & Tindowen, 2018) and improve students' conceptual understanding and mathematical thinking (Öçal, 2017; Özgün-Koca & Meagher, 2012) particularly for tertiary mathematics courses like calculus.

Borji et al. (2018) demonstrated the use of APOS-ACE (Action, Process, Object, and Schema-Activities, Classroom discussion, and Exercises). It integrates with the MAPLE software to explore the students' graphical understanding of the derivative. They reported that students in the experimental group (who were exposed to APOS-ACE) showed a better understanding of the derivation compared to the control group. However, they noticed that this technique is not beneficial to the unsuccessful response in the experimental group who are weak in their mathematics foundation (prerequisite concept in derivatives, formula of slope of a straight line, functions, and limits), inactive and passive in their group, and fail to participate in classroom discussion.

Interestingly, researchers advocating the use of technology, however, admit and accept the superiority of by-hand work for mathematics (Hong & Thomas, 2015). They identified two main factors one needs to consider when integrating the use technology in the tertiary education level instruction: level of technology usage in the learning processes of students; and the didactical nature of the technology use. Therefore, it is important for intervention seizing the advancement of technology to focus on its use as a tool for knowledge construction and do not overdo the technology role. In addition to everything else, the element of fun and enjoyment in any intervention should also be considered.

2.5 Game-based Learning in Education

Play is a fundamental activity that enables mankind to learn and grow. The adoption of play and games in tertiary education is getting attention recently with its buzzword: gamification – the process of incorporating the game elements to the non-game context (Zainuddin, Chu, Shujahat, & Perera, 2020; Zimmerling et al., 2019). The game elements are meant to balance the subject matter; aiming for the students to retain and apply what has been learned (Kingsley & Bittner, 2017). The application of game pedagogies encompasses the use of the education game theory to design instruction that blends in the games and play element (Smith & Golding, 2018; Morrison & Secker, 2017). Three key components of game-based learning include competition that provides motivation for students to learn; engagement, that results from competition, which captures the students' curiosity and keep them immerse in the learning; and immediate rewards in terms of descriptive feedback, earning points, or feeling successful, which continuously retain the students in the game and thus the learning, even without knowing that they are learning to learn (Kingsley & Bittner, 2017).

Studies revealed that gaming in education intertwines well with embodied learning environments. Its learning materials encourages hands-on learning experience (Bassford, Crisp, O'Sullivan, Bacon, J. & Fowler, 2016) that promotes student-centred learning (active learning), captures learners' engagement, and stimulates their motivation to learn (Clarke, Peel, Arnab, Morini, Keegan, & Wood, 2017; Humphrey, 2017). There are plenty of educational games of which they are predominantly digital-based games like computer, mobile and online games; and some non-digital-based games like board, card, word, and puzzle games (Khan & Pearce, 2015) which undoubtedly play a significant role in the game-based learning tool. The benefits of board games particularly stand out as it allows users to physically get in touch with it. They are interesting and enjoyable by nature as playing the games boost social interactivity and collaboration among the players (Hassinger-Das, Toub, Zosh, Michnick, Golinkoff & Hirsh-Pasek, 2017) and thus promote peer-learning. Effective integration of board games in instructions develops students' mathematical problem-solving skills and increases their interests in learning mathematics (Rondina & Roble, 2019; Vogt, Hauser, Stebler, Rechsteiner & Urech, 2018). Students are reported to learn while experiencing 'enjoyment, pleasure, relaxation, laughter, and learning' (Frey & Wilhite, 2005, p.157). Such engaging and enjoyable experiences eventually enable the students to develop soft skills needed for real-world living: teamwork, problem-solving, communication, leadership, observational, and mathematical skills (Humphrey, 2017, p.53). Nonetheless, games, mostly digital, developed for calculus are very limited and mainly focus on tackling basic skills or techniques in the derivatives and integration (Cezar, Garcia, Botelho & Miletto, 2019; Hamid, Saari, Razak & Omar, 2019; Forman & Forman, 2008). Studies on game-based learning for topic related to the applications of derivatives like analysis of functions that incorporate embodied learning, offering visualization and hands-on experience with optimum technology application could hardly be found.

