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Master's Thesis

New design in game and visualization approach for physics formula learning

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Abstract

As we progress further into the 21st century, the role of science in molding and influencing human society grows increasingly significant. The rapid advancements in technology, medicine, and environmental sciences, to name a few areas, highlight the ever-growing importance of scientific knowledge in driving progress and innovation. However, a concerning trend has emerged in recent years – a noticeable decline in students' interest in science education, especially in fundamental subjects like physics. This decline is not just a minor educational issue; it has far-reaching implications for our collective future.

The waning interest in subjects such as physics is particularly troubling. Physics, often considered a cornerstone of the natural sciences, plays a vital role in understanding the universe's fundamental laws. From the smallest particles to the vastness of space, physics provides the framework for understanding how the world works. It is the foundation upon which many modern technologies are built, including computers, telecommunications, and medical imaging devices. Without a strong grounding in physics, the next generation of innovators, researchers, and thinkers may find themselves ill-equipped to carry forward the mantle of scientific discovery and technological advancement.

The consequences of this trend extend beyond the realm of scientific and technological progress. A robust understanding of scientific principles is more critical than ever in a world increasingly defined by complex global challenges – such as climate change, energy sustainability, and public health crises. Science education, particularly in areas like physics, is not just about producing scientists and engineers; it is about creating informed citizens capable of making knowledgeable decisions and contributing to public discourse on scientific issues.

The reasons behind the declining interest in science education are multifaceted. One factor could be the perceived difficulty of subjects like physics. Physics often involves abstract concepts that can be challenging to grasp, and traditional teaching methods may not effectively engage all students. Additionally, how science is taught may not adequately convey its relevance to students' lives and future careers. This leads to perceiving science as a purely academic pursuit disconnected from the real world.

Another factor might be the broader cultural context in which science education exists. In a world where attention is increasingly fragmented and immediate gratification is often

valued over long-term investment, the disciplined study required for subjects like physics can be a hard sell. The portrayal of science and scientists in media and popular culture also plays a role in shaping young people's perceptions and interest in the field.

Addressing this decline in interest requires a multifaceted approach. First, it is crucial to rethink how science, particularly physics, is taught. Educators and curriculum developers must find ways to make physics more accessible and engaging, connecting abstract concepts to real-world applications that resonate with students. Innovative teaching methods, such as project-based learning and the technology integration, can play a significant role in this regard.

Furthermore, there is a need to change the narrative around science education, portraying it not just as a pathway to a career in research or engineering but as a critical component of a well-rounded education. Science literacy is essential in an increasingly complex world, and understanding scientific principles enables individuals to make informed decisions about everything from healthcare to environmental policy.

Inspiring the next generation of scientists requires role models and mentors. Highlighting diverse figures in science – individuals who have made significant contributions to the field and come from various backgrounds – can help students see themselves as future scientists. Partnerships between schools and universities, research institutions, and industry can also provide students real-world exposure to science and its applications, further sparking their interest and curiosity. Reversing the trend of declining interest in science education, particularly in fundamental subjects like physics, is imperative for the future of our society. It requires innovative approaches to teaching, a shift in how we talk about science in education, and efforts to connect students with the broader scientific community. The 21st century presents numerous challenges and opportunities, and a strong foundation in science is crucial for the next generation to navigate and shape this rapidly changing world.

In response to this issue, educational methodologies have evolved, incorporating game-based learning approaches. These approaches have been successful in various learning contexts, particularly in enhancing student motivation. Recent advancements in educational methodologies have seen the integration of game approaches into various learning contexts, demonstrating significant success in addressing student motivation issues. However, there is a caveat. While game-based learning has shown promise in certain areas, its effectiveness in teaching abstract scientific knowledge, such as that found in fundamental physics, has been limited. This limitation stems from the inherent complexity of physics concepts, which are often difficult for students to grasp and retain through traditional game approaches. Prior research indicates limitations in the effectiveness of these methods, particularly in the realm of abstract scientific knowledge acquisition, such as in fundamental physics. Students often struggle to enhance their understanding and retain complex concepts through traditional game approach for learning.

This study introduces an innovative system that synergizes formula visualization with a game approach tailored explicitly for fundamental physics subjects to address these challenges. The core idea is to transcend beyond traditional game-based learning by integrating advanced visualization tools that make abstract physics concepts more tangible. This innovative approach has several key components. Firstly, the system uses advanced graphical representations to visualize physics formulas and theories. This visualization aids in demystifying complex equations and concepts, making them more accessible and understandable to students. By seeing the physical representation of an abstract concept, students can form a mental image that aids in comprehension and retention.

Secondly, the system incorporates these visualizations within a game-based framework. This framework is designed to be engaging and interactive, encouraging students to explore and experiment with physics concepts in a virtual environment. The gamification elements, such as point scoring, levels, and challenges, are carefully crafted to motivate students and provide a sense of achievement as they progress.

One of the unique aspects of this system is its adaptability to different learning styles. Recognizing that students have diverse ways of learning, the system offers various modes of interaction and exploration. For instance, some students might prefer direct experimentation with formulas and concepts, while others might benefit from guided tutorials embedded within the game.

Furthermore, the system leverages the power of storytelling and context-based learning. By situating physics concepts within relatable scenarios and narratives, the system helps students understand the practical applications of these theories. This approach not only enhances engagement but also aids in the contextual understanding of physics, making it more relevant to the students' everyday experiences.

The effectiveness of this innovative system was evaluated through a series of studies.

These studies involved a diverse group of students and used a combination of quantitative and qualitative research methods. The results were promising, showing a significant improvement in both the understanding and retention of fundamental physics concepts among students who used the system, compared to those who relied on traditional learning methods.

However, the implementation of such a system has its challenges. Developing a sophisticated educational game that accurately represents complex physics concepts requires a multidisciplinary approach, involving educators, game developers, and subject matter experts. Additionally, there are practical considerations, such as the availability of technology and resources in educational institutions.

In conclusion, integrating formula visualization and game approach presents a promising approach to addressing the challenges in teaching abstract scientific knowledge, particularly in fundamental physics. This innovative system not only enhances student engagement and motivation but also facilitates a deeper understanding of complex concepts. As educational methodologies continue to evolve, it is crucial to embrace such innovations to prepare students for a future where scientific literacy is increasingly important.

Keywords: physics learning, game approach, visualization

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Chapter 1
Introduction

1.1 Background of Game Approaches

The acquisition of scientific knowledge plays a crucial role in the advancing of human society, as it equips individuals with the understanding and skills necessary to navigate and contribute to an increasingly complex world. Learning science helps in fostering critical thinking and analytical skills, enabling people to assess information critically and make informed decisions. In 2001, Oliveira, M., & Rodrigues, A. found that physics learning involves students interpreting explanations or texts, forming hypotheses, planning experiments, considering different options and their consequences to make decisions, and proposing and evaluating conclusions, all of which require the use of deductive or inductive reasoning skills [1]. This is particularly vital in an era where misinformation can easily spread. Scientific literacy also underpins innovation and economic growth, as individuals with a strong foundation in science are better equipped to drive technological advancements and solve complex problems, ranging from medical challenges to environmental issues. Moreover, understanding science enhances our appreciation of the natural world and the intricate systems that govern it, promoting environmental stewardship and sustainable practices. In a broader sense, science education cultivates a sense of curiosity and wonder, encouraging lifelong learning and a continuous quest for knowledge, which is essential for the overall intellectual and cultural development of society. In the book named *National Science Education Standards*, it is claimed that science and societal development are closely related [2]. Therefore, learning in science disciplines is not just beneficial but essential for the progress and well-being of human society.

Unfortunately, the recent decline in student motivation in science education is a significant concern, impacting not only current educational outcomes but also the future of scientific progress and technological development. Dana Vedder-Weiss's 2011 research highlighted a worrying trend: from 5th to 8th grade, students show a marked decrease in their motivation to study science [3]. This decline is not limited to the classroom environment, where individual mastery goals and participation drop, but extends to extracurricular engagement with science-related activities. The waning of interest and engagement in science is particularly pronounced in subjects that involve abstract concepts, complex processes, and dynamic interactions. Ann M.L. Cavallo et al. further discovered that a lack of understanding of scientific concepts does not just result in lost interest; it actively contributes to a regression in learning [4]. In 2014, Potvin, Patrice, and Abdelkrim Hasni verified that young people's interest in science subjects declines in schools [5]. These findings underscore the urgency of rethinking and revitalizing science education to sustain student interest and make learning content more engaging and accessible. Traditional teaching methods, which often struggle to captivate students and foster a deep understanding of science, might contribute to this decline in motivation and achievement in science subjects. Addressing these challenges is crucial for nurturing future generations of scientists and innovators who are essential for continued progress in science.

