The Conquest of Arithmea: A Game-Based approach to learning BODMAS

Owais Bin Asad[1], Isbah Premjee[2], Imaara Zulfiqar Ali[3], Ubaidullah Jamal[4], Daniyal Ahmad Siddiqui[5], Javeria Samad[6] and Humaira Qureshi[7]

[1,6,7] Dhanani School of Science and Engineering, Habib University, Karachi, Pakistan
[2,3,4,5] School of Arts, Humanities & Social Sciences, Habib University, Karachi, Pakistan

*Corresponding author

Abstract

"The Conquest of Arithmea" is a newly-created, role-playing board game inspired by Dungeons & Dragons, which puts the players into the fictitious world of Arithmea, where they navigate the land with the help of the narrator – "Ziphius The Wise", to fight battles and defeat the evil – "Ivan The Terrible". Each battle is a math problem that teaches a different aspect of the BODMAS rule. The game has a narrative style to effectively deliver the standards of mathematics as set by The National Council of Teachers of Mathematics, which include thinking, reasoning and problem-solving. Thirteen participants of 5th grade, both male and female, between the ages of 10-12 were included in the study. Players' confidence, correctness and motivation was assessed through a pre-game and a post-game questionnaire. Participants were timed by the narrator at the start and end points during the game to assess improvement. The results indicated that the participants, post-game, showed an overall confidence of 84% in solving questions. Their motivation-level jumped from 69% to 92% and correctness increased to 33 out of 39 (post-game) versus 25 out of 39 (pre-game). However, the game did not have any significant impact on the time it took to solve arithmetic equations. Eighty-one percent of the players favored game-based learning over traditional methods demonstrating that incorporating such methods generates interest and improves learning. Recommendations for improving the game included adding more interactive elements which allow multiple players to strategize together, and offering it in the form of an app for online playing.

Keywords: pedagogy, gamification, arithmetic, teaching, role-play

1. Introduction

For generations, classroom-based learning has employed textbooks and conventional testing methods, with limited development in student-centric teaching pedagogies. The advent of another paradigm, game-based learning, aims to inculcate the same knowledge as classroom-based learning but using games that put the student in an alternate reality. With the use of exciting storylines and integrated questions in the form of challenges and quests, this new paradigm is striving to make effective learning engaging and interactive.

Our game, 'The Conquest of Arithmea', is a role-playing game that puts the student into an alternate reality, the fictitious world of Arithmea, where they must navigate the land with the help of the navigator-'Ziphius The Wise', to fight battles and defeat the evil-'Ivan The Terrible'. As an educational game, each battle is a math problem that teaches them a different aspect of the BODMAS rule.

RPG's are highly interactive, which led us to designing this experiment by creating a game that can serve as a productive platform where students can practice the mathematical problem-solving skills. This will be a refreshing change as conventional learning instruments can end up being monotonous.

The inspiration for The Conquest of Arithmea was taken from a role-playing boardgame "Dungeons & Dragons" that came out in 1974 and, ever since has been one the most loved boardgames of all time. Just like its inspiration, The Conquest of Arithmea employs a trusty guide and navigator, Ziphius The Wise, to guide and teach the player at each step of the game. There are a series of challenges (BODMAS equations) that the player must go through, each more challenging than the one before. These must be overcome for the player to reach their final enemy, the notorious dragon: Ivan The Terrible.

1.1. Literature Review

Three waves have been presented in the game industry, starting from the theorizing gaming as a tool for educational learning; the second wave was a revolution in the industry due to the introduction of 'serious-games' as non-entertainment learning games; the third and final wave is of Technology-enhanced learning (TEL), which is essentially a hybrid mode of games and physical/virtual instructions by an instructor (De Freitas, 2018). Role-playing games mark a revolution in educational games, wherein the player assumes the role of a protagonist in a storyline. Usually, the storyline of an RPG game incorporates elements of fantasy/mythology. As the protagonist, the player often has to complete various quests by interacting with non-playable characters (NPCs) to advance through the game. NPCs are the AI that are operationalized by the game itself; these characters either serve as guides and aides to the player or as their adversaries and rivals. The quests that the player must complete to win the

game could be as rudimentary as delivering a message to an NPC, or as exciting as defeating an ogre by stabbing it in its toe.

