An Empirical Study on Game-Based Learning for Solar System Education using E Game Flow Education Model

Nurain Farzana Mohd Fauzi, Azlan Abdul Aziz, Ahmad Kamalrulzaman Othman and Yusnita Sokman

Computer Science Department, Universiti Teknologi MARA Cawangan Melaka, Malaysia

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ABSTRACT

Science is one of the core subjects in primary education. The conceptual complexity of topics such as the solar system poses persistent challenges for young learners, leading limited interest, low motivation and limited conceptual retention. This paper addresses this problem through Space Adventure, a game-based learning application developed using the Rapid Application Development (RAD) methodology and evaluated with the EGameFlow model. Thirty Year 3 students completed the EGameFlow questionnaire that measured five dimensions of engagement – concentration, goal clarity, feedback, challenge and knowledge improvement. Both the Flow Theory and Cognitive Load Theory served as interpretive frameworks to strengthen the methodological validity analysis with bootstrapping and theoretical sensitivity simulation used to evaluate the stability of the results. Findings revealed the overall enjoyment level of 90.8% (M=4.54) with concentration attained the highest mean (M=4.79). The findings support the idea that gaming mechanics that are pedagogically aligned can produce flow-like engagement with a manageable cognitive load. The study offers a reproducible conceptual model integrating EGameFlow dimensions with flow and cognitive-load processes for an instructional game design in primary science education.

Keywords— Solar System Education, Game-based Learning, EGameFlow, instructional design, learning engagement

INTRODUCTION

Science can be considered both a process and body of knowledge and understanding as human beings acquire over a long time of discovery, observation, and through experimentation. The term “science,” as defined by the Merriam–Webster Dictionary, refers to knowledge that can be tested and reproduced. This definition is well rooted in the Latin word “scientia,” which means knowledge. The term philosophy of science is used to describe the area of study that deals with the purpose and goals of science, which is not to gather data but information that can be tested and evaluated so as to obtain a measurable and reliable result.

One of the basics in the elementary class is the solar system, which is one of the main units in the curriculum of science studies. The solar system is the star system, which is the sun, and all celestial bodies such as the planets, natural satellites, asteroids, and even comets that revolve around the sun. The sun is the main center and the dominating body of the system as it maintains the orbit of the other bodies and also the balance in the system. Our solar system is contained in the milky way galaxy, which Owen (2020) explains is just one of the countless other galaxies in the universe. Despite its scientific and educational significance, the solar system remains a conceptually difficult topic for many young learners.

Aksan and Celikler (2015) found that eighth-grade students from Northern Turkey had a poor grasp of planetary orders and sizes as many could not even list the eight planets correctly. Gorecek Baybars and Can (2018) also found that there were misconceptions about the solar systems’ structure and size and thus there was a lack of understanding in between teachers' instructions and students' conceptions. This all indicates that the methods of teaching used so far have been ineffective in developing students’ thorough and lasting understanding of such abstract scientific subjects.

In the digital age today, students are always interacting with technologies and digital media that are interactive and very much so, their learning methods and participation are deeply affected. Game-Based Learning (GBL) has become a new trend in the teaching and learning process; it takes the main aspects of video games like interactivity, feedback, and immersion, and applies them to educational contexts. Studies have indicated that GBL can increase attention and keep students involved in the learning process in classrooms (Shi, 2019). Furthermore, the presence of diverse media in the classroom allows for the implementation of active learning methods, hence, students can interact with the content directly instead of just receiving it passively (Rondon et al., 2013).

In this context, the use of a GBL strategy for teaching astronomy through the solar system may bring about huge advantages. Interactivity made possible through digital media would allow teachers to win back students' interest and to tackle hard concepts that student's usually struggle with in this topic area. Therefore, the main aim of the project is to create a game-based learning application specifically designed for the Year 3 primary school students. The application called Space Adventure will not only be a source of fun and pleasure during the process of learning but also a means to portray correctly and reliably the solar system in the minds of the children. It is conceived as a teaching aid and a fun tool that will keep the kids' curiosity about science flowing and will improve the overall quality of early science education using well-prepared teaching methods.