The game-based approach has been applied to learning in various disciplines and has been widely found to be effective in enhancing students' knowledge acquisition in the scientific field. In 2013, Wang, Tianchong, and Dave Towey utilized the mobile version of Minecraft as a learning platform for physics [6]. They employed the physical engine characteristics of the Red Stone Powered Rail in Minecraft to teach fundamental physics, specifically Newton's Laws of Motion. The results were proven to be effective. In recent 2022, Tan, Jun Wen et al. utilized board games, incorporating medical teaching with the characteristics and rules of the board games, successfully designing an enjoyable and fun learning environment [7]. This study discovered the potential of games to enhance students' learning motivation.

1.2 Shortcomings of Game Approaches

In 2021, A Manzano-León et al. systematically reviewed game approaches in education across different levels, from schools to universities. They found that the game approach not only helps in enhancing students' motivation but also benefits their engagement and academic achievement [8]. However, when they considering the main gamification elements used in education, such as points, medals, and rankings, they found that if the gamified environment is overly simplified, for instance, using only one or two gamification elements, the impact on student motivation could be minimal or even negative. Through analysis, they believed that this phenomenon emerged due to the overly simplistic game rewards, leading students to focus only on the related game elements and lacking motivation for learning the knowledge.

Not only game elements in the game can affect the impact of the game approach on learning knowledge. In 2021, Deta, U. A., et al. found that although board games and card games could improve students' learning outcomes, not all games are suitable for enhancing students' learning levels [9]. This indicates that the choice of game type may also affect the impact of the game approach.

In another study on the shortcomings of the game approach in the same year, Valerie J. Shute and her team used games to teach physics concepts. They found that some people who relied on in-game skills gained a very relaxed learning experience but little knowledge of physics [10]. They prepared several simulation game scenarios for various basic physics concepts, and then provided students with an advice system to help them better experience learning through the game approach. Students can find a way to cheat to pass the game. Their engagement in the game was very high, utilizing hints in the advice system to bypass the underlying knowledge of the educational game to score points. This resulted in a lower-than-expected improvement in learning outcomes and ran counter to the original purpose of designing the game approach. In other words, there is currently no guarantee that students will learn the knowledge behind how games are played. There is still a gap between the game and the knowledge behind the game.

1.3 Research Objective and Questions

The main objective of the research is to improve the game approach for physics knowledge by visualizing formulas and contributing valuable insights into the realm of game approach in education. The following research questions lay the foundation for the study. We can reach the objective by combining learning object with game, merging visualization into game and evaluating the improvement of combination between visualization and game.

- RQ1: How to combine learning of physics formulas with game? Before filling the gap mentioned in the second section, a game environment must be deployed for students to learn physics knowledge.

- RQ2: How visualization combined with game? To fill the gap mentioned in the second section, it is essential to discuss about how to combine the visualized knowledge with game.

- RQ3: How to evaluate the improvement of combination between visualization and game? After applying our proposed method, it is important to evaluate it.

It is important to fill that gap we mentioned in the second section. We would like to find a better method to test people to acquire knowledge of physics. Our study's significance is the potential to fill the gap between the game and the knowledge behind the game. We will design a card game approach for physics learning which requires Visualization ability during gameplay.

Chapter 2
Related Works

2.1 Works related to Target Subject

It is necessary to identify subjects that exemplify the complexity of abstract knowledge absorption for students and are amenable to gamification strategies before responding to Research Question 1 (RQ1).

In their comprehensive review of the physics subject in 2023, Shrestha, Polanski Snyder, and others pinpointed the profound difficulties junior high students face in grasping physics, illustrating the wide-ranging challenges these students confront while trying to understand basic scientific concepts [11]. According to their findings, the key to igniting student interest and comprehension in intricate physics topics lies in adopting teaching methods that are both innovative and interactive, blending hands-on experiences with real-world applications. This approach necessitates moving away from traditional, lecture-based techniques towards more engaging, interactive, and exploratory methods, thereby allowing students to engage practically and relevantly, experiment, and learn the principles of physics. The study also found that it is extremely important to integrate real-life applications into physics courses and to implement interactive, inquiry-based teaching methods. Such methods allow students to establish connections between abstract physics concepts and their everyday life experiences, thereby better understanding the former. Through active participation in experimental activities, students can better understand physics concepts such as mechanics, energy, waves, and electricity. Providing real-life scenarios can enhance students' comprehension abilities while also deepening their interest in the subject.

Games are particularly well-suited for incorporating elements of real-life scenarios into the learning environment. In 2018, Medine Baran et al. They used real-world game scenarios, such as swings, dominoes, bumper carts, billiards, etc., to teach students about Newton's Second Law of Motion and the Law of Action-Reaction [12]. It was found that students' enthusiasm significantly increased, and there was an effective improvement in their learning outcomes. Games incorporating real-world elements can have a positive impact on the learning of subjects with abstract knowledge, such as physics.

These studies show that physics is also a subject that is suitable for applying a game environment with real-life scenarios.

2.2 Works related to Types of Game Environment

Before responding to Research Question 2 (RQ2), choosing the right type of game is very important. In the previous introduction section, we discussed the importance of selecting the appropriate type of game for the game approach, and more research has corroborated this point.

In 1999, Amory, Alan, et al. discovered students' preferences for types of game approaches. Young biology students appeared to favor 3D adventure games (such as Zork Nemesis) and strategy games (like Red Alert), while expressing dissatisfaction with simulation games like SimIsle [13]. The subjective information obtained from students in their study revealed that graphics, sound, and storylines are of great importance to students. They generally believe that skills such as visualization, logic, and memory are essential when playing these games.

In 2020, Dimitra, Kirstavridou, et al. found that video games hold immense potential and value within the educational sphere, effectively engaging the youth [14]. These games serve as useful tools for research and assessment. Moreover, they assist youngsters in establishing objectives, guaranteeing the accomplishment of these goals, offering feedback, reinforcing progress, and keeping track of behavioral developments. However, in 2014, Borges, S. S., Durelli, V. H. S., Reis, H. M. et al. found that there exists a deficiency in methodologies that integrate gamification with computer-supported collaborative learning (CSCL) [15]. In this case, video games in computer can potentially become a breakthrough point in our study.

Based on these related studies, we can observe that when physics is presented in the form of video games, students gain significant motivation to learn, and the choice of different video games is also crucial to the game approach.

And only video games in computer are not specific enough, to have a to achieve a structured, adjustable, and sustainable learning environment, card-based electronic games have been identified in prior research as possessing highly suitable characteristics. In 2011, Umetsu, T. et al. found that the characteristics of card games like card array, card stack, player, player hand, and player scores are suitable for structured data [16]. This type of game is suitable for learning environments and provides an environment for researchers to gather data from students' actions during game approaches.

2.3 Works related to enhancing the Game Approach

To respond to Research Question 2 (RQ2), we need inspiration about improving the game approach.

Visualization is a common means to acquire knowledge because it taps into the human brain's innate ability to process and understand visual information efficiently. Our brains are wired to perceive and interpret visual cues rapidly, which makes visualization an effective tool for learning and comprehension.

In 2020, De Haro, Sebastian, and Henk W. De Regt discovered that visualization could give scientists confidence, aiding them in understanding what they are doing [17]. For instance, in the Feynman diagram expansion of group field theory, the characteristics of this visualization, although not a direct spatiotemporal visualization of reality, offer an indirect form of spatiotemporal visualization that assists in understanding reality, where direct spatiotemporal visualization of reality lacks explanatory power.

In 2012, Miller, Arthur stated that the visual imagery of visualization (i.e., mental abstraction, or equivalently, intuition) is superior to that of visualizability (i.e., sensory perception) [18].