Due to the immensely interactive nature of RPGs, we believe that they can serve as a productive platform where students can exercise the mathematical problem-solving skills they have learned in their classrooms. This will be a refreshing change as conventional learning instruments are can become quite dull. According to Ahmad, Shafie, & Latif (2010), conventional learning instruments: a) fail in motivating students to fully engage with the lessons as they simply shovel instructions down their throats; b) are quite boring, and, as such, fail to attract interaction from the students; c) offer little to no opportunity for self-learning; and d) are not meaningful as there is little resonance between what the pupils learn in the classroom and what they experience in everyday life. Similarly, a study done by Hwang et al. (2014) aimed to gauge the effects of digital game-based learning on students' self-efficacy, motivation to study, anxiety levels, and performance. The results of the study concluded that the students who were exposed to game-based learning displayed increased levels of self-efficacy, higher motivation to study, and improved performance; although, their mathematical anxiety levels did not show any significant improvement.

Incorporating game-based learning actually imparts a positive impact on the students' learning process and conducive to their understanding of the subject (Hwa, 2018). Entertainment has become an important part of life, and games have played an important role in the process of entertainment. Gamification has been a success commercially, and we can use the same technique and apply it to the learning experience and make it worth it. (Muntean, 2011).

While game-based learning proved to be fruitful in most researches, researchers also found that it is crucial to ensure that the cognitive load imposed by the game does not, at any point, become too much for the player to handle. If that happens, the game will lose its appeal and will do more damage to the learning process than a regular class because the student would've invested more time into it than a regular class but they would not have learned anything.

1.2. Objectives:

Our objective was to combine aesthetics, learning and gaming together to provide a mystical experience of the world of Arithmea, where participants conquer challenges using their knowledge of mathematics learned throughout the game, especially BODMAS rule. Following is a breakdown of our prospective learning outcomes:

- To teach the concept of BODMAS step by step starting from brackets to subtraction.
- Make the process of learning mathematics interesting and interactive
- To help participants understand BODMAS so that they can solve problems confidently and with high motivation in the future.

The purpose of this study was to assess if The Conquest of Arithmea has a positive influence on the confidence, motivation, correctness, and the time taken by 5^{th} graders to solve mathematical equations using BODMAS rules

1.3. Bloom's Taxonomy:

To ensure that The Conquest of Arithmea is sufficiently complex for fifth graders, the board-game has been designed to incorporate the following mathematical learning objectives from Bloom's Taxonomy;

- Comprehension: Conquest of Arithmea involves the player (the student) navigating their way through a fictitious world by listening to the narrator describe the events, evaluating those events, and comprehending how they affect the story-world inside their minds.
- Analysis: At each stage, the player will be exposed to new knowledge about a particular rule of BODMAS. At each of these points, the player will have to critically examine the content they're being taught and then question ideas and aspects that they may not understand. This will include problem-solving and situational reasoning.
- Application: At the final stage of the game, the player would be given a challenge that incorporates all the concepts they have learned throughout the game. They will then employ those concepts to solve the final challenge, i.e., defeat the final boss.
- Evaluation: The role-playing nature of the game means that the player will have to judge their standing in the game, assess what kind of challenges lie ahead of them, and finally, compare the paths offered to them to pick the one that they predict will suit them the best.

