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DEVELOPMENT OF A GAME FOR LEARNING LINEAR FUNCTIONS IN A REAL-WORLD CONTEXT TO IMPROVE THE CONCEPTUAL UNDERSTANDING OF JUNIOR HIGH SCHOOL STUDENTS

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Abstract:

Linear functions in math are essential for advanced topics like calculus and physics. In Indonesia, linear function teaching is limited to whiteboard calculations or simple drawings without contextual explanations. It's crucial to emphasize factual and conceptual math knowledge for deep understanding and effective learning by bringing more contextual problems. Many teachers use traditional games or modeling activities to create contextual problems for students. However, none of them was created for the learning function in digital games. This project aims to develop a game for learning linear functions using contextual challenges. The game was created utilizing an ADDIE model. Validation is using Learning Object Review Instrument (LORI) with three different validators who have different expertise in content, technology, and classroom implementation. The data shows that this game may reinforce learning linear functions. A future research project may examine the impact of playing this game on students' conceptual understanding of linear function.

Keywords: Linear Function, Mathematics Game, Conceptual Understanding, ADDIE

PENGEMBANGAN PERMAINAN UNTUK PEMBELAJARAN FUNGSI LINIER DALAM KONTEKS DUNIA NYATA UNTUK MENINGKATKAN PEMAHAMAN KONSEPTUAL SISWA SEKOLAH MENENGAH PERTAMA

Abstrak:

Fungsi linear dalam matematika sangat penting untuk topik lanjutan seperti kalkulus dan fisika. Di Indonesia, pengajaran fungsi linear dibatasi hanya pada perhitungan di papan tulis atau gambar-gambar sederhana tanpa penjelasan kontekstual. Sangat penting untuk menekankan pengetahuan matematika faktual dan konseptual untuk pemahaman yang mendalam dan pembelajaran yang efektif dengan memberikan lebih banyak masalah kontekstual. Banyak guru menggunakan permainan tradisional atau aktivitas pemodelan untuk menciptakan masalah kontekstual bagi siswa. Namun, tidak ada yang dibuat untuk pembelajaran fungsi di dalam game digital. Proyek ini bertujuan untuk mengembangkan game untuk pembelajaran fungsi linear dengan menggunakan tantangan kontekstual. Game ini dibuat dengan menggunakan model ADDIE. Validasi dilakukan menggunakan Learning Object Review Instrument (LORI) dengan tiga validator yang memiliki keahlian berbeda dalam konten, teknologi, dan implementasi kelas. Data menunjukkan bahwa game ini dapat memperkuat pembelajaran fungsi linear. Proyek penelitian masa depan dapat menguji dampak bermain game ini pada pemahaman konseptual siswa tentang fungsi linear.

Kata Kunci: Fungsi Linear, Game Matematika, Pemahaman konseptual, ADDIE

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INTRODUCTION

Mathematics has significant use for understanding almost everything in the world (Hodanova & Nocar, 2016). Mathematics is also helpful to solve any problem in the world. Furthermore, learning mathematics equips us with powerful skills which will be very beneficial to live in this era, such as logical reasoning and problem-solving skills (Fonteles-Furtado, Hirashima, Hayashi, & Maeda, 2019). Promoting conceptual understanding in learning Mathematics is one way to achieve those mentioned earlier (Andamon & Tan, 2018). Therefore, students must get support to encourage their mathematical-conceptual understanding.

Mathematical Conceptual understanding is presented when there is a connection between factual knowledge and underlying mathematical procedures or algorithm and building thorough understanding (Andamon & Tan, 2018). Allen, Froustet, LeBlanc, Payne, Priest, Reed, Worth, Thomason, Robinson, and Payne, (2020) stressed the importance of mathematical, conceptual understanding to help students become reflective and effective learners. Furthermore, NCTM also mentions that conceptual understanding will give students more confidence and perseverance in tackling challenging situations and problems. Students who understand mathematics conceptually will retain their procedural knowledge and quickly transfer it to a novel problem.