To our best knowledge, although there was research about the importance of Visualization ability in physics learning [19], but no one had further explored the sight of the role of visualization during game approaches for learning knowledge. It could be the key to improving the game approach, especially for learning scientific knowledge.

Chapter 3
System Design

3.1 Game for Physics

In this research, we choose foundational physics learning as the targeted subject matter for the game approach. The selected topic must involve abstract concepts and relations in science education, encompassing complex processes and dynamic interactions that are often difficult to comprehend. Fundamental physics precisely fits these criteria, as it deals with numerous abstract concepts like speed, mass, density, and their interrelationship. Figure 3.1 shows some basic physics formulas about speed, mass, and density. Without proper guidance, students cannot understand the various scientific elements of these concepts.

Velocity Formula				
Physical Quantity	Formula	International Primary Unit	Common Unit	Conversion Relationship
V	V = s/t	m/s	Km/h	1m/s = 3.6km/h
s	S = vt	m	Km	$1k_m$ = 1000m
t	t = S/V	s	h	1h = 60min = 3600s

Density Formula				
Physical Quantity	Formula	International Primary Unit	Common Unit	Conversion Relationship
ρ	ρ = m/v	Kg/m^3	g/cm^3	$1g/cm^3$ = 1000 Kg/m^3
m	m = ρv	kg	g	1kg = 1000g
v	v = m/ρ	m^3	cm^3	$1m^3 = 10dm^3$

Figure 3.1: Some basic physics formulas

In fundamental physics, there are many occasions for learning based on formulas, and many physical elements need teaching to be understood. Therefore, before teaching, there are a lot of abstract concepts for students. The formula conversion in the basic physics shown in Figure 3.1 is a very suitable relationships between concepts. Moreover, another reason why students have difficulty with those formulas is that these formulas are learned in different physics units, and students are not often aware of the relationship between those units in the regular educational curriculum. Based on those difficulties, this selection will provide a solid basis for evaluating the impact of the game approach on learning in a specific scientific domain.

3.2 Card Game

In this research, we use a card-based game format. This format offers a versatile structure that can facilitate engagement, competition, and skill-building, all of which are vital components of effective learning with a game approach. The choice of a card-based game will cater to various learning preferences and ensure an interactive learning experience.

Lea Kopf et al. found that card games are powerful tools not only for learning science knowledge, but also for introducing computing [20]. Card games have shown promising potential as educational tools for facilitating comprehension of physics formulas. Card games inherently provide an interactive, competitive environment promoting engagement and critical thinking.

In this research, we choose a classic card game named SPEED as the prototype of the game environment. SPEED is an exhilarating, fast-paced, two-player card game, designed to be the first player to run out of cards.

Figure 3.2: Original SPEED

As Figure 3.2 shows, each participant begins with 20 cards. Five of these are used to form a draw pile for each player, and the remaining cards are held in their hands. The game starts with a burst of energy as two center cards are flipped over from separate spit piles, laying the foundation for the game's dynamic. As the game unfolds, players must rapidly play cards onto these central piles from their hands. The key is to place them in either ascending or descending numerical order, with the suit of the card being irrelevant. This rule adds a layer of strategic thinking to the game, as players must quickly assess their options and act accordingly. The game's pace is unrelenting and requires players to engage in simultaneous play, without the structure of taking turns. This creates a high-energy environment where quick thinking and faster reflexes are essential. Players need to be constantly aware of the evolving state of play and ready to adapt their strategy at a moment's notice. Each player can flip a card from their draw pile when no moves are possible, opening new possibilities and keeping the game's momentum. An additional exciting feature of SPEED is the ability to reset the game. This is achieved by slapping the center pile and exclaiming "Speed!", which can instantly turn the tide of the game. . The winner is determined in one of two ways: either being the first to deplete all their cards or, in cases where both players cannot proceed, the one with the fewest cards remaining in their hand and draw pile combined. This rule ensures that the game remains competitive until the very end, as even a player with a significant lead can be overtaken if they are not careful. The essence of SPEED lies in its name. It is a game that demands and rewards quick reflexes and even quicker decision-making. Each round tests mental agility and dexterity, making it a challenging yet thrilling experience for players. Its blend of strategy, speed, and excitement makes SPEED a unique and captivating card game, perfect for those who enjoy a lively and engaging challenge.

In a previous study, Hassan and Marashi chose a card game for a different subject matter, which aimed at naming compounds, serving the purpose of chemistry education [21]. They employed a pretest-posttest experimental design, administered a chemistry exam to all participants, and then randomly assigned participants to experimental and control groups. The experiment indicated that the card game for naming chemical compounds significantly improved students' scores. However, in this current study, the subject of investigation is basic physics, focusing on understanding physics concepts and formula calculations. We selected the game SPEED because it possesses not only engaging qualities but also simplifies abstract concepts, providing a conducive environment for calculations.

In our innovative variation of the classic SPEED card game, we transformed the original board game into a video game, motivated by the conclusion from previous research that using video games can make the gaming environment more appealing to young people.

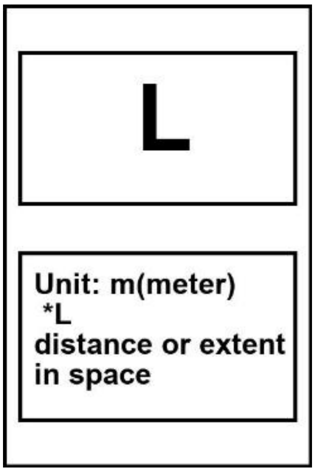

Figure 3.3: Example of the card information

As shown in Figure 3.3, we replaced the traditional playing cards with basic physical element cards, such as the Length card. We designed a title for it, positioned at the top half of the card, and included supplementary information at the bottom half. This information encompasses the international unit of the physical element; potential calculation methods that might be used; in this case, a method involving multiplication by length; and a basic, brief explanation of the physical element. In addition to the basic physics element cards like Time and Mass cards, we implemented significant modifications to the original card interaction rules to enhance the gameplay experience and educational value. This approach concretizes an abstract physical concept, transforming the concept of length into a tangible symbol on the card.

Some of the designs will remain in the new SPEED game. In the original classic SPEED card game, the condition for playing a hand card onto a central card is that the hand card and the central card differ by 1. However, in SPEED for Physics, this condition has been modified so that if there is a potential to form a calculable formula between the central and hand cards, then the hand card can be played onto the central card. This action generates a new physical element card with a new unit, constituted by the formula on the central card. Thus, the interactive nature of card games is utilized to concretize the transformation and relationships between elements. The calculation of physical formulas becomes a combination and synthesis of card play.

The original game's mechanism, which allows playing a card when it differs by one from the middle pile, was adapted for our physics-themed game. However, simply allowing cards to be played based on a calculable formulaic relationship between the hand and middle cards was insufficient. This new rule, compared to the original game's 13 different types of playing cards, could lead to a rapid and unfulfilling conclusion due to the limited variety of basic physics element cards. We introduced new gameplay elements: objective cards and a scoring system to address this. In other words, players score points by synthesizing specific target physical elements. To ensure the game concludes, we imposed limits on the number of target synthesis cards and the overall game duration.

To elevate the intensity of the game, thereby enhancing player focus and engagement, we incorporated a game AI to compete with the player in accomplishing a set of scoring objectives within a limited timeframe.

To introduce a gradient of difficulty and complexity to the game, we meticulously designed various stages:

- Stage 1: a single-player mode without game AI involvement. This stage serves as an introduction to game mechanics. It allows players to familiarize themselves with the basic elements and strategies without the pressure of competing against an AI opponent. It is an essential stage for beginners to grasp the core concepts and for seasoned players to refine their skills.

- Stage 2: Moving to the next level of challenge, which features a competitive setting where the player is pitted against a game AI. This stage is designed to simulate a more dynamic and challenging environment, pushing players to not only apply their knowledge of the game's mechanics but also to strategize against an AI opponent. Including the AI in this stage adds a significant layer of complexity, as players must anticipate and counter the AI's moves while also focusing on achieving their own objectives.