2. Methods

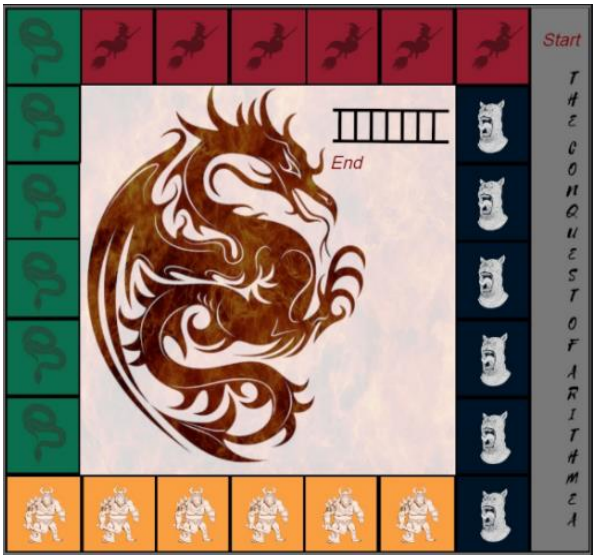
2.1 Study design

Thirteen participants, all of which had already studied BODMAS in their schools, served as both the control group and the experimental group in this experiment. The participants were requested to fill a pre-game (control-group's findings) and a post-game questionnaire (experimentalgroup's findings). Both the questionnaires asked participants to rate on a scale of 1-5 (5 being the highest, 1 being the lowest) as to how motivated and confident they felt in solving BODMAS-based arithmetic equations; moreover, both questionnaires had three arithmetic equations, the results of which were used to compare the Correctness of participants' solutions..

Finally, to analyze the influence of the board-game on the average time taken by fifth-graders to solve arithmetic questions, the research-team timed the participants at two points during the game. They were first timed as soon as the game started and a challenge was thrown at them, and they were timed again towards the end of the game when they had been taught all the concepts related to BODMAS. An effort was made to keep the equations as similar as possible in terms of their complexity and specificity to ensure accurate results. The research-team will then compared the results to see if there has been a change in the average time taken by the participants in solving BODMAS equations.

Informed consent from guardians of participants was undertaken and participants engaged with the research-team for a duration of 2-3 hours maximum

Figure 1: The board for The Conquest of Arithmea, created in-house on Adobe Illustrator. The designers obtained appropriate permissions and rights to use the vector graphics in the designs.



2.2. How is the Game Played?

In the Conquest of Arithmea, the player assumes the role of the descendant of a renowned mathematician in the Kingdom of Arithmea. Ever since the death of his/her father, the orcs of the West, along with the assistance of various other monsters, have perpetually wreaked havoc in the player's kingdom. According to an ancient spirit, a prophecy dictates that the son/daughter of a great Mathematician will drive the monsters out of Arithmea by reviving the ancient wisdom of mathematics. Moreover, before the Kingdom was officially established, the player's father had, with the help of mathematics, constructed such weapons that could defeat the monsters, who did not stand a chance due to their inept intellectual powers. Now, the player too must follow in the steps of his/her father by going through his various notes; he/she must learn the proper rules and regulations of BODMAS to save his/her beloved Kingdom from the barbaric spite of the Western savages.

As the game begins (Figure 1), the player is greeted by an ancient spirit, Ziphius the Wise (the narrator, one of the research team members), who informs the player of the events that have unfolded in the Kingdom of Arithmea ever since the death of the former's father. Throughout the game, Ziphius serves as a navigator who guides the player regarding what he or she must do to defeat the numerous monstrosities that plague the Kingdom. Before the player sets out on his/her journey, he/she is suddenly attacked by an Orc. To defeat the Orc, the player must solve an arithmetic equation (Figure 2) - here, the time taken by the player to solve the problem is recorded to compare with the time it takes for the same player to solve a question after he or she has completed the game. In case the player fails to solve the math problem, he or she is allowed several attempts to ensure that he or she does not feel discouraged.

Figure 2: The cards for The Conquest of Arithmea, created in-house on Adobe Illustrator. The designers obtained appropriate permissions and rights to use the vector graphics in the designs.

At this point, the narrator – Ziphius the Wise – informs the participant that the remaining enemies are only going to get stronger and more terrible; as such, he advices the player to go through the notes of his/her father. The first note informs the player that the foremost step in solving an arithmetic equation through BODMAS is solving the content that resides inside the bracket; moreover, the note tells the player that the content inside the bracket should be solved in the following order: division, multiplication, addition, and subtraction. Furthermore, a solved arithmetic equation is also presented to the player that illustrates the application of the aforementioned instructions. Finally, Ziphius the Wise requests the player to solve a basic arithmetic equation that focuses on teaching the student the first rule of BODMAS i.e., opening the brackets. This equation is kept quite simple to ensure that the player's focus is directed towards learning how to open the brackets rather than solving a complex arithmetic equation that requires the application of all BODMAS rules. An example of such an equation is: (3 + 5) + 4.