Mathematic conceptual understanding can be built by bringing the visual to represent abstract things (Purwadi, Sudiarta, & Suparta, 2019), constructing a connection between the knowledge and students' experience (Haryani, 2020), and contextualizing the mathematical concept to get more sense of it (Nitsch, Fredebohm, Bruder, Kelava, Naccarella, Leuders, & Wirtz, 2015). However, in practice, most teachers ask their students to recite and have many mathematics exercises that sometimes only require procedural understanding. This routine brings students mathematics anxiety and gives non – a meaningful learning experience where they can easily forget the concepts being taught.

Contextualizing the problem brings experience and personal situations (Widjaja, 2013), making the problem seem natural to students. However, we need to be aware of what makes it essential in contextualizing the problem. One of the main characteristics of contextualizing the problem is bringing multiple interpretations and various strategies for solving the problem and relating to their own experience (Freudenthal, 2002). This strategy will serve as a bridge from non-formal to formal until the abstraction stage in Mathematics. The other characteristic when contextualizing the problem is bringing out the variety of mathematical interpretation and solution strategies (Widjaja, 2013). This will serve as scaffolding for students to come from the basic idea of mathematics to more formal and sophisticated mathematics.

Some researchers have shown various implementations in contextualizing the problem (Freudenthal, 2002; Lutfianto, Zulkardi, & Hartono, 2013; Widjaja, 2013; Wijaya, 2018). They engage students with various mathematical contextual problems adapted from traditional games or activities and model activities when students begin the activity by collecting the data. Those implementations are said to be successful as they are able not only to engage the student in mathematically rich discussion, but also develop their conceptual understanding. This concludes the importance of using the contextual problem in classroom teaching.

A linear function is the first concept where the students will learn the relation between two things, which we called variables, for the first time (Pierce, 2005), so it then becomes an important chapter in the student's mathematical development. Furthermore, a solid foundation in elementary algebra is dependent on students' comprehension of linear functions (Piercea, Stacey, & Bardini, 2010). This area of mathematics serves as an initial introduction to the idea of using letters to represent variables, rather than solely focusing on determining a set value for an unknown. Additionally, students must understand that algebraic principles can be applied to link such variables. The commonly used linear function formula, y = mx + c, requires students to not only comprehend the variables x and y but also the parameters m and c. Students need to recognize the different roles played by these two categories of letters within the formula. However, some research showed that students are still struggling in learning the linear function especially when it comes to interpreting the linear function, the component of linear function like the m or slope and the c or constant (Pierce, 2005; Piercea, Stacey, & Bardini, 2010; Postelnicu, 2011). Therefore, there is an urgency to bring the linear function topics to this research by doing more contextual problems in classroom practice.

Game development and industry are lately becoming a trend in the last few years, especially in Indonesia. Based on statistics, "in 2017, there will be 43.7 million gamers in Indonesia " (Newzoo, 2018). The game's development is further aided by the ease with which it can be accessed by people of all ages, from anywhere, at any time. The development happened because of technological advancements such as cell phones, laptops, and PCs. The digital game is also very convenient in this pandemic situation where all students are prevented from learning face-to-face in school.

The covid-19 pandemic also creates demotivation for students as they start feeling anxiety because the learning activity seems to be too monotonous, not interactive, and focused on drilling practice (Elmas & Oztufekci, 2021) This situation justifies the need to engage more students in the learning process. Using games can be one of the alternatives. The game can be designed to engage more participants to finish and reach the designed objective. The conclusion is that we need a platform (game) that can engage students in a mathematics learning experience so that they can connect and relate. Moreover, students can also think of various strategies and interpretations while connecting to their personal experiences, embedding contextual problems inside the game.

METHODOLOGY

This research is a form of research and development, or R&D for short. Developmental research is the scientific study of planning, producing, and assessing instructional programs, procedures, and products that meet internal consistency and effectiveness requirements (Miller, 2017). This research utilizes the ADDIE model (Branch, 2010). Although the ADDIE model is usually used to create and develop an instructional design for teaching and learning, educational game development has similar steps to creating the instructional design. The ADDIE model consists of analysis, design, development, implementation, and evaluation phases. However, the scope of this research will only cover the stage of development since the next two phases will be covered by a different line of research.