- Stage 3: the stage where the difficulty is further escalated. In this stage, the game AI's strength is increased, presenting a more formidable opponent. Additionally, the number of target cards required to achieve victory is also increased, demanding more strategic planning and quicker decision-making from the player. This stage is tailored for experienced players who have mastered the earlier stages and are looking for a more intense and demanding gameplay experience.

These progressively challenging stages are intended to cater to a wide range of players, from beginners to advanced, and are designed to enhance the player's skills and strategic thinking progressively. The gradual increase in difficulty not only keeps the game interesting and engaging but also provides a sense of accomplishment as players advance through the stages, overcoming greater challenges and honing their abilities in the process.

The card game turns abstract physics elements into cards. During the game, students will make the connection between card-to-card interactions and computational relationships between physical elements (physics formulas). Therefore, designing a physics-learning card game satisfies RQ1.

3.3 Visualization of Formulas

To address RQ2, we enhanced the game approach using visualization knowledge by using visual feedback. In this study, we aim to facilitate learning abstract formulaic knowledge within a game environment, making the visualization of formulas a key aspect of our game element design. For this purpose, we have chosen to use Manim [22]. Manim, short for Mathematical Animation Engine, is an open-source Python library for creating precise and educational mathematical animations. Initially developed by Grant Sanderson for his popular YouTube channel "3Blue1Brown", Manim has evolved into a powerful tool widely used by educators, mathematicians, and enthusiasts to demonstrate complex mathematical concepts and principles visually. The core idea behind Manim is to provide a framework that enables the creation of high-quality, programmable animations. It uses Python, known for its readability and ease of use, making it accessible even to those who are not professional programmers. The library allows users to create animations that range from simple geometrical shapes and text to intricate 3D animations and interactive visualizations. One of the key features of Manim is its ability to integrate mathematical content into the animations seamlessly. For example, it can precisely render complex equations and formulas, graph functions in multiple dimensions, and animate geometric transformations. This makes it an excellent tool for visualizing mathematical topics like calculus, linear algebra, differential equations, and more. Manim also provides a high degree of customization. Users control almost every aspect of the animation, including colors, movement, timing, and camera angles. This flexibility means users can tailor their animations to specific educational or illustrative needs.

We designed our game animations to aid in the visualization of complex concepts. Formulas involving mass were represented with animations featuring colored spheres. Formulas containing vectors were visualized through videos of objects moving in specific directions. Length-related formulas were depicted using animations of line segments (representing length), rectangles (for area), and cubes (for volume). Based on these principles, we visualized several classical physics formulas as game hints. A pre-made animation corresponding to that element is played when a player successfully synthesizes a particular physical element. This visual feedback, appearing alongside the game, serves as an instructional tool, in line with previous research findings. These animations, composed of collective geometric shapes, are designed to aid players in understanding their actions within the game, enhancing their engagement and comprehension of the underlying physical concepts. We decided to make a physics formula visualization by Manim as hints to improve the game approach for learning physics.

Chapter 4
System Development

Upon completing the design of our system, this chapter will delve into a detailed description of all aspects encountered during its development.

While designing the gameplay rules, we considered that the original version of the game was a speed-based game. Consequently, we chose to set the input method as keyboard input, considering that, compared to the mouse, keyboard inputs allow for more diverse and rapid responses. This decision was grounded in the understanding that the essence of a speed game lies in its ability to challenge players' quick thinking and reflexes. Using the keyboard, we could map numerous functions to different keys, enabling a more complex and engaging gameplay experience.

The keyboard's versatility also allowed us to design a more dynamic game interface. Players could use specific keys for different actions, such as selecting cards, performing calculations, or executing special moves. This arrangement not only made the game more interactive but also added an additional layer of strategy, as players had to think not only about the physics concepts involved but also about the best way to utilize their keyboard controls for optimal play.

In our game's design, we strategically assigned the keyboard keys "a", "s", "d", "f", and "g" to correspond respectively to the action of playing each of the five cards in the player's hand onto the first central playing area. Similarly, the keys "h", "j", "k", "l", and ";" were designated for playing cards in the second central playing area. This setup was meticulously chosen to facilitate intuitive and rapid gameplay, allowing players to manage their hands efficiently and respond to the dynamic changes in the game.

To mitigate the inability of players to play any card – a situation that can stall the game and diminish the excitement – we implemented an innovative feature where the Up-arrow key on the keyboard is used to refresh half of the cards in the central playing area. This mechanism introduces new potential combinations and strategies, encouraging players to continuously adapt their approach and think creatively about the evolving configurations of the game board.

The layout of the card game, as illustrated in Figure 4.1, was created using the Pygame library for Python. This choice gave us the flexibility and functionality required to bring our vision to life. The structure of the game board closely resembles that of the classic

SPEED card game, maintaining a familiar and accessible format while introducing our unique modifications.

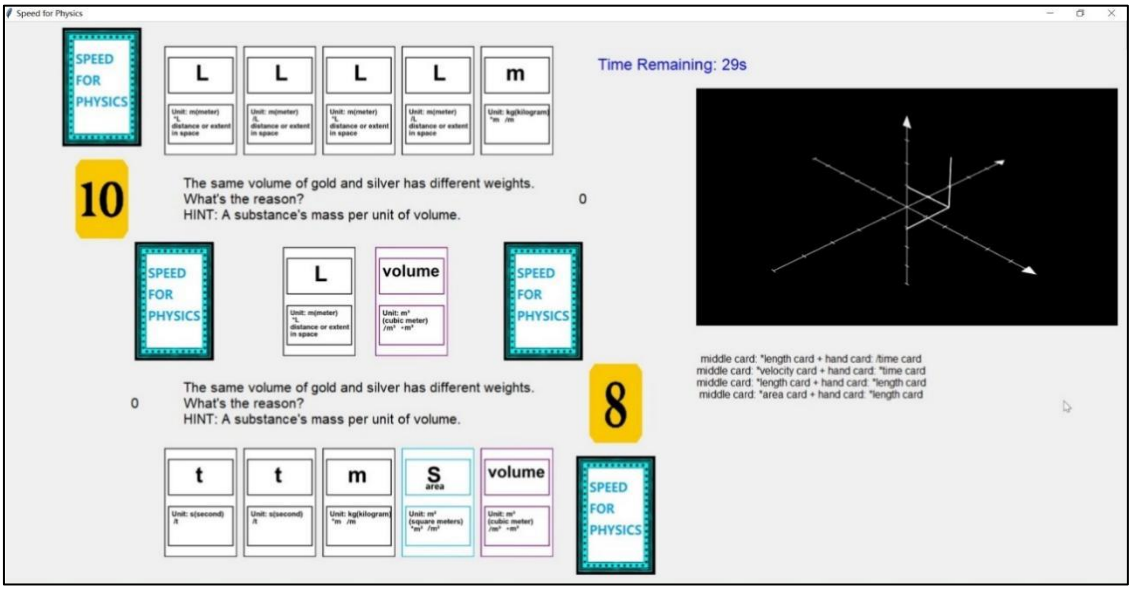

Figure 4.1: Scenario of the Gameplay & Demo for the game elements

In the graphical representation, the top section of the image displays the five cards in the hand of Player 1, which is the game AI, while the bottom section presents the five cards in the hand of Player 2, the human player. Situated between these two areas are two central piles of cards. Player 1, the game AI, can refresh the pile on the left, while the human player can refresh the pile on the right by pressing the Up-arrow key. This layout not only maintains a balance between the two players but also adds a strategic layer to the game, as players must not only consider their own hands but also anticipate and react to the actions of their opponent.

As depicted in Figure 4.1, located between the central card piles and the players' hands, there are cues for each player's objectives. Instead of directly displaying the target physics element cards or their formulas in this game version, which could potentially lead to players cheating by memorizing card information or formulas, we have innovatively employed a combination of engaging riddles and hints to represent each target physics element card. This approach enhances the game's intellectual challenge and intrigue.

When players synthesize simpler cards, such as the Area (S) card, created by multiplying two Length cards, we have designated these as blue cards, signifying their lower level of difficulty in composition. Purple cards indicate more challenging syntheses to differentiate the complexity levels. For instance, in Figure 4.1, the purple Volume card is an example of a more complex target. Upon successful combination of cards to create a Volume card in the middle of the play area, as illustrated, an animation related to the volume formula – depicting lines forming a surface and surfaces forming a volume – is triggered on the right side of the game screen. This visual aid not only reinforces the conceptual understanding but also adds an engaging element to the gameplay. Below the animation is a record of the player's last four moves, providing a helpful reference for strategizing future plays.