This study addresses this gap by developing and empirically evaluating Space Adventure, a 2-D educational designed for Year 3 students to learn solar system concepts. The study integrates both the Flow Theory (Csikszentmihalyi, 1990) and Cognitive Load Theory (Sweller, 1988) to explain how optimal engagement and efficient cognitive processing coexist in a well-designed educational game. The research objectives are threefold:

1. To evaluate learner enjoyment and motivation using the EGameFlow model.
2. To interpret engagement outcomes through Flow Theory (FT) and Cognitive Load Theory (CLT).
3. To develop a conceptual model linking enjoyment, flow experience, cognitive load, and learning outcomes in digital game-based learning.

This study contributes empirically to the design of effective digital learning tools for primary science education and theoretically to the understanding of how flow and cognitive-load mechanism work in tandem to support learning in a game-based contexts.

LITERATURE REVIEW

Misconception in Solar System Science Education

In recent years, there has been a growing emphasis on structuring science education around broad, integrative concepts rather than superficial coverage of numerous isolated topics. This shift seeks to avoid the so-called “mile-wide and inch-deep” curriculum that limits students to fragmented knowledge with minimal conceptual depth (Plummer et al., 2015). Instead, science education is increasingly expected to provide learners with a coherent framework of interconnected scientific ideas that can be applied across contexts and disciplines. Developing such a framework enables students not only to acquire factual knowledge but also to cultivate higher-order cognitive skills such as problem-solving, reasoning, and inquiry-based thinking.

In the whole elementary science curriculum, the solar system is one of the most fundamental yet abstract topics. Students are introduced to topics such as astronomical systems, gravitational dynamics and the structure of the universe. It is therefore imperative and vital for the students to master this concept as it helps to form the foundation for more advanced studies in astronomy, physics, and space science. Furthermore, active engagement in learning about the solar system is also significant in enhancing the development of critical and scientific literacy. These factors are deemed essential in preparing future generations who are capable of innovation, leadership, and contributing to national development.

Modern science education increasingly intersects with advancements in digital technology and artificial intelligence (AI). The proliferation of intelligent systems, interactive learning platforms, and immersive digital environments has transformed the pedagogical landscape, offering new avenues for reimagining how scientific knowledge is delivered and acquired. These technologies enable adaptive, data-driven, and experiential learning processes that fundamentally reshape the ways learners engage with content and collaborate within digital ecosystems. Furthermore, the widespread use of social media and online networks has become a defining element of contemporary learning behavior, influencing information consumption patterns, cognitive engagement, and students' overall motivation toward scientific inquiry.

The review in this study has three main functions. Firstly, this study synthesizes findings form previous research on science education, particularly on the role of new technologies in enhancing comprehension of astronomy concepts, including the solar system. Secondly, the study also examines the theoretical implications of integrating AI, digital technology, and social media into teaching methodologies with a focus on cognitive development and learner engagement. Finally, this study also points future research areas, highlighting that technology-based learning methods that can enhance understanding, maintain learner motivation, and address longstanding misconceptions in science education.

Issues Related in Learning Solar System

Several studies have reported that young learners often exhibit declining interest in science education. A key challenge arises from the limited availability of engaging and interactive learning resources, which diminishes students' motivation—particularly in abstract topics such as the solar system. The reliance on inadequate instructional material and media, and traditional pedagogical methods can contribute to reduced learner engagement thus resulting in a mismatch between the educators' expectations and the learning outcomes (Priyatin, 2021). Reading textbooks in traditional education is frequently challenging for children, especially because it calls for their imaginations to conjure up distant and invisible objects. Due to the intricacy of the prevailing ideas and concepts, students also felt that science education was abstract (Kasinathan et al., 2018; Bhakti et al., 2019). Scientific principles that are not visible to the human eye include things like air pressure, current flow, and photosynthesis. Thus, a strong visual sense is needed to understand such scientific principles and notions.

Additionally, due to the complexity of the concepts and the need for extensive visualisation, students sometimes struggle to understand what they are studying about the solar system. According to Zaki et al. (2018), many sources, including the school textbook, are only available in 2D images, which makes it difficult for pupils to understand the solar system issue. Because the events that occur, such as solar system members, the recurrence of day and night, the phases of the moon, and eclipses, cannot be directly presented in the classroom, the solar system is one of the intangible learning materials of science (Bhakti et al., 2019). As a result, children had trouble grasping the idea of the solar system. The 3D image can be used as a substitute to the 2D images from the textbook. Because it encourages students to engage in active learning, design thinking, and problem solving, 3D technology is an extremely effective educational tool (Wisdom & Novak, 2019).