Ziphius the Wise asks the warrior to roll the dice to pave his way to the red-zone. As the warrior reaches the red-zone, he/she encounters a witch who would not let him/her through until he/she solves the questions of division. Ziphius the Wise encourages the warrior to stay put, as his father has left some notes which will help the warrior defeating the witch. Throughout his journey in the red-zone he is assisted by Ziphius the Wise, so he/she does not feel alone in the world of division. An example of such an equation is: (3+11) ÷ 7.

After the player has learned the second rule of BODMAS i.e., division, Ziphius requests them to roll the dice and make their way to the green zone – the Multiplicationarium. Here, the player encounters the Archimedi-snake, so named owing to the fact that, in its prime, it had swallowed the skilled Greek mathematician Archimedes. As the Archimedi-snake creeps up to the player, Ziphius once again requests the protagonist to refer to his father's notes. The third note, in turn, informs the player that one must solve the multiplicative functions in an arithmetic equation only after opening the brackets and solving the functions of division. The snake hisses at the player, and once again he or she is forced to solve another arithmetic

equation that includes all the rules of BODMAS the player has learned thus far. An example of such an equation is: (6 ÷3) x 4.

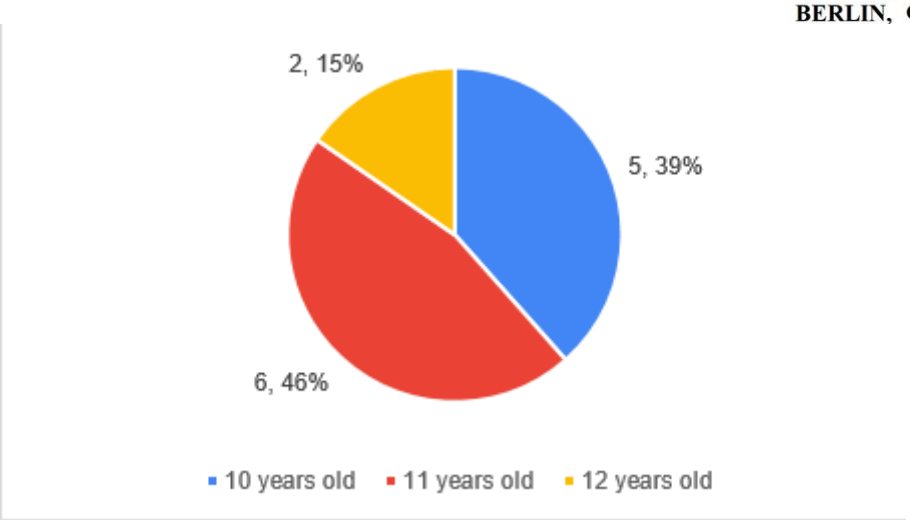
After the player has stormed his/her way through the first and second part, he/she is asked by Ziphius to roll the dice again and make their way to the yellow zone where he/she encounters the wrath of the orc. Ziphius instructs the player to understand the rules of addition along with his/her knowledge of the previous two zones. The player shrieks but Ziphius gives him/her confidence by telling him/her that he/she has the notes from his/her father by his/her side. The player carefully follows the BODMAS rules to defeat the Orc: (2 + 5 x 3) + 1.

The participant is now led towards the mighty blue zone, and the last of the zones, by Ziphius the Wise. Since, Ivan the Terrible has sensed the location of the participant, he/she is approaching swiftly towards the location of the participant and in order to take over the throne of the Kingdom of Arithmea. However, before this ultimate battle, the player must fight Ivan's most loyal henchman i.e. the Werewolf. Ziphius the Wise presents the last of the notes of the player's father where they are given an instruction for the subtraction operation combined with the previous four. The participant, with all their courage and valor, begins to solve the second-last of the game's arithmetic equations using all the BODMAS rules that they have learnt throughout their journey: [(6/3) x 2] + [(16-8/2) + (1x8)]
The final stage of this game is an evaluation of the entire process of learning that the participant has gone through. In this part, the player, through his/her own knowledge, has to defeat the ultimate evil – the dragon, Ivan the Terrible by solving an equation consisting of all the mathematical operations 'Brackets, Division, Multiplication, Addition, Subtraction' i.e., BODMAS. Following is the example for such an equation: [(9/3) x 2] + [(12-8/2) + (4x8)].