Adjacent to the intriguing riddle, as shown in Figure 4.1, is a score counter, initially set to zero. This score reflects the player's progress in achieving the targeted physics elements. In the scenario where a player successfully creates a volume card in the center but does not match the target card, no points are scored. The riddle provided in Figure 4.1 reads: "The same volume of gold and silver has different weights. What is the reason? HINT: A substance's mass per unit of volume." In this state of play, the player's objective is to synthesize a Density card, as implied by the riddle's hint towards a fundamental physical property – the mass per unit volume of a substance. This innovative integration of riddles not only deepens the educational aspect of the game but also adds a layer of cognitive challenge, engaging players in a more profound and thought-provoking experience.

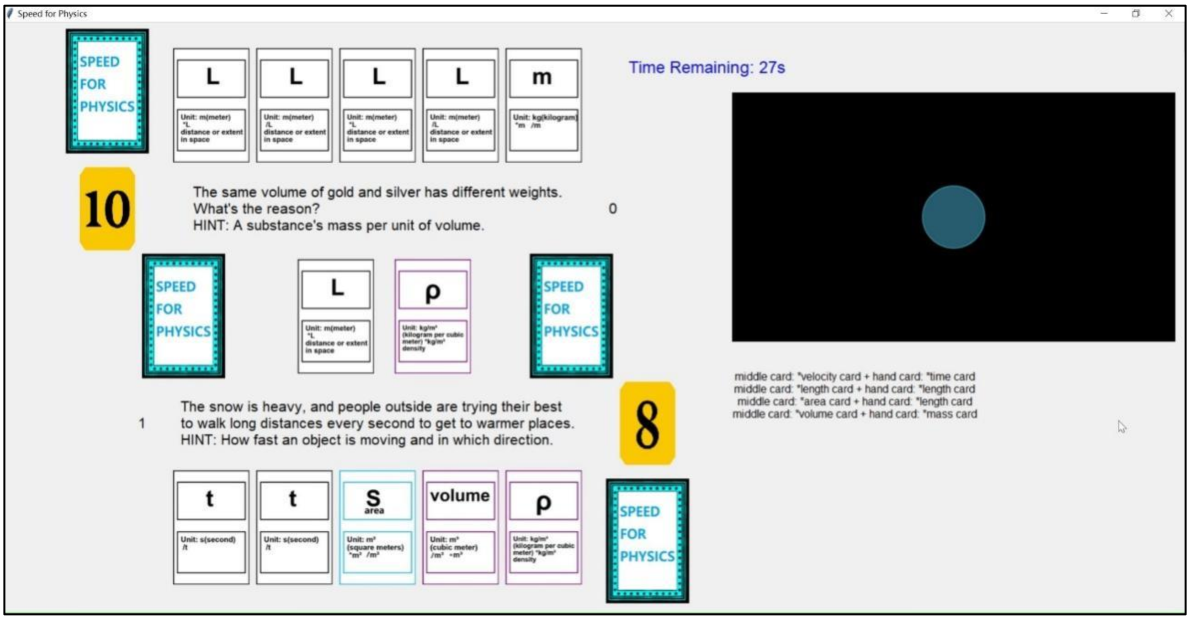

Figure 4.2: Scenario of the Gameplay & Updated Status

If the player, in the scenario depicted in Figure 4.1, decides to play their third hand card onto the second central card pile, a Mass card would interact with a volume card featuring a division function, which would synthesize the target card, the Density card. This action would transition the game state from that shown in Figure 4.1 to the new state depicted in Figure 4.2. As a result of successfully creating the targeted Density card, the player would be awarded a point, reflected in the updated score displayed on the screen.

Subsequently, the riddle would randomly change, providing hints for a new target physics element card. This continuous change in objectives keeps the game dynamic and challenging, ensuring that players remain engaged and intellectually stimulated throughout the gameplay. In addition, the corresponding animation for the Density formula would be activated and displayed. This animation, illustrating the concept of density as mass per unit volume, serves not only as a visual reward for the player's achievement but also reinforces the educational value of the game by providing a clear and intuitive representation of the physical concept involved.

Furthermore, the history record, a crucial feature for strategic gameplay, would also be updated to reflect the player's most recent four moves. This updated record allows players to review their previous actions, helping them to strategize and plan their future moves more effectively. The integration of these dynamic elements – the evolving riddles, the educational animations, and the updated history record – all work in concert to create a rich and immersive learning experience, making the game not only a tool for understanding physics concepts but also an engaging and intellectually stimulating pastime.

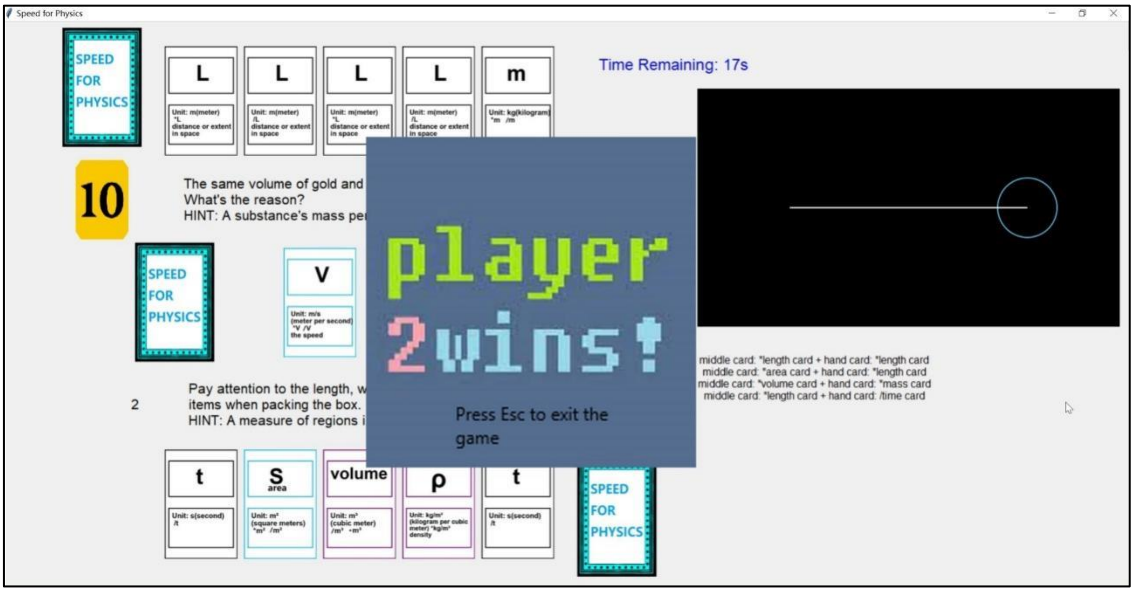

Figure 4.3: Scenario of the Gameplay & Winning Situation

Continuing from the gameplay scenario described in Figure 4.2, the player proceeds to score additional points. The animations on the right side of the screen are updated accordingly, alongside the continuous refresh of the historical record of moves. Given that this scenario is set in Stage 1, where the objective is to synthesize two target cards, achieving the second point triggers a celebratory graphic to pop up, signifying the player's victory as Figure 4.3 shows.

Transitioning into Stage 2, the game introduces an AI component that competes with the player by randomly playing cards onto the central piles at a pace of once every six seconds. The challenge here is for the player to synthesize two target cards swiftly within one minute. In Stage 3, the difficulty escalates significantly as the AI increases both its card-playing speed and the frequency of refreshing the card piles. Additionally, the number of target cards to synthesize is raised to three.

This detailed explanation encapsulates the specific gameplay process and the development aspects of the gaming environment we have created. Our design offers a dynamic and progressively challenging experience, engaging players in a competitive yet educational setting. Each stage is crafted to enhance the learning experience through visual cues, strategic gameplay, and interactive components. The integration of AI in Stages 2 and 3 not only heightens the game's intensity but also provides a scaling difficulty that caters to different skill levels, ensuring that the game remains challenging and enjoyable for a wide range of players.