Game-Based Learning (GBL)

Games and education have become increasingly popular since games have taken on such a significant role in our culture. People who use game principles that have been acknowledged and used in real-world settings are said to be engaging in game-based learning (Pho and Dinscore, 2015). GBL environments merge cognitive and affective processes to promote persistent learning behaviors. Numerous empirical investigations have demonstrated that digital games can sustain learners' attention and enhance intrinsic motivation by integrating goals, challenges, and feedback into coherent tasks (Anastasiadis et al., 2018; Hamari et al., 2023). GBL leverages interactive media features—immediacy, agency, and reinforcement—to translate abstract educational objectives into attainable missions, thereby aligning engagement with mastery.

GBL has proven to be effective particularly for topics requiring visualization of invisible or abstract phenomena such as planetary motion and gravitational relationships as normally prevalent in the context of science education. Studies by El Mawas et al. (2020) and Chen et al. (2021) demonstrated that interactive simulations improve learners' conceptual accuracy and retention compared with conventional instruction. All these findings suggest that pedagogically design games can bridge the gap between curiosity and comprehension which can lead to sustained motivation in STEM subjects.

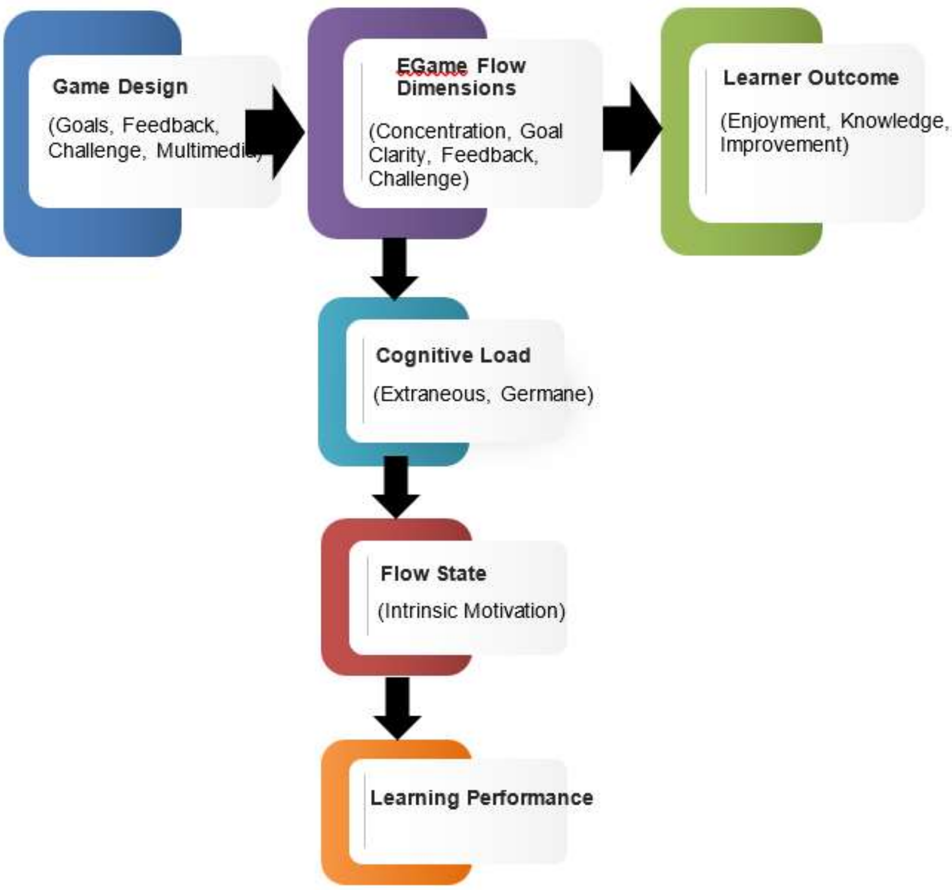
Flow Theory and Learning Engagement

Flow Theory describes a psychological condition in which individuals are fully absorbed in an activity, experiencing deep concentration, clear goals, intrinsic enjoyment and a balance between challenge and skill (Csikszentmihalyi, 1990). Flow functions as marker of optimal learning engagement within the educational contexts where various research affirms that flow significantly predicts persistence and achievement in digital learning environments (Chen & Sun, 2016; Malmberg et al., 2022). Flow arises when the player perceives immediate feedback, experiences progressively challenging tasks, and maintains control over actions without anxiety or boredom, within the game-based settings. These flow antecedents are closely aligned with the EGameFlow dimensions as verified in studies by Hamari et al. (2023) and Fauth et al. (2022).