The first step is starting the analysis phase. The analyze phase aims to identify the probable causes for a performance gap. The main procedures often associated with the analyze phase are validating the performance gap, determining instructional goals, confirming the intended audience, identifying resources required to complete the entire ADDIE process, determining how to deliver the instructional goals in the form of media, and seeing how the evaluation process was taken. The typical form of the analyze phase is an analysis summary. For the analysis phase, this study will conduct a literature review based on a report from prior research that reported the need for conceptual understanding, and the problem that emerged during the implementation of conceptual understanding–teaching. This stage will also bring the base idea for developing the game. During the design phase, the first product design as well as the media validation instruments are developed. This initial production will include the selection of software to develop the game.

In the design phase, the validation of this product is using Learning Object Review Instrument or LORI (Nesbit, Belfer, & Leacock 2009). With LORI, eight components were reviewed: content quality, learning goal alignment, feedback and adaptation, motivation, presentation design, interaction quality, accessibility, and standard compliance with a scale from 1 to 5. The development phase will thereafter be determined by the validation outcome and the validator's suggestion.

RESULT AND DISCUSSION

1. Analyze Phase

The importance of mathematics conceptual understanding has been the main concern for much mathematical educational research (Abdullah, Zakaria, & Halim, 2012; Green & Blankenship, 2015; Gultepe, Celik, & Kilic, 2013; Kanive, Nelson, Burns, & Ysseldyke, 2014; Purwadi, Sudiarta, & Suparta, 2019; Szydlik & Oshkosh, 2000). The researchers believe that students can apply and use their understanding in the larger context if they possess conceptual knowledge. The mathematics conceptual understanding will allow students to integrate the idea, facts, methods, and algorithms in mathematics to solve the problem. The mathematical conceptual understanding builds the connection among mathematical concepts that help them organize which one is important to learn a new idea (Nahdi & Jatisunda, 2020).

There are several strategies to build mathematical, conceptual understanding. One way to build it is by routinizing the contextual problem in the daily teaching and learning activities (Nitsch, Fredebohm, Bruder, Kelava, Naccarella, Leuders, & Wirtz, 2015). A contextual problem is defined as a problem that can be experienced in an actual situation (Zaremba & Smoleński, 2000). However, several problems emerged in the implementation of routinizing the contextual problem. One of the main problems in the contextual problem is that the students mostly rely on the keywords and directly transform them into mathematical operations (Fonteles-Furtado, Hirashima, Hayashi, & Maeda, 2019). They did not imagine the whole situation first in their mind.

To help the student to understand the problem, students need to be introduced to the problem, which can build their mental image towards the problem. Adding visualization and interpretations about the problem will help students understand the context of the concepts and start to build their mental image whenever they encounter the problem. Visualization problems can be in the form of paper-based or computer-based. Some researchers state that visualization using computer-based is more effective, flexible, and easy to use (Abykanova, Nugumanova, Yelezhanova, Kabylkhamit, & Sabirova, 2016; Guven & Kosa, 2008; Wyels, 2011). Moreover, as the Covid-19 pandemic starts, the closure of schools forces us to have more computer-based teaching and learning activities.

During this covid-19 pandemic, exposure to technology is increasing (Edtech World Bank, 2020). Governments worldwide have decided to perform social distancing to minimize the transmission of the covid-19 virus. Therefore, technology is the only way we can still use to connect with other people in the virtual model. The need to use computer-based teaching and learning activities then is justified. It also justifies the need for visualization using computer-based activity.

Games are a remarkable innovation in the world of education. Divjak and Tomic (2011) research found a massive development in the last 15 years from 2011 in mathematical games development. They said 32 journals from around the world prove that the effectiveness of games in teaching mostly has the same conclusion (Divjak & Tomic, 2011). The game provides more flexible visualization and helps to achieve the learning objective in a more entertaining environment.

In addition, a previous study (Agung & Surtikanti, 2020; Allo, 2020; Gilbert, John, & College, 2015) indicates that many students feel discouraged and unmotivated throughout the covid-19 pandemic. A game is one approach for increasing students' enthusiasm to learn mathematics, particularly linear functions. There are several practical studies on teaching linear functions in a meaningful way, but none of them use games as teaching aids especially to utilize the contextuality of the content material (Loc & Hao, 2016; Mudaly & Fletcher, 2019; Piercea, Stacey, & Bardini 2010). Therefore, to improve their conceptual comprehension, this project will design a game about linear functions which employs the contextuality of the problem to improve their conceptual understanding.