3. Results:

The distribution of our sample size (Figure 3) shows that there were 6 participants who were 11 years old, 5 participants who were 10 years old and 2 participants who were 12 years old. Gender inclusivity was ensured by having 7 male and 6 female participants.

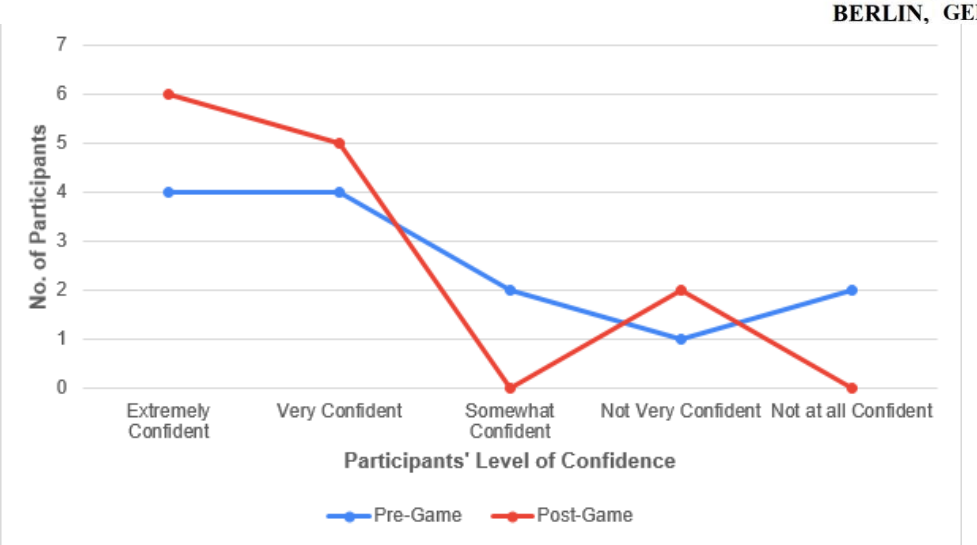
Figure No 3: Distribution of Participants by Age



3.1 Confidence:

- The confidence levels of participants are a self-check for participants as to how confident they are in their ability to solve mathematical problems correctly using the BODMAS Rule (Figure 4).
- In the pre-game survey, as indicated by the blue line, the participants' confidence level is spread across the scale, that is we have 2 participants who are 'Not at all Confident', 1 participant who is 'Not very Confident', 2 participants who are 'Somewhat Confident', and the of the remaining 8 participants, 4 are 'Extremely Confident' and 4 are 'Very Confident'.
- In the post-game survey, as indicated by the red line, there is an increase in the number of participants who are 'Extremely Confident' from 4 to 6, participants who are 'Very Confident' from 4 to 5, participants who feel 'Somewhat Confident' reduce from 2 to 0 and similar is the case with participants who do not feel confident at all.
- However, interestingly, there is an increase in the number of participants who do not feel very confident from 1 to 2 which might be an indication that previously the participant who was 'Not at all Confident' has observed an increase in their confidence scale.

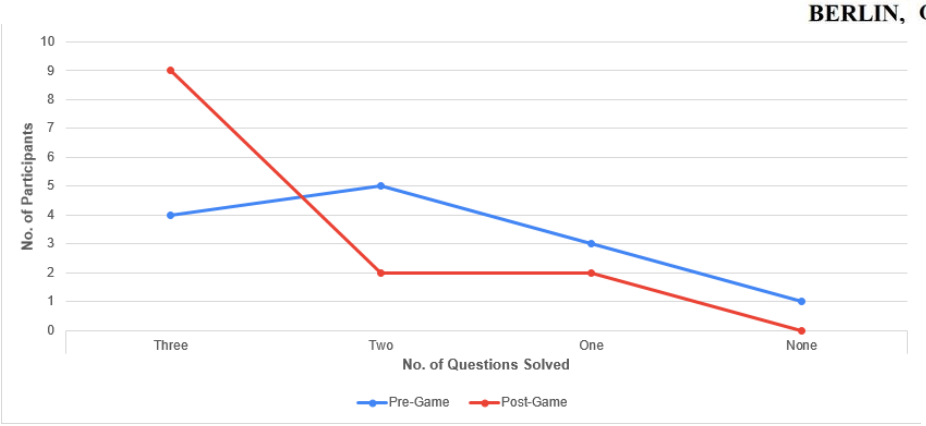
Figure 4: Comparative Analysis of the Participants' Confidence in Pre-Game and Post-Game Surveys