Studies discussed in the above sections eventually reveal the need to close the gap in relating the graph of a function and its derivatives through a game-based learning education tool innovated by incorporating five main elements. First, it should provide an environment for embodied learning that involves meaningful learning through interaction between learners' physical body and their physical world (Duijzer et al., 2019; Oudgenoeg-Paz et al., 2016; Tall, 2013). Second, it enables visualization of abstract concepts and relates the results of derivatives obtained procedurally (Borji et al., 2018; Mendezabal & Tindowen, 2018; Orhun, 2012). Third, it engages hands-on activities that involves active mental or cognitive engagement (Rohaenah et al., 2019; Rondina, 2019). Fourth, it grabs hold of the technological advancement with optimum didactical nature (Hong & Thomas, 2015). Lastly, it blends in the games and play element (Smith & Golding, 2018; Morrison & Secker, 2017). Consequently, GP is developed based on these five elements for a game-based learning approach, comprising the aspects of competition, engagement, and immediate rewards. It is an education board game cum teaching and learning aid to assist students in overcoming the gap of comprehending the relationship between the results they obtained from the analysis of a function via derivatives and the graph sketching of this function.

3. Intervention with Graph Puzzle (GP)

In this study, intervention with GP (Liew et al., 2019) was implemented in an Introduction to Calculus or the first level calculus course for students enrolled in the computer science, applied science, and engineering undergraduate programmes. The course content is foundational calculus topics including limits and continuity, techniques of derivatives and integration, and applications of derivatives and definite integration. The students are required to pass this course before they can enrol for the second level of calculus course in the following semester. GP was introduced after the students learned the topic of using derivatives in function analysis for the sketching of the function graph. The students were enrolled to different groups by the faculty and were taught by the lecturers who are also the authors of GP. Although different lecturers are teaching the groups, these lecturers use the same syllabus and lesson plan, share similar teaching materials and constantly meet up for discussion of course delivery approaches particularly for this topic (function analysis and graph sketching using derivatives) besides being experienced in delivering the course. Typical course delivery and practices are carried out for the students in a control group where the students discuss typical problems in a group of two to four persons for the tutorial session. GP is introduced for the students in a treatment group where the students manipulate GP in a group of two to four persons for the tutorial class. In both groups, the lecturers act as facilitator during the tutorial sessions and provide timely feedback whenever needed.

GP is developed for a topic in level one calculus: analysis of a function for graph sketching. The scope of functions is limited up to the third-degree of polynomial function and rational function with linear expression for both the numerator and denominator. It is aimed to provide an environment for learners to build their skills in soliciting all the required derivative results of a function and their analyses to sketch the graph of the function. The use of GP is twofold: a board game for learners who have learned the concept needed to further enhance and strengthen their skills in soliciting results analyses obtained from the derivatives of a function given algebraically, and a learning aid for novice learners to garnish the skills. Targeted users are both the students and lecturers or course instructors of the first level calculus. For the students to use GP, they should have gone through the topic of analysis of functions using derivatives under the topic of applications of derivatives.

The user guide of GP provides detailed instruction to guide either the facilitators to fully use it as a teaching aid or the students to play it as a board game or learning tool so both parties could get the best out of it. The magnetic plane board serves as the Cartesian coordinate system plane with x-axis and y-axis where the puzzle of the graph will be formed. As for the puzzle pieces, they include all the necessary pieces needed for the representation of x-intercept, y-intercept, local maximum point, local minimum point, inflection point, the curve for a polynomial function, and curve for a rational function. Task cards for GP are cards where clues to a task of fixing the puzzle of graph for a given function are printed. Scores allocated for each task are also printed on each task card for the competition aspect of GP. The cheat sheet given in GP serves as a reference with regards to all the prior-knowledge or concepts needed in sketching the graph of a function by analysing its derivatives. Each content is presented as a short animation in MP4 video format and is accessible via quick response (QR) code. Lastly, the answer booklet serves as the immediate reward aspect of GP and is prepared for the users to check the solution for each task in the task cards. It details out the rubrics on how each point could be scored by the users or players. At the end of the play, the user with the highest score will be the winner. Alternative access for the solution is also provided through another QR code. All digital information with regards to GP is kept in Padlet, a web 2.0 tool (Deni & Zainal, 2018). Other materials comprise dice, pencil, notepad, marker pen, and duster.

An example of the task card content is given in **Figure 1** with standard clues shown**.** As mentioned above, the focus of this intervention is to close the cognitive gap of the students' procedural and conceptual (that is the algebraic, symbolic, numeric, and graphic) knowledge about the derivatives of a function and its graph. The clues given are thus designed so that students need the least computation, which also reduces the time needed for all the procedures of finding the derivatives based on the rules that they have learned. This will at the same time retain the fun element of the tool so that students get engaged and learned; encompassing the engagement aspect of GP. As clues are presented according to the information needed to sketch the graph of a function, the emphasis on the importance of procedural knowledge will not be neglected.