2. Design Phase

The purpose of the Design phase is to verify the desired performances and the appropriate testing methods (Branch, 2010). The design phase is started by conducting a test inventory. To learn about the type of function, the students should have the prerequisite knowledge. The teacher should have taught about linear functions to explore and develop knowledge. A real-life situation must be brought to practice so that the learning experience becomes more contextual and meaningful. Meaningful cognitive tools may engage students in the teaching-learning process and motivate them to reflect on the concepts (Widjaja, 2013). It is believed that the use of manipulatives improves students' conceptual comprehension and problem-solving abilities and develops favorable attitudes toward mathematics since they allegedly give 9 "real experiences" that focus attention and raise motivation. In the context of mathematics, a concrete experience is characterized not by its physical or real-world properties but rather by the meaningful connections it may make with other mathematical concepts and circumstances (Durmus & Karakirik, 2006). Figure 1 below is the projection plan for designing the media using the framework from (Durmus & Karakirik, 2006).

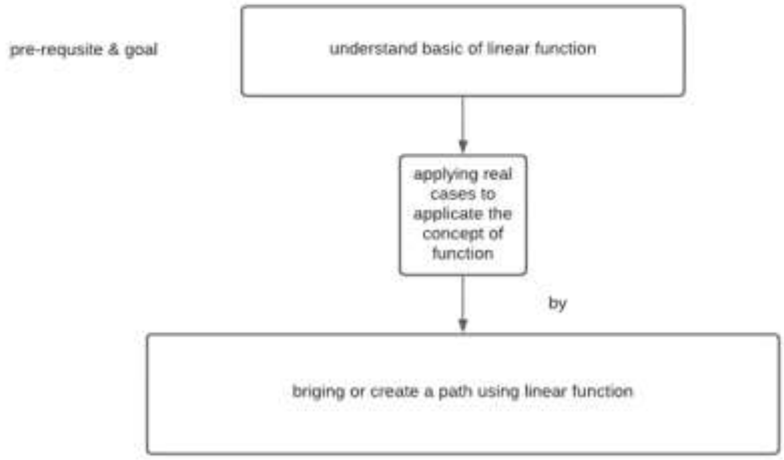


Figure 1. Projection Plan

Following the projection plan, the game was created in a scratch game with guided instruction. The game is about delivering a ball to the bowl in a cartesian coordinate.

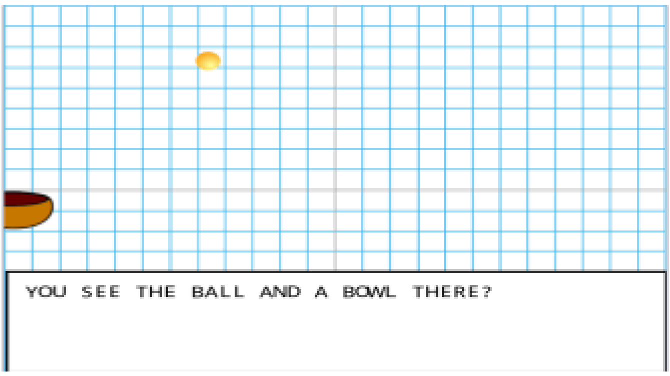


Figure 2. Game Design

The student needs to create a straight-line graph to transport the ball to the bowl as depicted in figure 2. In the design phase, the media developer also creates the game mechanics as follows:

The student will be shown the ball and a bowl on a cartesian coordinate. Then they were given a series of these questions.

a. The student will be asked what the function is.
b. The student will be asked what the function's gradient is.
c. The student will be asked about the constant.

After students have responded to these three questions, the graph of the linear function will be constructed and will serve as a bridge or a road. If the ball reaches the bowl, the students will continue to play. If not, they will repeat the procedures until they succeed.

3. Develop Phase

In the development phase, the researcher will create a game prototype. The prototype will be validated for its functionality, user experience, gameplay, and mechanics. After the validators' approval, it will reach the second phase of prototyping, where everything will be polished into beta (second prototype), as an improvement from alpha (prototype) based on the critics and suggestions from the validators. The beta-tester will have more range than three college students and two teachers to be evaluated and get better critiques to check the clarity of the content and its effect on the user. After that, it goes into the production stage, where the product will be polished, and bugs or errors should be minimalized.