3.2 Correctness:

- The correctness levels measure the ability of participants to correctly solve the arithmetic equations using the BODMAS rule. There were in total 3 mathematical problems given to the children in, both, the pre-game survey and the post-game survey (Figure 5).
- In the pre-game survey, the greatest number of questions solved were two, by 5 participants. Only 4 participants were able to solve all three questions. 3 participants solved one question each and 1 such participant solved none of the questions correctly.
- In the post-game survey, the greatest number of questions solved were three, by 9 participants. Only 2 participants were able to solve all three questions and similarly, 2 participants were able to solve one question correctly. There was no participant who solved none of the questions correctly.
- While on one hand there was a decrease in the number of participants being only able to solve one, two or no questions after the post-game survey, on the other hand there was also a sharp increase in the number of students who were able to correctly solve all three questions after the game.
- The participants who were not able to solve any of the questions correctly fell down from 1 to 0.
- The number of participants correctly solving all three of the mathematical equations raised from 4 in the pre-game survey to 9 in the post-game survey.

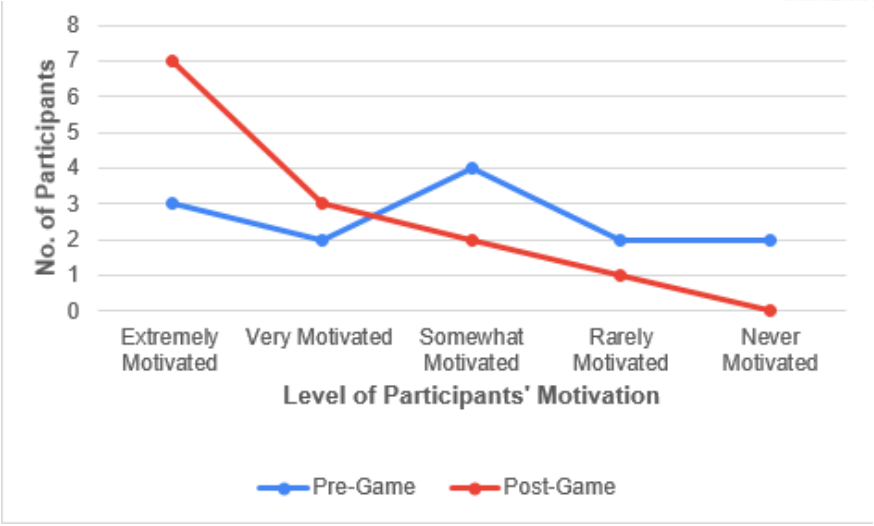
Figure 5: Comparative Analysis of the Participants' Correctness in Pre-Game and Post-Game Surveys



3.3 Motivation

- The motivation levels were a check to measure how motivated the participants feel to solve arithmetic equations using BODMAS Rule (Figure 6).
- The pre-game survey does not give us remarkably high motivational levels and the greatest number of students, i.e., 4, are only 'Somewhat Motivated' to solve arithmetic problems.
- In the post-game survey, however, the greatest number of participants, i.e., 7, are 'Extremely Motivated' to solve mathematical problems followed by the second greatest number of participants, i.e., 3, who were 'Very Motivated'.
- We see that from pre-game survey to post-game survey respectively, the number of participants who were 'Never Motivated' reduces from 2 to 0 and the number of participants who were 'Rarely Motivated' reduces from 2 to 1 which indicates that more participants lie on the scale of greater motivational level.