CLUES:
Given f(x) = $-x^3 + 6x^2 - 9x$
y-intercept: (0, 0)
Critical points: (1, –4) & (3, 0)

Interval	(–∞, 1)	(1, 3)	(3, ∞)
Sign of f'(x)	Negative (–)	Positive (+)	Negative (–)
Direction of f(x)			

Interval	(–∞, 2)	(2, ∞)
Sign of f''(x)	Positive (+)	Negative (–)
Shape of f(x)		

Task: Fix the puzzle of this graph, with the maximum point (if any), minimum point (if any), inflection point (if any), and the x- and y-intercepts.

(7 points)

Fig. 1 An Example of Task Card

For the task presented in **Fig. 1**, a function $f(x) = -x^3 + 6x^2 - 9x$ $f(x) = -x^3 + 6x^2 - 9x$ is given and its y-intercept, (0,0), critical points, (1,–4), and (3,0), the interval of the function where the sign (negative or positive) of its first and second derivatives are provided. Based on these clues, the task that the students need to act on is to identify, if any, the x-intercept, the relative extrema (maximum point (3,0) and minimum point (1, 4)) from the analysis using the first derivative, the inflection point (2, –2) from the analysis using the second derivative and by finding the value of f(2), the interval where the function is increasing, (1, 3), and decreasing, (–∞, 1) and (3, ∞), and concaves upward, (–∞, 2), and downward, (2, ∞) before they could fix the puzzle of the graph for $f(x) = -x^3 + 6x^2 - 9x$. When this puzzle is fixed correctly, the user will be awarded with seven points, as given at the bottom right corner of the task card shown in **Fig. 1**.

Fixing the puzzle requires the students to manipulate with physical objects (the puzzle pieces) involving embodied action. The process of figuring out the graphs empowers the visualization ability of the students when they relate the algebraic, symbolic, and numeric information of the function with their graphic representation. In the process of physically handling the puzzle pieces, the construction of concepts is happening. Observing other students fixing the puzzle and watching the animations of related concepts helps the students build their mental model (Thuneberg et al., 2018), and the discourse among the students during the puzzle fixing processes encourage verbalization of mathematical language. The interaction between students and the tool, and with their counterpart while manipulating objects provides a rich and immersive environment not only for cognitive engagement (Rohaenah et al., 2019) but also inspires affective enjoyment of the learners. It is believed such a learning experience is rewarding for the students.

4. Methodology

A quasi-experimental design with pre-test-post-test, control and treatment groups was used in this study. The respondents involved were 84 students taking Calculus 1 course from three faculties i.e. Faculty of Computer and Mathematical Sciences, Faculty of Applied Sciences, and Faculty of Civil Engineering. Randomly selected students were categorized into two groups i.e. control (38 students) and treatment (46 students). In this study, students under the treatment group received the GP intervention during tutorial session, in which GP is used as a manipulative in the topic of function analysis and graph sketching using derivatives in a group of 2 to 4, while the control group had their tutorial session by discussing typical problems, without GP. As the authors of GP, lecturers delivered the content of the topic according to syllabus, shared and utilized similar teaching materials. Regular meetings and discussions were conducted to ensure course delivery approaches were uniform and maintained. Before the implementation of GP for the treatment group, both control and treatment groups were given pre-test. Students were required to answer two parts of questions i.e. questions on polynomials and questions on rational functions. The main objective of these questions is to obtain the sketch of graphs through the application of derivatives. The questions were developed based on the current syllabus pertaining to derivatives and graph sketching. The post-test was administered four weeks after GP was introduced. Questions for the post-test are the same as in pre-test, with the sequence shuffled. Therefore, the level of difficulties remains the same. In order to ensure the reliability and validity of the self-developed pre- and post-test as well as the rubric, intensive discussions were conducted by the authors, who are also experienced lecturers in delivering the course. After this process, necessary changes were made based on recommendations and feedback.

The recorded marks were then subjected to one-way ANCOVA to determine whether a significant difference existed between the mean post-test scores of students for both groups after controlling the pre-test scores using SPSS. Results from study should be interpreted and generalized within the scope of the data collected.