The process of validating a game involves multiple stakeholders with different areas of expertise. In this case, the validators include a mathematics lecturer, technology experts, and a mathematics teacher. The mathematics lecturer is responsible for evaluating the game's content suitability. They will review the game's content to ensure that it aligns with the mathematical concepts that are typically taught in the 8th grade. The technology experts are responsible for evaluating the game's technical implementation. They will review the game's user interface, ease of use, navigation process, and other factors related to the technology used to create the game. They will look for any technical issues that may impact the game's performance, such as bugs or glitches. Finally, the mathematics teacher is responsible for evaluating the game's suitability for use in the 8th-grade classroom. They will review the game to ensure that it is appropriate for the age and grade level of the students who will be using it. They will also evaluate the game's educational value, ensuring that it supports the curriculum and enhances students' understanding of mathematical concepts.

The validation was carried out twice to ensure the quality of the resulting product by using Learning Object Review Instrument or LORI with general comments on each test. The following table 1 and table 2 are the results of the validation.

Table 1. The First and the Second Validity Results

No.	Statement	Average Score (out of 5)	
		1st Validation	2nd Validation
1.	Accuracy, balanced presentation of ideas, the appropriate level of detail, and reusability in varied contexts	3.33	4.67
2.	Adaptive content or feedback is driven by differential learner input or learner modeling	2.67	4.67
3.	Ability to motivate and interest an identified population of learners	3.33	4.67
4.	Design of visual and auditory information for enhanced learning and efficient mental processing	3.33	4.33
5.	Ease of navigation, predictability of the user interface, and quality of the interface help features	3.33	4.33
6.	Design of controls and presentation formats to accommodate disabled and mobile learners	3.33	4.00
7.	Adherence to international standards and operability on commonly used technical platforms	3.33	4.00
	average score	3.33	4.38

Table 2. General Comment of the First Validation and the Second Validation

No.	Validator ID	General Comment	
		1st Validation	2nd Validation
1.	V001	the game needs a better response when the player answers correctly. due to that, the error is not noticeable to the player	1. The next improvement is some audio to facilitate visually impaired learners. 2. The developer needs to add something like a. Press the green flag button to start. b. Press the spacebar to continue 3. The revision by adding character and color choices for marking the axis makes it easy to spot the axis and origin.
2	V002	Representing linear equations in a context of bridging two points between the ball and the bowl might help the learners to understand linear equations better	please proceed to the next stage

No.	Validator ID	General Comment	
		1st Validation	2nd Validation
3	V003	The game is an excellent game for students to learn linear functions. However, the player might struggle to get the ball inside the bowl due to several issues. First, they do not know that the gradient could not be inputted using fractions. Thus, it needed several trials to realize that the game only accepts decimals. It will be better if there is instruction/information about number input.	1. The idea is innovative and creative, 2. the instruction is attractive and could be understood easily, 3. This game might help students build their understanding of gradients and constants while building their mathematical sense.

After having the first validation result, the author tries to apply the suggestion from the validators. It will be explained further in the next paragraph by showing the difference between the prototype and the second prototype. Every aspect of each step has improved between the first and second tests. Because, in the initial test, the product's developer only focused on the game's core program with few user interface (UI) features, the improvement was greatly enhanced by adding character and color selection to various panels to facilitate computation. Instructions and the clarity with which they are presented are other aspects that enhance points. Furthermore, this game validation results is answering the problem in linear function teaching about the contextualization of the gradient and constant (Postelnicu, 2011). Finally, the comparison of game aspects between the first and second prototypes is depicted in the following pictures.