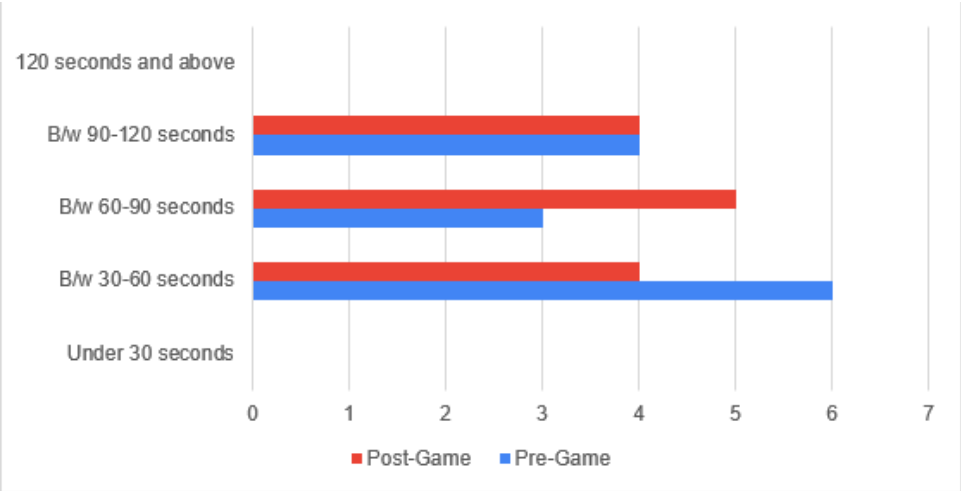
Figure 6: Comparative Analysis of the Participants' Motivation in Pre-Game and Post-Game Surveys



3.4 Time

- The time records how quickly are the participants able to solve arithmetic equations (Figure 7).
- In pre-game survey, the average time a student takes to solve a question is 1 minute and 15 seconds, and even for the post-game survey, average time for a student to solve arithmetic sums is 1 minute 15 seconds.
- Individual results of participants show that some even recorded an increase in the time taken to solve the arithmetic equations.

Figure 7: Comparative Analysis of the time taken by Participant' to solve questions in Pre-Game and Post-Game Surveys



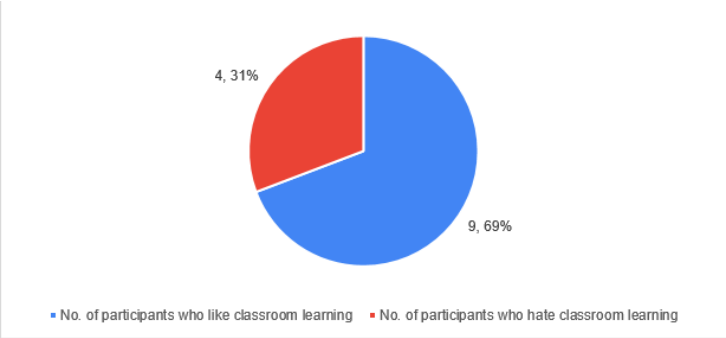
3.5 Discussion:

3.5.1 Opinion on Classroom-learning and Game-based learning:

In the pre-game survey, when participants were asked whether they like or hate typical classroom learning, out of a population sample of 13, 9 students i.e., 69% said they

liked classroom learning and 4 participants i.e., 31% said they hated classroom learning (Figure 8).

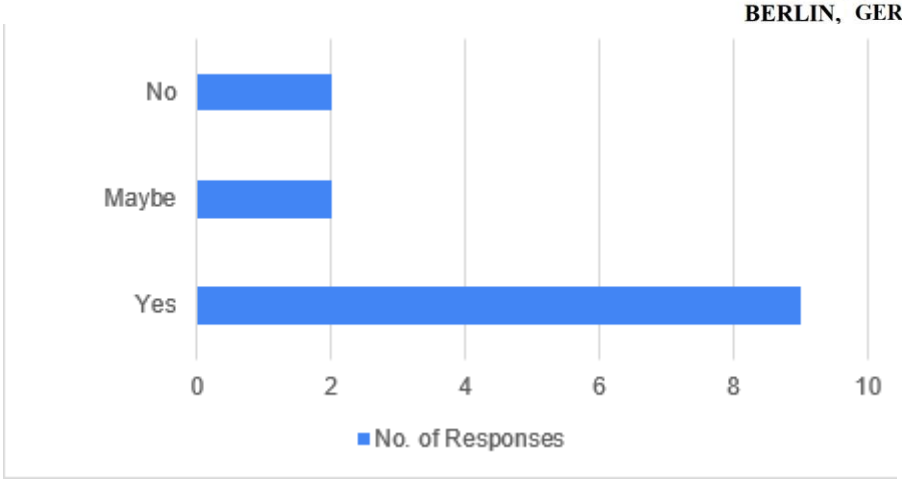
Figure 8: Distribution of participants on the basis of liking typical classroom learning



3.5.2 Preference of Game-based Learning over Classroom Learning

- In the post-game survey, when participants were asked whether they would prefer game-based learning over classroom learning, 9 participants said yes, while 2 participants were skeptical and the remaining 2 said they would not prefer game-based learning over classroom learning (Figure 9).
- There is an indication of increased interest in game-based learning and many participants are inclined to learn mathematical concepts via a game rather than in simple classroom setting.