5. Result and Discussion

5.1 Comparison of Calculus Performance on Polynomial function between Control and Treatment Groups

The normality measures in the control and treatment groups during pre-test and post-test are presented in Table 1 below. Normality tests were analysed to examine the normal distribution of scores in this section. The result of distributions of scores being normal can be assumed using Shapiro-Wilk ($p > 0.05$).

Table 1:Test of Normality

Function	Group	Statistic	df	Sig.
Polynomial	Control	.967	38	.320
	Treatment	.964	46	.158

Table 2 displays the comparison of calculus performance between the control and treatment groups for polynomial function. The control group has recorded a mean score of performance of 4.16 (sd = 2.76), while the treatment group has the mean score of 4.89 (sd = 3.01). This indicates the effectiveness of GP in increasing the scores for students in the treatment group based on the difference of mean scores.

Table 2: Descriptive Measures for Post Test Scores Polynomial Function

Function	Group	N	Mean	SD
Polynomial	Control	38	4.16	2.76
	Treatment	46	4.89	3.01
	Total	84		

Table 3: Test of Between-Subjects Effects for Polynomial Function

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	101.333[a]	2	50.666	6.847	.002
Intercept	336.933	1	336.933	45.534	.000
Pre Score	90.139	1	90.139	12.182	.001
Group	32.057	1	32.057	4.332	.041
Error	599.370	81	7.400		
Total	2447.000	84			

In performing ANCOVA, all the assumptions such as normality, homogeneity of variance, and linearity between variables were met. From Table 3 shown above, the pre score row indicates that the covariates (pre-test scores) are significantly related to post-test scores ($F(1, 81) = 12.182$, $p = 0.001$). The group row information shows that, after controlling the score before the intervention, the mean scores significantly differ between groups ($F(1, 81) = 4.332$, $p = 0.041$). The pairwise comparison in Table 4 has also shown significant results. This implies that the students have performed better after engaging themselves with GP for polynomial function. Students' ability to apply the concept of the derivative in obtaining the sketch has improved through GP interactions.

Table 4: Pairwise Comparison for Polynomial Function

(I) Group of students	(J) Group of students	Mean Difference (I-J)	Std. Error	Sig.[a]
Control	Treatment	−1.284*	.617	.041
Treatment	Control	1.284*	.617	.041

5.2 Comparison of Calculus Performance on Rational function between Control and Treatment Groups

The normality measures in the control and treatment groups during pre-test and post-test are presented in Table 5 below. Normality tests were analysed to examine the normal distribution of scores in this section. The result of distributions of scores being normal can be assumed using Shapiro-Wilk ($p > 0.05$). Although the treatment shows p-value less than 0.05, it is considered approximately normal as the skewness and kurtosis values are −0.136 and −1.399 which fall under the acceptable range of normality, in between −1.96 and 1.96.

Table 5: Test of Normality

Function	Group	Statistic	df	Sig.
Rational	Control	.964	38	.263
	Treatment	.950	46	.048

On the other hand, Table 6 for rational function has shown similar results in which the treatment group has recorded a higher mean score of 4.22 (sd = 2.37) compared to the control group with the mean of 4.05 (sd = 2.71). Although the treatment group scored higher, the difference is not much.

Table 6: Descriptive Measures for Post Test Scores Rational Function

Function	Group	N	Mean	SD
Rational	Control	38	4.05	2.71
	Treatment	46	4.22	2.37
	Total	84		

In Table 7, pre-score row indicates that the covariate (pre-test scores) is significantly related to the post-test scores (F (1,81) = 6.516, p = 0.013). According to the group row information, the value of (F (1, 81) = 0.04, p = 0.841) obtained shows that no meaningful difference of post-scores was detected between control and treatment groups, after controlling the scores before the intervention. The pairwise comparison in Table 8 has also shown non-significant results. This revealed that there is no difference in scores whether the students use GP or not in solving questions involving rational function.

Table 7: Test of Between-Subjects Effects for Rational Function

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	39.707[a]	2	19.853	3.305	.042
Intercept	561.229	1	561.229	93.427	.000
Pre Score	39.142	1	39.142	6.516	.013
Group	.243	1	.243	.040	.841
Error	486.579	81	6.007		
Total	1968.000	84			

Table 8: Pairwise Comparison for Rational Function

(I) Group of students	(J) Group of students	Mean Difference (I-J)	Std. Error	Sig.[a]
Control	Treatment	−.108	.538	.841
Treatment	Control	.108	.538	.841