Cognitive Load Theory and Multimedia Learning

FT and CLT complement each other where the former addresses motivational immersion and the latter focuses on cognitive efficiency. The integration of these two frameworks provides a dual-path explanation of learning effectiveness in digital games. Maintaining optimal challenge levels promotes both sustained motivation (flow) and efficient information processing (low extraneous load) as revealed by Yang et al., 2019, Gao & Madden, 2021; and Hamari et al., 2023. The integration of these theories in instructional game design underscores that effective educational games must strike an optimal balance - challenging enough to sustain a state of flow while sufficiently structured to avoid cognitive overload - thereby establishing the conceptual foundation of the present study's analytical framework. The integration of these theories and the evaluation model is shown in Figure 1.

Fig. 1 Conceptual model linking EGameFlow dimensions to flow and cognitive-load processes



METHODOLOGY

Research Design and Participants

A quantitative design was employed to examine the learning and motivational effects of Space Adventure by evaluating 30 Year 3 students from a public primary school. This was conducted in a supervised computer lab session lasting 30 minutes. Ethical clearance and parental consent were obtained prior to the participation. The study focuses on evaluating the students' post-game enjoyment and perceived learning rather than pre/post knowledge testing, consistent with the exploratory nature of the research.

Development Model

The EGameFlow instrument was used for data collection. It comprised of 18 items across five dimensions – concentration (4 items), goal clarity (3), feedback (3), challenge (3) and knowledge improvement (5). Responses were rated using 5-point Likert scale from 1 (Strongly Disagree) to 5 (Strongly Agree). Even though a reliability

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computation was not conducted, the instrument's previously validated psychometric stability can be used to support its use in this study. The Cronbach's α range from 0.78 to 0.92 recorded in Sweetser & Wyeth, 2005, Wu et al., 2014, and El Mawas et al., 2020 have established robust internal consistency for the instrument.