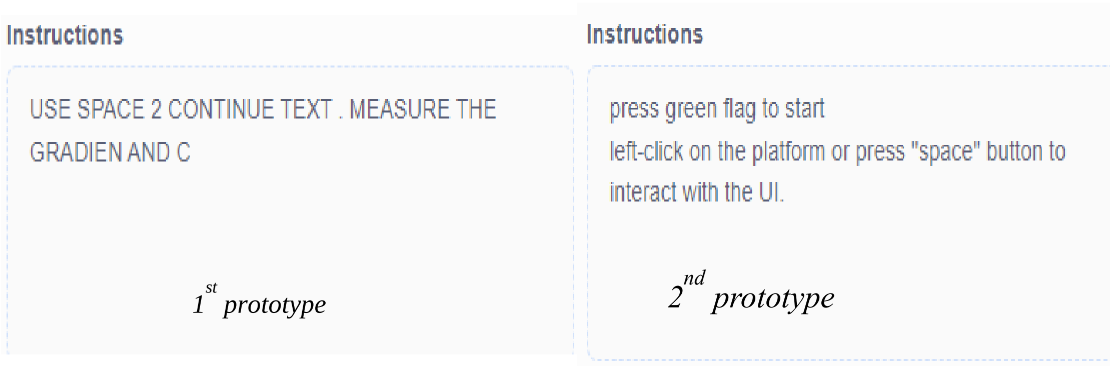
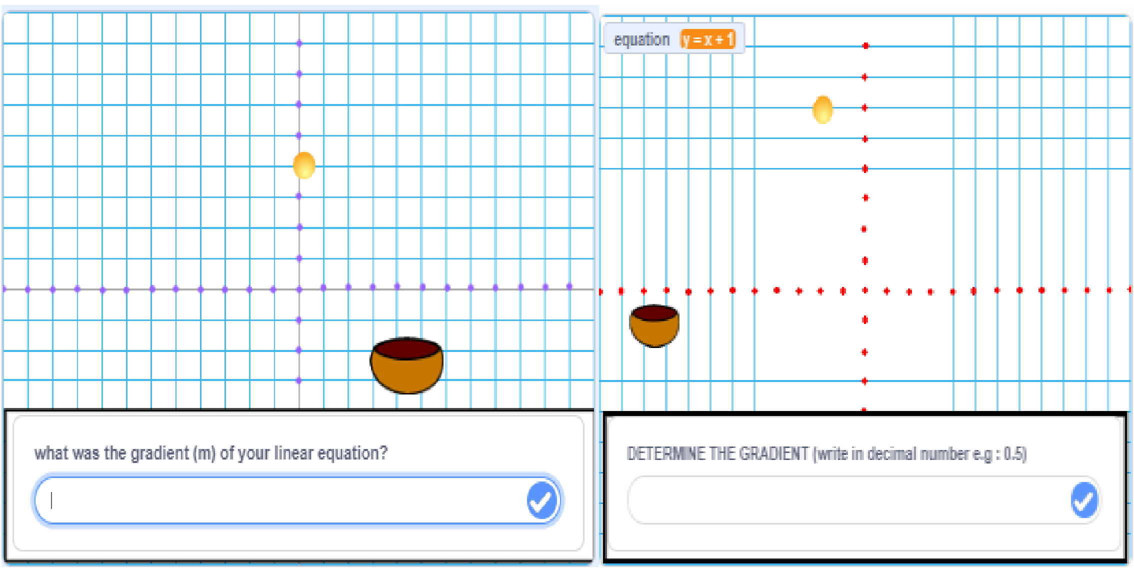


Figure 3. First Instruction Comparison

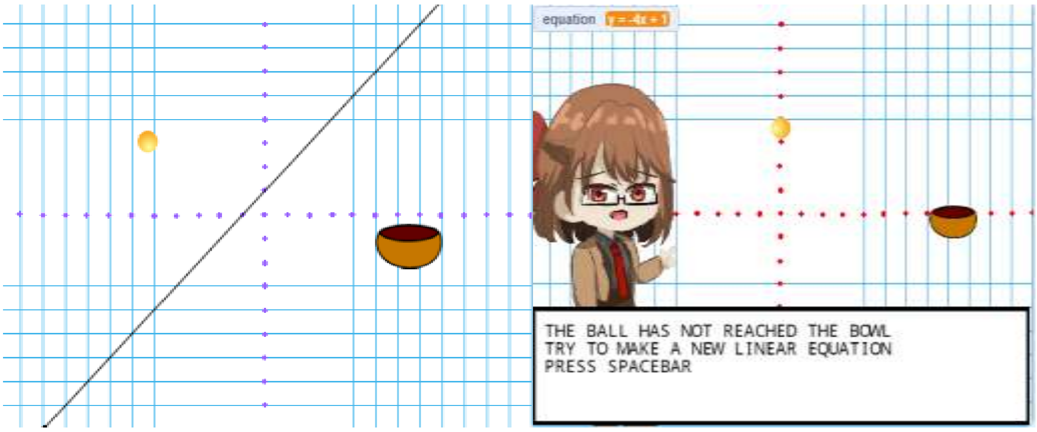
From figure 3. we can see that the instructions were getting more clear and more straightforward to avoid confusion. This change is a result of applying the validator's suggestion (please see table 2).