The findings of the present study first revealed that the students' engagement on GP has assisted their ability to solve and obtain the sketch of polynomial functions. It is evident that this tool is effective in supporting students' performance for this type of question. Hands-on activities such as manipulating GP enables students to gain and develop constructive knowledge conception pertaining to graph sketching using the derivatives (Rohaenah et al., 2019). This finding is supported by many researchers inclusively by Sulaiman et al. (2019) and Ekwueme et al. (2015) which revealed that hands-on approach has significantly and positively impacted student's academic performance in mathematics, including calculus. The ability to visualize abstract concepts such as the graphic representation of a function could be developed as manipulating GP enables active cognitive engagement (Borji et al., 2018; Mendezabal & Tindowen, 2018; Orhun, 2012). The result is also in line with the studies by Rohaenah et al. (2019) and various researchers (Rondina, 2019; Ekwueme et al., 2015; Dhanapal & Wan Zi Shan, 2013) who stipulated that embodied learning environment involving close relationship between physical experience processes and the abstract concept formation processes (Duijzer et al., 2019) is effective for the teaching and learning of abstract subjects like calculus. It supports the claims that on-going physical experience as in working with GP to fix a graph could produce meaningful abstract concept formation where students could comprehend the relationship of algebraic, symbolic and graphic representation of a function, using the application of derivatives (Duijzer et al., 2019; Oudgenoeg-Paz et al., 2016).

Moreover, the element of visualization is indeed a valuable alternative to assist students to comprehend topics in mathematics (Borji et al., 2018; Mendezabal & Tindowen, 2018; Tuh, Liew, Ahmad Bakri & Chang, 2017), inclusively calculus. Hence, GP has the potential to integrate the advantages of visualization, hands-on, and embodied learning in bridging the cognitive gap of comprehending the relationship between the results students obtained from the analysis of a function via derivatives and the graph sketching of this function; through a game-based learning approach. Above and beyond all this, the capacity of instilling play in education is facilitated by GP in providing a game-based learning environment as well as applying technology to conceptualize the above-mentioned derivatives approach. This is consistent with the findings articulating that a game-based learning environment promotes students' engagement and stimulates their motivation and interest to learn (Clarke et al., 2017; Humphrey, 2017). Having the three key components – competition, engagement, and rewards – in GP, the students learn even without their knowing (Kingsley & Bittner, 2017). It is also supported by research outcomes such as Borji et al. (2018), and Mendezabal and Tindowen (2018) who have proven that technology helps learners visualize the mathematics content, thus assisting students to master the application of derivatives to obtain the right sketch.

However, the results have also shown that GP does not have a significant effect on students' ability in obtaining the sketch of rational functions. In other words, students in both groups had similar skills when answering questions related to rational function. Although GP has been introduced, students might have difficulties to adapt to the usage of this tool to solve rational function questions due to lack of experience and time factor. Students are not optimally engaged, and less active students might not utilize the GP fully. This result agrees with the result of Mahayukti (2018) and Yaghmour (2016) which showed lack of significance difference due to the newness and the optimization of the teaching method. Moreover, this unfavourable result was also reported by Hung, Huang, and Hwang (2014) in which the learning achievements of the e-learning group and the traditional instruction group did not have a significant difference. Furthermore, sketching a graph of rational function involves mastering the concept infinity via limits (both infinite limits and limits at infinity), which is another confusing abstract concept for students (Zerr, 2010).

6. Conclusions

The purpose of this study is to look into the effect of GP on students' calculus performance in obtaining the sketch of polynomial and rational functions. From the experimental results, the treatment group revealed significantly better post-scores than the control group when dealing with polynomial functions questions while for rational function questions, both groups have shown similar ability which resulted in insignificant effect. The results suggest that the utilization of GP has improved the performance for polynomial functions, particularly. Graph Puzzle (Liew et al., 2019) and its future improved versions innovated have its basis developed based on the integration of embodied learning approach, visualization, enjoyment in learning, and technology enhancement. It is a potential tool to be a solution to the teaching and learning difficulties faced on graph sketching in calculus. Future research recommended includes investigating on how students' demographic profile such as gender, cumulative grade point average (CGPA), students' motivation as well as students' efficacy factors; a bigger sample size with equal size of both investigated groups; and enhancing the integration of infinity concepts into GP can contribute to the effectiveness of GP.

7. Acknowledgements

The authors would like to recognize the invaluable resources and facilities provided by UiTM, Sarawak Branch, and the time our colleagues and students spent in supporting this study. The authors also wish to extend their gratitude to the reviewers for their insightful comments.

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