Chapter 5
Experiment

5.1 Experiment Design

To verify the effectiveness of the system designed in the previous chapter in addressing the research questions posed in our study, we conducted a controlled experiment. The following Table 5.1 is an expanded description of the experiment's flow:

Table 5.1: Experiment's Flow

Total Duration: 1 hour	
Section	Content Explanation
Introduction (5 mins)	● Begin with an overview of the experiment's steps. ● Explain the objectives and what participants can expect during the session. ● Emphasize the importance of their honest feedback and responses for the study's success.
Pre-quiz (10 mins)	Assess participants' initial understanding of basic physics concepts. The quiz will consist of questions targeting four key areas: ● How familiar are they with the physics elements? (3 points) ● How familiar are they with the relations between physics elements? (1 point) ● How familiar are they with the physics formulas? (1 points) ● How do they imagine when dealing with physics problems? (3 points) This quiz will also help us further analyze the impact of our solution to Research Question 1 (RQ1), which involves choosing the subject of fundamental physics, on our study.

Control Experiment with Card Game (30 mins)	We split participants into two groups for a comparative study. Group A is a cohort that is provided with formula visualization feedback, meaning that members of this group have the advantage of visual aids that graphically represent formulas as they work through them. This feature is designed to enhance their understanding and interaction with the formulas, offering a more intuitive and engaging learning experience. In contrast, Group B does not have access to this formula visualization feedback. We successfully recruited ten volunteers for each group, all of whom were confirmed to be students either from non-physics related majors or those who have not been in contact with physics for an extended period and have consequently forgotten their physics knowledge. We introduce "SPEED for Physics" card game to participants and explain its relevance to the experiment. Students will go through different levels of the game. ● Level 1: Tutorial (5 mins): Solo playthrough of five rounds, familiarizing participants with game mechanics. ● Level 2: Versus Game AI (10 mins): Engage in 10 rounds playing against the game AI, maintaining consistent rules. ● 5-minute break before Level 3 ● Level 3: Advanced Challenge (10 mins): Compete against a more sophisticated AI with increased target numbers. Group A will play with visual aids illustrating the underlying physics concepts, while Group B will play without these aids.
Post-quiz	Re-evaluate participants' understanding of basic physics

(10 mins)	concepts. The quiz will mirror the pre-quiz in structure but will feature different questions based on the same four targets.
Questionnaire (5 mins)	● Collect detailed feedback on participants' experience during the experiment. ● Gather insights on the perceived impact of the visual aids (for Group A). ● Seek suggestions for improvements and personal observations.

When the game is closed, it automatically generates a LOG file in a designated folder. Figure 5.1 presents a sample excerpt from such a LOG file. The column on the left side of the figure lists timestamps, which are crucial for tracking the time players spend on each step of the game. "Start" denotes the record of the game's commencement, while "END" marks the record when the game reaches its time limit. The phrase "Event ‘a’ triggered" refers to a player action previously described in Chapter 4, "System Development". It specifically indicates the moment a player presses the "a" key. In this case, it corresponds to the event that the first card from the player's hand is played to the first middle deck.

```
[16:30:20.747] START
[16:30:27.487] Event 'a' triggered.
[16:30:27.575] GIF combination triggered: 5 + 5
[16:30:29.128] Event 'd' triggered.
[16:30:29.226] GIF combination triggered: 5 + 14
[16:30:29.226] added: 1
[16:30:45.399] Event 'h' triggered.
[16:30:45.399] wrong combination: 6 + 1
[16:30:48.712] refresh
[16:30:49.512] refresh
[16:30:50.352] refresh
[16:30:53.704] Event 'l' triggered.
[16:30:53.789] GIF combination triggered: 5 + 5
[16:30:56.456] refresh
[16:30:57.539] refresh
[16:31:06.673] refresh
[16:31:07.026] refresh
[16:31:07.419] refresh
[16:31:08.280] refresh
[16:31:09.496] refresh
[16:31:12.848] Event 'l' triggered.
[16:31:12.953] GIF combination triggered: 3 + 5
[16:31:12.954] added: 2
[16:31:12.954] Player2 Wins
[16:31:20.975] END
```

Figure 5.1: Sample of actions recorded in the Log File

Following the trigger of a key event, the LOG file also documents whether any computational relationship was successfully formed between the player's hand cards and the middle cards. In other words, it checks whether the player was successful in forming a formula using the physics element cards. In Figure 5.1, the entry "GIF combination triggered: number + number" signifies that a formula was successfully created and an animation visualizing this formula was played in the game. Despite this, the log files indicate that the members of Group B are able to complete formula synthesis tasks at a level comparable to those in Group A. Here, 'number' refers to the reference number of the cards used in our card game. However, it is important to note that Group B accomplishes this without the benefit of visual prompts or guides within the game environment, which could potentially make the task more challenging and reliant on abstract understanding and memory of formulas. Conversely, "wrong combination: number + number" indicates that a particular pairing of cards did not constitute a valid formula, resulting in a failed combination with no formula visualization occurring in the game.

The term "refresh" in Figure 5.1 is associated with the player triggering the "up" key event, which activates the function to refresh the middle cards. "Added: number" refers to the cumulative scoring, and in the scenario depicted in the figure, the final accumulated score reached 2, leading to the game declaring the player as the winner.

This intricate system of logging and tracking within the game provides a comprehensive overview of player actions and their outcomes, offering valuable insights into player strategies and their understanding of the game mechanics, particularly the integration of physics concepts through card combinations. This comprehensive approach aims to quantify the effectiveness of the designed system in enhancing the understanding of physics concepts, particularly through interactive learning methods like the "SPEED for Physics" card game.

5.2 Analysis

Upon the completion of our experiment, we have acquired data pertaining to 20 students, divided equally between Group A and Group B, with each group comprising 10 students. For each student, the collected information encompasses a variety of aspects. This includes their performance scores in two distinct quizzes, which are intended to evaluate their understanding and application of the concepts being studied.

Additionally, we have amassed a substantial collection of digital records, specifically 25 sets of automatically generated game log files for each participant. These log files are instrumental in providing detailed insights into the students' interaction with the game-based learning environment, including their problem-solving strategies, time spent on each task, and overall engagement with the educational content.

Furthermore, we have gathered results from a carefully designed questionnaire that was administered to each student. This questionnaire is aimed at eliciting their subjective experiences and perspectives regarding the learning process. It includes questions about their feelings of motivation, the perceived difficulty of the tasks, the effectiveness of the formula visualization feedback (for Group A), and their overall satisfaction with the educational experience. As Table 5.2 shows, these are data and result of Group A students. These samples demonstrate potential elements that could be utilized for further analysis.

Table 5.2: Data, quiz and questionnaires results from Group A students.

Players	Pre-quiz	Change of quiz score	Fun	Avg Scores	Avg Reverse Times	Avg Refresh Times	W-rate	Avg Used Time for scoring	Visual use
A1	8	-2	2	1.25	1	4.428571	0.48	15.9635	1
A2	5	2	2	1.25	0.571429	13.35714	0.16	18.68232	2
A3	3	4	5	1.28	1.36	11.48	0.40	24.22368	5
A4	6	2	5	1.2	0.666667	11.14815	0.34	20.74326	4
A5	6	0	3.5	1.740741	0.555556	17.14815	0.31	19.30233	1.5
A6	5	2	5	0.84	0.64	13.72	0.31	13.61844	5
A7	2	3	4	1.4	0.84	17.64	0.30	16.2496	3
A8	4	1	1	1.12	0.6	11.76	0.18	19.21908	4
A9	4	1	5	1.192308	0.615385	14.53846	0.24	19.91892	3
A10	6	2	2	1.230769	0.423077	10.96154	0.22	17.98	3

Armed with this set of data, our next step is to embark on a thorough classification and analysis of our subjects. This will involve scrutinizing the quiz scores to assess academic performance, dissecting the game log files to understand behavioral patterns, and interpreting the questionnaire responses to gauge student attitudes and perceptions. Through this multifaceted analysis, we aim to draw meaningful conclusions about the impact of formula visualization feedback on learning outcomes and student engagement.