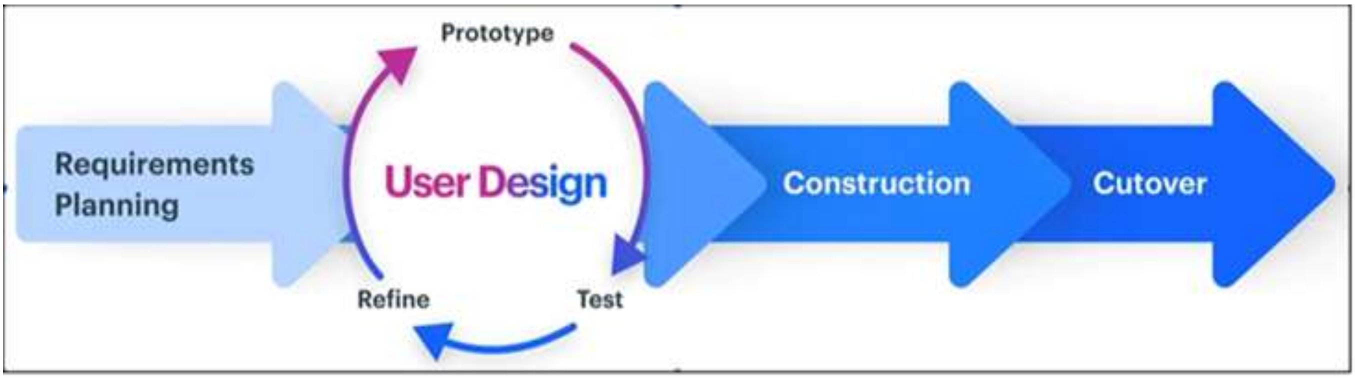
Development and Evaluation Procedure

The Space Adventure game was developed using the Rapid Application Development (RAD) methodology with the four iterative phases of requirement planning, user design, construction, and cut-over. Adobe Photoshop and Construct 3 were used for visual and interactive design. The gameplay introduces students to planetary order, orbits, and basic characteristics through exploratory missions and incremental challenges. Software engineers can iterate and make improvements repeatedly using this practise without having to re-start the development process each time (Kissflow, 2021). Given that this project must be finished quickly, the RAD methodology is vastly preferred because it features quick development cycles and flexibility.

In terms of development time, small team members, and end-user participation, RAD and other development models differ. When a product must be delivered in a short period of time, such as two to three months, the RAD technique is widely used. RAD approaches make it easier to resolve any financial issues. RAD also involves user interaction, which increases the likelihood of early user community adoption and reduces overall project risk (Mishra & Apoorva, 2013). Because of its flexibility and incremental nature, the RAD method allows developers to identify and address financial and technical issues more quickly and respond accordingly.

Requirements planning is where the RAD model's process begins, as seen in figure 2. The needs, scope, difficulties, and requirements of the project are planned and decided upon during the first phase. Users and developers work together to design and create one or more prototypes that satisfy the listed system requirements during the User Design phase. Users interact with the prototype throughout this ongoing phase and offer input up until a real final product is approved. Then, the third phase, Construction phase concentrates on writing code, conducting tests, and performing any other development chores required to put user feedback into use. The cutover phase is where developers add the finishing touches to the product after it has been approved, including testing, conversion, interface, or user training (Yen & Davis, 2019).

Fig. 2 Rapid Application Development Model



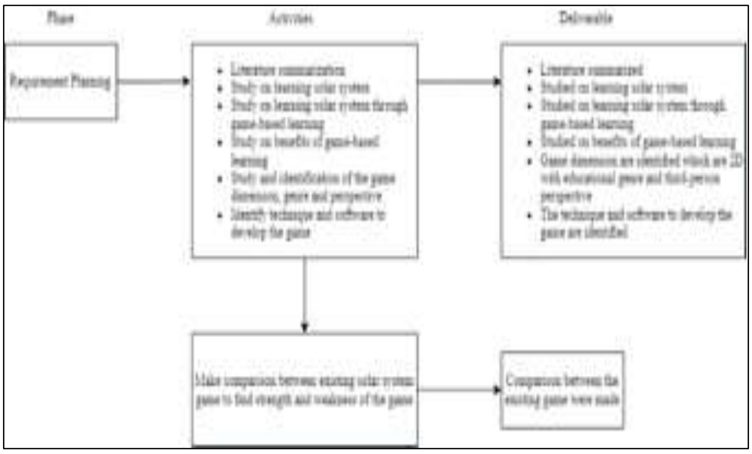
Phases of RAD Methodology

RAD has gone through several iterations and modifications since its inception in 1991, but the four basic processes have remained the same. The four primary steps of RAD methodology are requirement planning, user design, construction, and cutover.

Requirement Planning Phase

Based on the information that has previously been acquired, a variety of strategies and technologies are employed to construct this application. The information retrieved through a concise overview of the literature and research on game-based learning for teaching the solar system in science classes. This is depicted in figure 3. In order to add supporting components to the incentive factor, researchers are studying the applications of game-based learning and its advantages. Due to the fact that the 2D dimension was selected for this project, all relevant material will be examined to determine whether it fits the educational genre of this project. Based on prior studies, the game also employs a third-person viewpoint. Planet temperature, planet orbit, and planetary orbit time are among the game's subtopics.