Figure 9.: Preference for Game based learning over classroom learning



4 Conclusion

In accordance with the results and discussion above, it can be concluded that *after playing the game,* the ability of participants to *correctly* solve the mathematical problems is improved and the correctness levels increase. Likewise, the motivation of students to solve the arithmetic equations and their confidence levels to correctly solve them also observes an overall rise. There is a larger population of participants who prefer game-based learning over classroom learning. Moreover, the game does not have any effect on the average time taken by a student to solve three BODMAS questions. Thus, it can be said with some confidence that the 'The Conquest of Arithmea' has a positive influence on the confidence, motivation and correctness of 5th graders to solve mathematical equations using BODMAS rules. However, as no obvious change was observed in the time taken by participants to solve problems in the pre-game and post-game survey, the same does not stand true for this condition.

4.1. Limitations and Improvements:

The sample size was very small due to limitations incurred by the COVID-19 pandemic, as the board game required us to play it in-person and we could not reach out to a greater number of students. Moreover, the game only allows for one player to play at a time. A class-room setting involves group work as well and, so, if the game could incorporate multiple players, that would allow for an element for of cooperation and team work spirit to be incorporated into the mix. Additionally, this game was primarily designed in English and, right now, is only offered in that language. This creates a barrier for non-English speakers. Having translations in various languages, local and international, would increase the impact of the game. Finally, the inclusivity can also be improved by altering the design to allow differently-abled people to play the game as well. One example would be to create an audio-only version of this to enable people with eye-sight difficulties to play. According to one participant, "the snake [in the board-game] was scary" while another suggested that the board-game "seemed a bit boring." In light of this suggestion, further iterations of The Conquest of Arithmea should be made more engaging and fun by incorporating interactive elements. Perhaps by integrating a framework that allows multiple players to co-operate and strategize together, the board-game will also be able to cater to suggestions such as "I want my friends

to also play" and "make it with more players", A sound suggestion that one of the participants provided us was to convert the game into an application so that it can be played online as well.

4.2 Acknowledgment

This paper is an output of the final project conducted as part of the course, Scientific Methods: A Biology Perspective. We are grateful to the participants as well as to Habib University for facilitating this study.

5 References

1. Ahmad, F., Shafie, A., & Latif, H. (2010). Role-Playing Game-Based Learning in Mathematics. *Electronic Journal of Mathematics & Technology*, *4*(2), 184-196.
2. De Freitas, S. (2018). Are Games Effective Learning Tools? A Review of Educational Games. *Journal of Educational Technology & Society*, *21*(2), 74-84. Retrieved November 9, 2020, from http://www.jstor.org/stable/26388380
3. Hung, C., Huang, I., & Hwang, G. (2014). Effects of Digital Game-Based Learning on Students' Self-Efficacy, Motivation, Anxiety, and Achievements in Learning Mathematics. *J. Comput. Educ.*, *1*, 151-166. doi: https://doi.org/10.1007/s40692-014-0008-8
4. Hwa, S. (2018). Pedagogical Change in Mathematics Learning: Harnessing the Power of Digital Game-Based Learning. *Journal of Educational Technology & Society*, *21*(4), 259-276. Retrieved from https://www.jstor.org/stable/26511553
5. Muntean, C. I. (2011,). Raising engagement in e-learning through gamification. In Proc. 6th international conference on virtual learning ICVL (Vol. 1, pp. 323-329).
6. Tobias, S., Fletcher, J., & Chen, F. (2015). Digital Games as Educational Technology: Promise and Challenges in the Use of Games to Teach. *Educational Technology*, *55*(5), 3-12. Retrieved November 9, 2020, from http://www.jstor.org/stable/44430402