1st prototype *2nd prototype*

Figure 4. Graphing Step Comparison 1

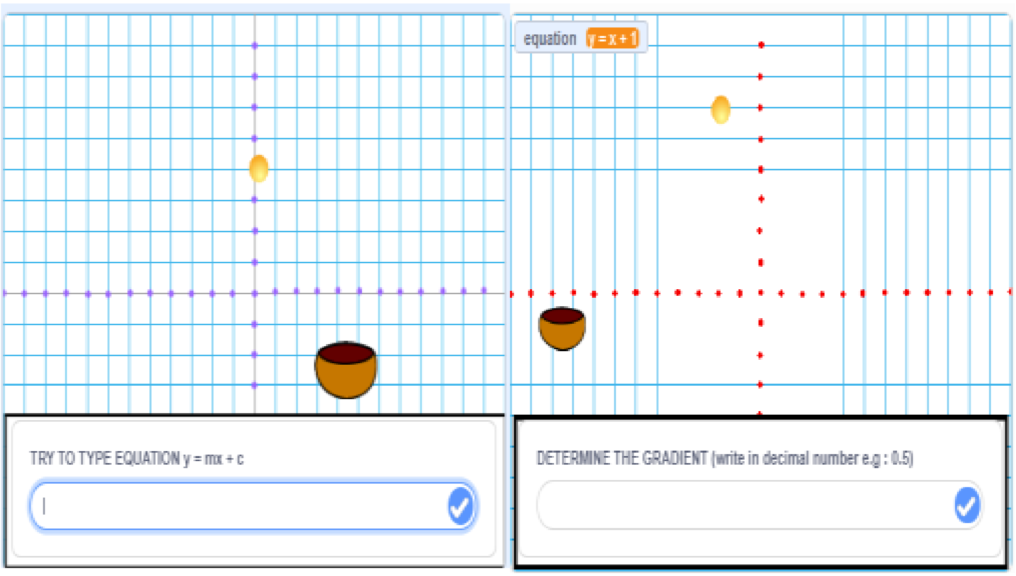
The next figure, figure 4 depicts that there is additional information to put the gradient in decimal numbers separated by a point (e.g. 0.5). This information will prevent students from getting errors in answering the problem.



1st prototype after correct or wrong answer *2nd prototype giving feedback when fail*

Figure 5. Feedback Comparison

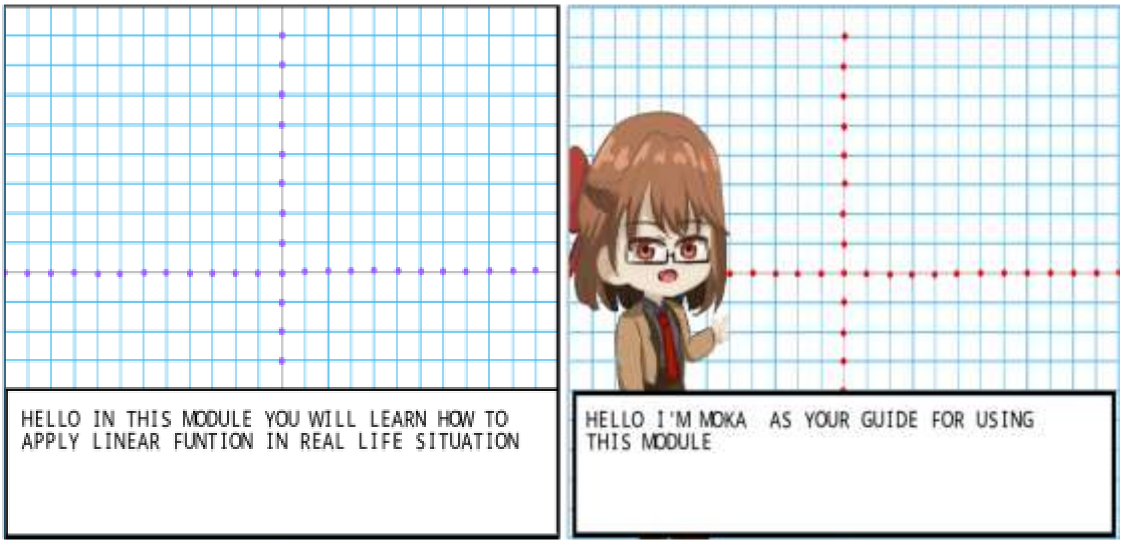
In figure 5, it is demonstrated that the second prototype provides feedback to students or players when they fail a mission, thereby enabling them to understand what steps they need to take to achieve success.