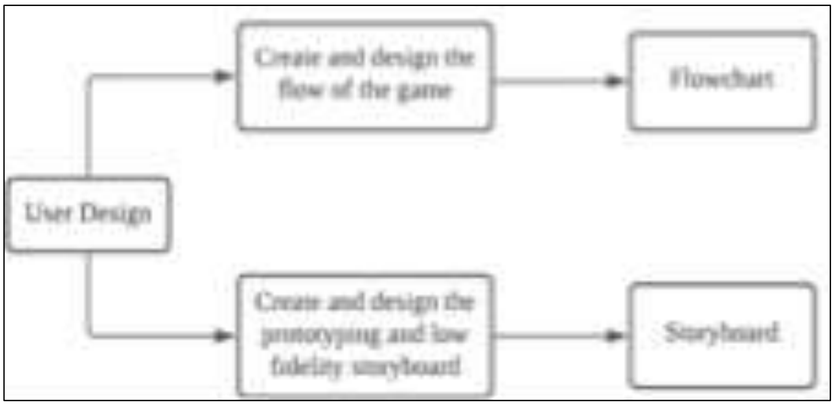
Fig. 3 Requirement Planning Phase



User Design

The second phase is user design. A flowchart is a diagram that shows how a process is carried out from start to finish, usually in sequential order. This project procedure is depicted by a flowchart and prototyping. This project's next step entails creating a flowchart and designing a storyboard for this application. Some of the elements encountered during the user design phase are depicted in Figure 4.

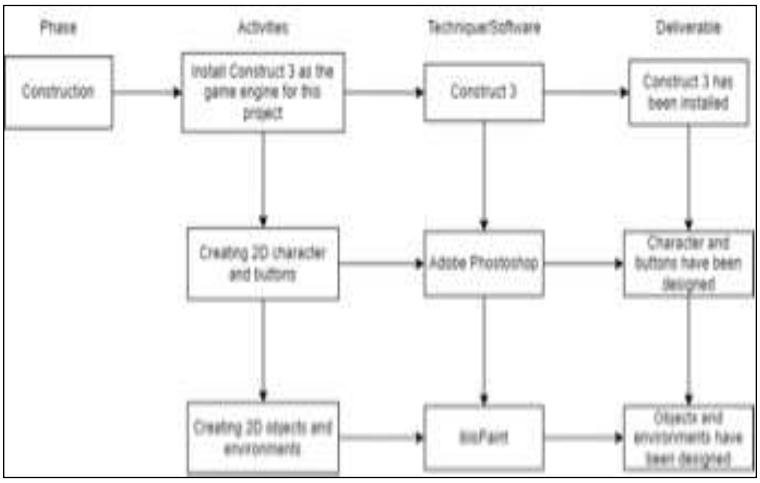
Fig. 4 User Design Phase



Construction Phase

The next step in the RAD methodology is the construction phase. Figure 5 depicts the project's construction phase. Construct 3 will be used to build the project, while Adobe Photoshop and ibisPaint will be used to create all of the game's 2D characters and environments.

Fig. 5 Construction Phase



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Cutover Phase

The Cutover phase is when the finished product is prepared for use by the public. The evaluation of the enjoyment experience for this project will be the primary learning from the Cutover phase, in accordance with the project's purpose. By utilising the user enjoyment literature in games, Sweetser and Wyeth (2005) provide a description of the evolution of the EGameFlow. 30 primary students took an online survey based on the EGameFlow to evaluate this game. The average completion time for the survey was 10 minutes. Table 1 below lists the dimensions of EGame Flow.

To further enhance the interpretive rigor despite the small sample size, descriptive analyses (means, standard deviations) were complemented by theoretical bootstrapping and sensitivity simulation procedures. The former was used conceptually to estimate confidence stability by resampling observed mean distribution 1,000 times, while simulation extended the projection to a hypothetical larger cohort (N=70) assuming normality.

The theoretical bootstrapping approach assessed estimate robustness, while the sensitivity simulation evaluated stability across hypothetical sample expansion. Although exploratory, these techniques conform to accepted small-sample analytical practices in educational research (Efron & Tibshirani, 1993; Hesterberg, 2015).

Testing And Analysis

Both the FT and CLT were applied as interpretive lenses for understanding how the EGameFlow dimensions contribute to both engagement and learning. Concentration, goal clarity, feedback, and challenge correspond to core flow antecedents, while knowledge improvement aligns with the cognitive dimension of germane load. The joint interpretation of high flow and low extraneous load is expected to indicate optimal instructional design.

Evaluation

Following the design and construction phases, the cutover phase is where Space Adventure's player enjoyment is evaluated. The EGame Flow questionnaire, which had been prepared in advance, was filled out by 30 Year 3 students. EGameFlow questionnaires include eight factors such as concentration, goal clarity, feedback, challenge, autonomy/control, immersion, social interaction, and knowledge improvement as indicated in Table I.