5.2.1. Preliminary Analysis

To evaluate our proposed method, we conducted a Preliminary Analysis first. Before conducting the preliminary analysis, when we didn't know if there was a significant difference in the improvement in post-quiz scores between two groups representing different levels of physics knowledge, we couldn't directly compare the data. Therefore, we performed a statistical test. We used the Mann-Whitney U test [23], also known as the Mann-Whitney-Wilcoxon test, a non-parametric statistical test used to determine whether there is a significant difference between the distributions of two independent groups. After establishing the hypothesis type for the data groups as H0, stating that the distributions of both groups are equal, we proceeded with the calculation.

$$U_1 = n_1 \times n_2 + \frac{n_1(n_1+1)}{2} - R_1$$
$$U_2 = n_1 \times n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

Figure 5.2: Calculate the Mann-Whitney U statistic using the formula

The test involved ranking all the observations from both groups together, then calculating the sum of ranks for each group. The Mann-Whitney U statistic was calculated based on these ranks, and its significance was determined by comparing it to critical values from the Mann-Whitney U distribution. As Figure 5.2 shows, n_1 and n_2 are the sample sizes of groups 1 and 2 respectively, and R_1 and R_2 are the sums of ranks for groups 1 and 2 respectively. Choose the smaller of U_1 and U_2 as the U statistic.

After calculation, by comparing the smaller U-value (which was 26 in our study) to the critical value in the reference table for U (with a sample reference critical value of 27), we used the reference table for U during one-tailed testing since we were comparing the students' learning improvement, and negative scores could be disregarded. When the U-value was less than the critical value, it indicated a Significant Difference between the two data sets.

Subsequently, we compared the Gaussian distribution medians of the two data sets. Group A showed an overall improvement of 2 points, while Group B showed no improvement (0 points). This demonstrated that the gaming approach with visualization feedback was more effective in helping students learn physics formula knowledge.

5.2.2. Clustering Group A Students

To further verify our solution to RQ3, we analyzed Group A students who played with the formula visualization feedback system.

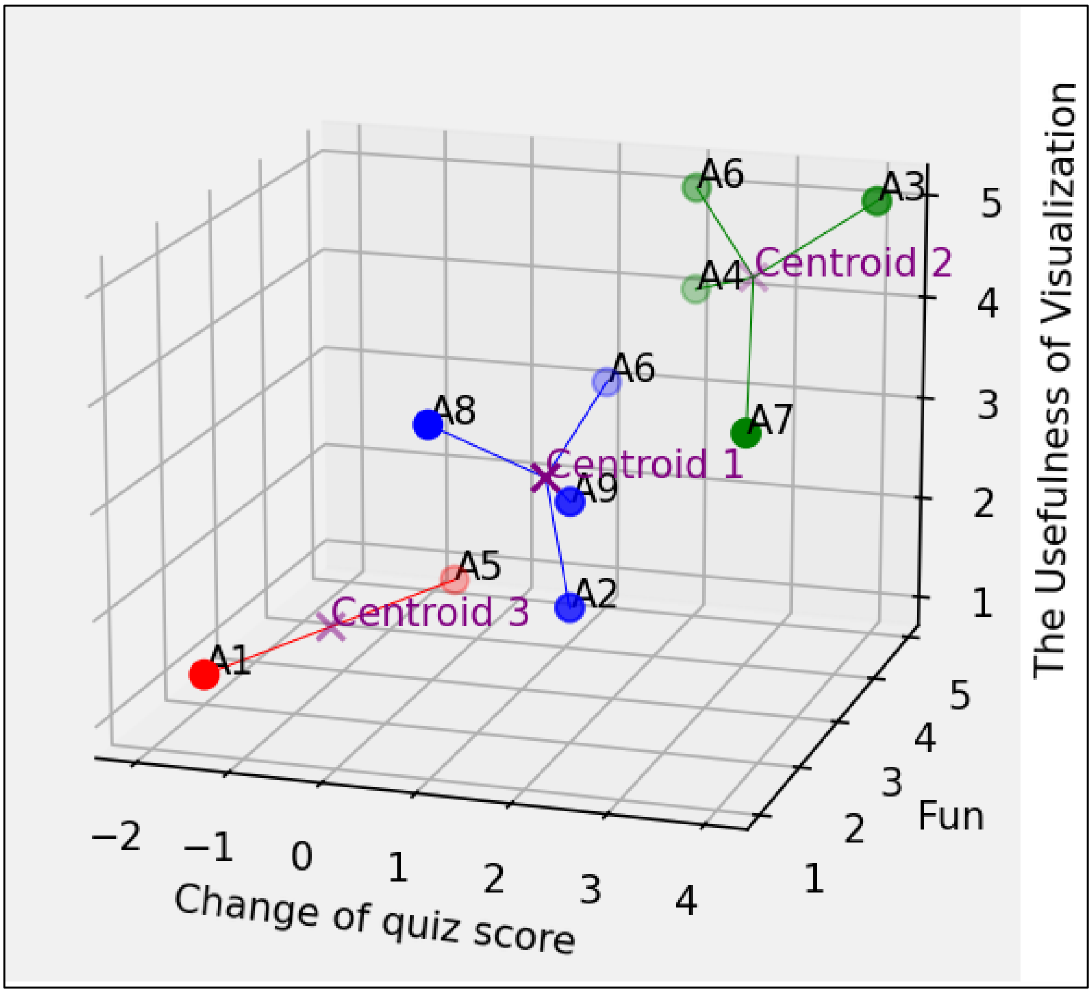

Figure 5.3: Clustering Group A students into 3 types by K-means

In this context, we employed the K-means algorithm [24] to categorize the twenty student participants. K-means is a widely recognized clustering algorithm in the fields of data science and machine learning. Originating from the domain of signal processing, it is a method of vector quantization. The primary objective of K-means is to partition 'n' observations into 'k' clusters, where each observation is assigned to the cluster with the closest mean. This means, often referred to as the cluster center or centroid, effectively acts as a representative prototype for the cluster. We selected three factors: the change in scores between the two quizzes, students' subjective ratings of the utility of the visualization feedback system obtained from the questionnaire, and the subjective rating of the game's enjoyment level derived from the questionnaires, to categorize Group A students. This resulted in a distribution chart of students across these three dimensions as shown in Figure 5.3, where students were divided into three main clusters. These clusters were primarily distinguished by the change in scores between the two quizzes and students' subjective ratings of the utility of the visualization feedback system from the questionnaire. Based on this classification, we further analyzed the Group A students.