1st 2nd

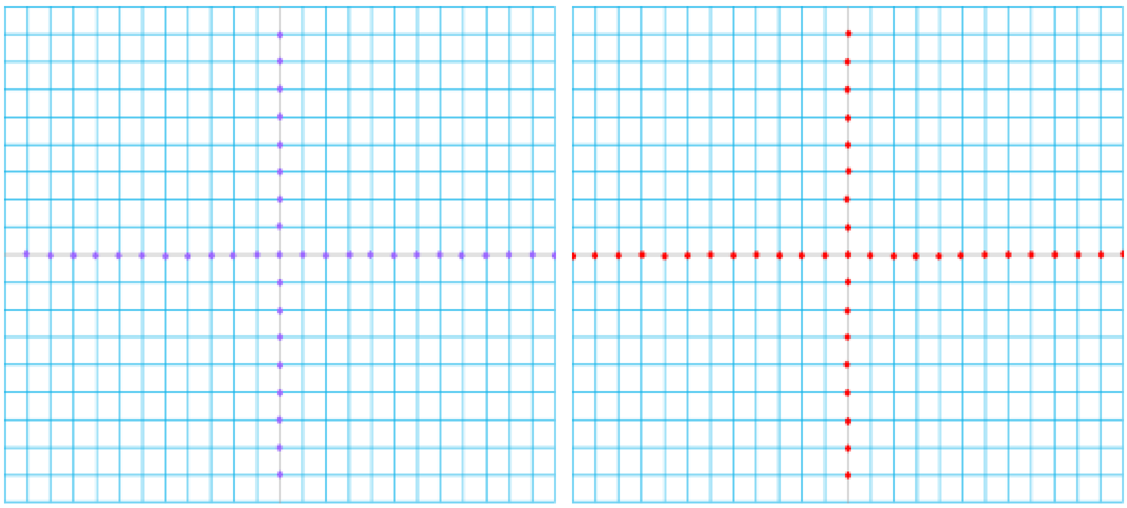
Figure 6. Graphing Step Comparison 2

Figure 6 shows that there is additional information to write the gradient in decimal numbers separated by a point. Finally, in figures 7 and 8 there is an improvement by adding the red spot to the axis, making it more visible. The additional character is also creating the game more attractive.



1^{st} prototype *2^{nd} prototype*

Figure 7. The First Look Comparison



1^{st} prototype *2^{nd} prototype*

Figure 8. Cartesian Plane Comparison

The results of the second validation indicate that the new prototype has demonstrated significant improvements, making it suitable for use in 8th-grade classroom teaching. Although there are a few suggestions for improvement, such as adding audio, this feature is still under development at the time of writing this manuscript.

The game provides an excellent example of how contextual problems can be presented engagingly and interestingly. It also meets the criteria for contextualizing problems by drawing on the personal experiences of students, as described by (Pierce, 2005; Piercea, Stacey, & Bardini, 2010). The game encourages students to view linear functions as a path that the ball follows to reach the bowl, thereby promoting different interpretations of this concept.
Overall, the second validation has demonstrated that the new prototype is effective in promoting engagement and understanding among 8th-grade students. By contextualizing mathematical problems and presenting them in a fun and relatable way, this game has the potential to enhance students' learning outcomes in mathematics.

CONCLUSION

Based on the results of the preceding validity test, this game is ready for use. The result for validity indicates a score of 4.38 out of 5. It indicates that the game's functionality, user experience, playability, and mechanics have been satisfied. Moreover, validation findings indicate that this game's concept is innovative and can aid in the contextualization of a linear function. Implementation is the next step for students who have received instruction on linear functions. Therefore, future studies might use this game in the classroom and assess its effect on students' comprehension.

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