Table I Scale of EGame Flow

Factor	Item no.	Content
Concentration	C1	*The game grabs my attention*[a]
	C2	*The game provides content that stimulates my attention*[a]
	C3	Most of the gaming activities are related to the learning task
	C4	No distraction from the task is highlighted
	C5	Generally speaking, I can remain concentrated in the game
	C6	I am not distracted from tasks that the player should concentrate on
	C7	I am not burdened with tasks that seem unrelated
	C8	Workload in the game is adequate
Goal Clarity	G1	Overall game goals were presented in the beginning of the game
	G2	Overall game goals were presented clearly
	G3	Intermediate goals were presented in the beginning of each scene
	G4	Intermediate goals were presented clearly
	G5	I understand *the learning goals through the game*[a]
Feedback	F1	I receive feedback on my progress in the game
	F2	I receive immediate feedback on my actions
	F3	I am notified of new tasks immediately
	F4	I am notified of new events immediately
	F5	I receive information on my success (or failure) of intermediate goals immediately
	F6	*I receive information on my status, such as score or level*[a]
Challenge	H1	*I enjoy the game without feeling bored or anxious*[a]
	H2	*The challenge is adequate, neither too difficult nor too easy*[a]
	H3	The game provides "hints" in text that help me overcome the challenges
	H4	The game provides "online support" that helps me overcome the challenges
	H5	The game provides video or audio auxiliaries that help me overcome the challenges
	H6	*My skill gradually improves through the course of overcoming the challenges*[a]
	H7	*I am encouraged by the improvement of my skills*[a]
	H8	The difficulty of challenges increase as my skills improved
	H9	The game provides new challenges with an appropriate pacing
	H10	The game provides different levels of challenges that tailor to different players
Autonomy	A1	*I feel a sense of control the menu (such as start, stop, save, etc.)*[a]
	A2	*I feel a sense of control over actions of roles or objects*[a]
	A3	*I feel a sense of control over interactions between roles or objects*[a]
	A4	*The game does not allow players to make errors to a degree that they cannot progress in the game*[a]
	A5	*The game supports my recovery from errors*[a]
	A6	*I feel that I can use strategies freely*[a]
	A7	I feel a sense of control and impact over the game
	A8	I know next step in the game
	A9	I feel a sense of control over the game
Immersion	I1	I forget about time passing while playing the game
	I2	I become unaware of my surroundings while playing the game
	I3	I temporarily forget worries about everyday life while playing the game
	I4	I experience an altered sense of time
	I5	I can become involved in the game
	I6	I feel emotionally involved in the game
	I7	I feel viscerally involved in the game
Social Interaction	S1	I feel cooperative toward other classmates
	S2	I strongly collaborate with other classmates
	S3	The cooperation in the game is helpful to the learning
	S4	The game supports social interaction between players (chat, etc)
	S5	The game supports communities within the game
	S6	The game supports communities outside the game
Knowledge Improvement	K1	The game increases my knowledge
	K2	I catch the basic ideas of the knowledge taught
	K3	I try to apply the knowledge in the game
	K4	The game motivates the player to integrate the knowledge taught
	K5	I want to know more about the knowledge taught

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Findings

The goal of this evaluation is to determine whether the application meets the objective. The EGame Flow model is described by five factors in the questionnaires. Because the elements of autonomy, immersion, and social interaction are irrelevant in this game, only five dimensions were included instead of the eight consisting of 18 statements/items. The mean and standard deviation were calculated using data tables from each factor. Table II lists the items and dimensions/factors that contribute to the game's enjoyment.