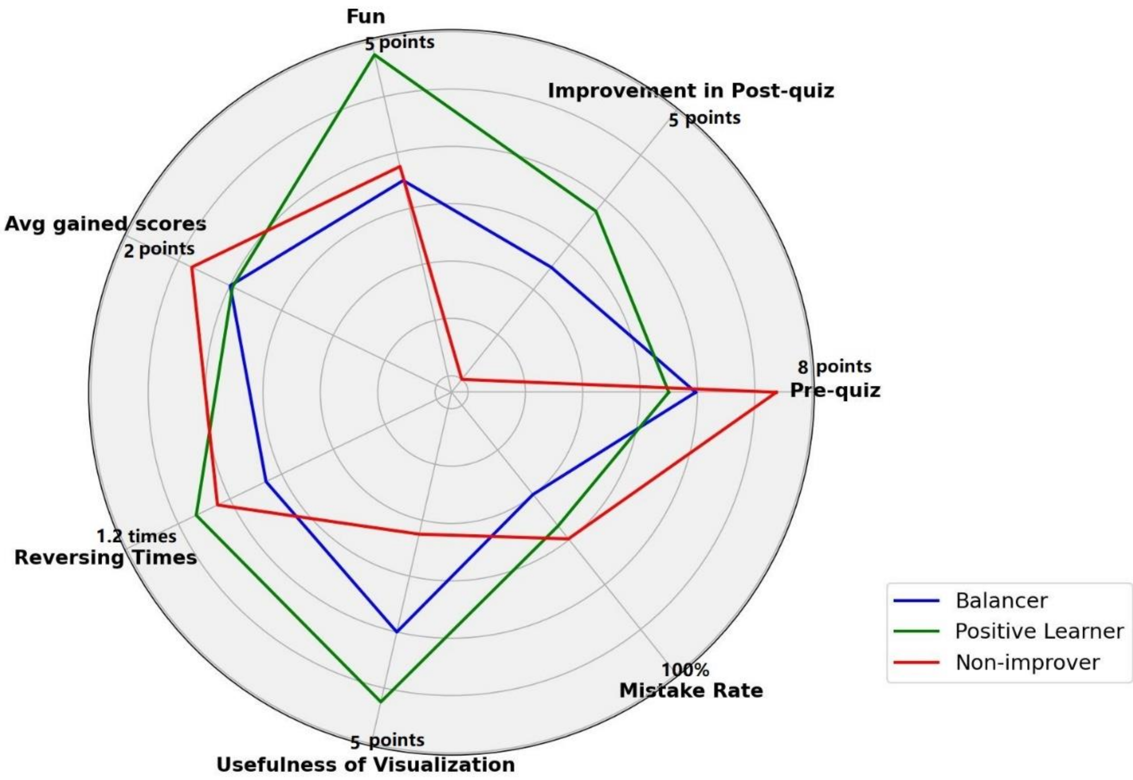

Figure 5.4: Comparison of 3 types of Group A students in across 7 dimensions

We analyzed these three types of students using seven dimensions. As shown in Figure 5.4, in addition to the three main factors: the change in scores between the two quizzes (labeled as "Improvement in Post-quiz", with a maximum score of 5 points); students' subjective ratings of the utility of the visualization feedback system obtained from the questionnaire (labeled as "Usefulness of Visualization", with a maximum score of 5 points), and the subjective rating of the game's enjoyment level derived from the questionnaires (labeled as "Fun", with a maximum achievable score of 5 points), we also considered four additional factors: the average score obtained across 25 rounds of the game (labeled as "Avg gained scores", with a maximum of 2 points); the Mistake Rate observed while playing the game cards (labeled as "Mistake Rate", with a maximum of 100%); the average number of attempts per game round made by students to use hand cards and middle cards to form the inverse operation of physics formulas (labeled as "Reversing Times", maximum usage capped at 20 times per round); and the score of Pre-quiz (labeled as “Pre-quiz”, with a maximum of 8 points). Here is the naming and analysis of the three types of students:

- **Non-improver** (represented by the color red): This type of student, despite having the best Pre-quiz scores compared to the other two groups and performing well in the game, tends not to refer to the formula visualization feedback system. Despite having the highest Mistake Rate while playing, they choose to rely on their existing knowledge and understanding to complete the game. In the second quiz, their scores showed almost no improvement compared to the first, indicating minimal enhancement in their grasp of physics knowledge.

- **Balancer** (represented by the color blue): These students had moderate levels of physics knowledge as seen in the Pre-quiz scores and expressed moderate opinions on the usefulness of the formula visualization feedback system. In the second quiz, their scores improved, indicating an enhancement in their understanding of physics.

- **Positive Learner** (represented by the color green): These students had lower levels of physics knowledge in the Pre-quiz and the highest Mistake Rate in the game, but this also implied a significant potential for improvement. They highly rated the enjoyability of the game environment in this study and expressed the highest subjective appreciation for the utility of the formula visualization feedback system compared to the other groups. They attempted to use the inverse operation of formulas, as mentioned in the previous subsection, more frequently than the other groups, demonstrating a strengthened understanding of formula knowledge. Ultimately, in the second quiz, they showed the greatest overall improvement, particularly in the type of questions involving the visualization of physics formulas, which accounted for 54.54% of their total score increase. In contrast, the Balancers, who also improved in their overall physics knowledge, had zero percent of their score increase attributed to questions involving the visualization of physics formulas.

In this subsection, we discuss how we evaluated those students who played with the formula visualization feedback system into three types using K-means and analyzed each group's characteristics. This analysis helped us validate the feasibility of the solution for addressing Research Question 3 (RQ3). That is, evaluating the improvement of combination between visualization and game by comparing result from two groups and clustering students by K-means.

Chapter 6
Conclusion

6.1 Summary

To address the three research questions (RQs), we posed for a better understanding of our study, we provided three solutions. We designed SPEED for Physics to solve RQ1, built formula visualization feedback to solve RQ2 and evaluate the improvement of combination between visualization and game by comparing result from two groups and clustering students by K-means to solve RQ3. Here is our summary after the experiment concluded:

- To solve RQ1, first, we designed a card racing game named SPEED for Physics, where players and game AI compete within a limited time to complete specified physical formulas using cards representing physical elements. The characteristics of our chosen card game allowed us to transform abstract physical elements into concrete game elements, and also supported the integration and collection of game data.

- To solve RQ2, we incorporated a formula visualization feedback system. serving as the environment for our game approach. While playing the game, students could improve their understanding of physics formulas by observing animations played when formulas were successfully combined.

- To solve RQ3, we evaluate the improvement of combination between visualization and game by comparing result from two groups and clustering students by K-means. We used the K-means algorithm to classify students who used the visualization feedback, resulting in Balancers, who were moderate in using the visualization feedback system, game interest, pre-quiz, and improvement in physics knowledge; Positive Learners, who showed great interest in the game, were very active in referring to the visualization feedback system and thinking actively during the game, and although their initial level of physics knowledge was not high, they showed the greatest improvement; and Non-improvers, who tended not to use the visualization feedback system, had a high error rate in the game, and although their final performance in the game and initial level of physics knowledge were excellent, they did not improve. We found that attention to visualization improved the learning efficiency of students for the type of knowledge we selected, especially for those with a poor foundation in knowledge mastery. We designed quizzes covering four aspects: understanding of physical elements, understanding of the relationships between these elements, comprehension of physical formulas, and visualization of these formulas. This was to help us better study how students' mastery of physics knowledge changed through our game approach.

6.2 Limitations

We summarized some shortcomings in the design of the experiment, the system, and the improvements to the game approach.

- Firstly, there were some flaws in our experimental design and execution:

  When we chose physics knowledge, we did not cover all formulas, but only designed quiz questions based on classical physics knowledge. The amount of quiz content was insufficient, limiting our ability to observe changes in students' mastery of physics knowledge. Apart from knowledge about the visualization of physics formulas and the relationships between physical elements, other types of knowledge sections were not discussed enough due to their smaller proportion in the overall score. Also, the number of participants in the experiment was not large enough due to recruitment challenges, resulting in the findings being more susceptible to randomness.

- Secondly, there were areas for improvement in our game design:

  Many students complained about the discomfort of our button design, especially those who rated the game as not very interesting; their experience was negatively affected by overly complicated controls. In terms of game functionality, our design was not comprehensive enough. The function to refresh the middle deck of cards was designed to be used unlimitedly without cooldown, leading to the exploitation of the game mechanics. This loophole allowed the recurrence of cheating behavior previously observed in research [10]. In classifying all students, one Scorer, who did not have visual feedback prompts, exploited this unlimited use of the refresh function. After scoring a point with a familiar target, this player would rapidly disrupt the middle deck by continuously pressing keyboard keys with the left hand while refreshing their own deck with the right hand, leaving the opponent with no cards to play, and maintaining a 1:0 score until victory. Ultimately, this student could have significantly improved his knowledge of physics. Although this issue could be prevented by limiting the frequency of skill use, the racing element of the card game means that forcefully reducing the maximum skill use frequency would degrade the gaming experience. Therefore, there is significant room for improvement in the overall game design.

- We also had shortcomings in our visualization feedback system:

  The animations in this system were displayed on the far-right side of the game, and players' attention was mostly drawn to the refreshing middle deck and new hand cards. Many students reported that during Stage 2 and later Stage 3, the visual prompts were often ignored amidst the fast-paced competition due to the distance from the focus of attention.

6.3 Future Work

In this study, we solely focused on learning knowledge related to physics formulas. Although, overall, we observed that card games and visualization positively impacted learning this type of knowledge, exploring a broader range of knowledge types and diverse gaming methods is worthwhile to address various issues mentioned in the Limitation Section. The use of visualization in this study was specifically applied to the game approach for learning physics formulas. However, this approach potentially holds the capability to be applied in other educational subjects, various fields, and different types of knowledge within game-based learning environments to assist students in enhancing their learning experience.

Acknowledgement

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