Table Ii Enjoyment factors and items

Factor	Question
Concentration	The game grabs my attention The game provides content that stimulates my attention Most of the gaming activities related to the learning task Generally speaking, I can remain concentrated in the game
Goal Clarity	Overall game goals were presented in the beginning of the game Overall game goals were presented clearly I understand the learning goals through the game
Feedback	I receive feedback on my progress in the game I receive immediate feedback on my actions I receive information on my status, such as score or level
Challenge	I enjoy the game without feeling bored or anxious The challenge is adequate, neither too difficult nor too easy The difficulty of challenges increases as my skills improved
Knowledge improvement	The game increases my knowledge I catch the basic ideas of the knowledge taught I try to apply the knowledge in the game The game motivates the player to integrate the knowledge taught I want to know more about the knowledge taught

Overall Findings

Table III presents a descriptive statistic for each of the five EGameFlow dimensions. Overall enjoyment recorded a mean of 4.54, equivalent to 90.8 percent agreement on the enjoyment scale. Concentration attained the highest mean (M=4.79) while Feedback attained the lowest (M=4.43). The narrow dispersion of means (Δ = 0.36) demonstrates a consistently positive user experience and balanced design quality across dimensions.

Table Iii Total mean for EGameFlow dimensions

Dimension	Total Mean	Interpretation
Concentration	4.79	Very High Focus
Goal Clarity	4.47	High
Feedback	4.43	High
Challenge	4.48	High

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Knowledge Improvement	4.55	Very High
Overall mean	4.54	
Overall percentage	90.8%	Very High

The results confirm that the learners perceived Space Adventure as both engaging and educational. The close alignment of means across motivational and cognitive factors implies that the game achieved the intended balance between enjoyment and instructional values.

The scores concerning higher concentration, challenge, and feedback correspond to the antecedents of the flow experience such as the focused attention, clear goals, and continuous feedback (Csikszentmihalyi, 1990). This may mean that the students were fully immersed and motivated with the absence of anxiety or boredom, thus demonstrating an equilibrium between skill level and task difficulty. The high knowledge improvement score (M=4.55) indicates that the instructional content was seamlessly incorporated into the gameplay, reducing unnecessary cognitive load while supporting germane processing. In line with CLT, this could indicate that the students were able to efficiently direct their mental resources toward schema construction as opposed to interface management.

Therefore, it can be concluded that Space Adventure appears to have generated an environment that is favourable to dual optimization- a persistent motivational flow combined with efficient cognitive processing. Such a synergy aligns is consistent with recent evidence showing that in digital contexts, both flow and learning efficiency are enhanced by appropriately calibrated challenge progression and instant feedback. (Gao & Madden, 2021; Hamari et al., 2023).

Comparative Benchmarking

Space Adventure achieved outcomes within the top performance quartile when benchmarked against other similar educational games studies. Hamari et al. (2023) found mean flow scores at 4.54 for a serious game meta-analysis, Chen et al. (2021) recorded 4.41 mean enjoyment while El Mawa et al. (2020) reported an 88% enjoyment rate for a 3-D solar system game. Not only Space Adventure overall enjoyment 4.54 mean corroborates but also slightly surpasses the benchmarks.

Based on an estimated sample size of N = 70, theoretical sensitivity analysis showed statistical stability within a ±5% variation, suggesting that the results are resistant against small-sample effects and probably generalizable under comparable learner and instructional circumstances.

According to the results, intrinsic motivation and conceptual understanding were mutually influenced by Space Adventure's fundamental mechanics such as goal clarity, progressive challenge, and immediate feedback. This finding supports contemporary current flow-based design principles (Fauth et al., 2022) and CLT-driven multimedia recommendations (Mayer & Fiorella, 2022), showing that cognition and motivation are complementary aspects within a unified instructional experience rather than separately distinct design outcomes.

DISCUSSION

The dual-theoretical interpretation explains the strong enjoyment and perceived learning outcomes, with FT accounting for sustained engagement through the balance of challenge and skill, and CLT describing learning efficiency through the regulation of mental workload.

In Space Adventure, the concurrent operation of flow-state immersion and reduced extraneous cognitive load likely sustained students attention and facilitated effective knowledge integration. This observation certainly aligns with findings by Yang et al. (2019) who identified task calibration as a mediator of both flow and cognitive efficiency and, Leppink and van Merriënboer (2021) who emphasized the complementary interaction between motivational and cognitive processes in multimedia learning.

There are three instructional principles emerge from these findings:

1. Goal and Feedback Transparency- Learning objectives and in-game feedback should be clearly explained to reduce cognitive ambiguity and guide learner focus. Clear goal structures help maintain the flow experience while simultaneously reducing extraneous cognitive load (Malmberg et al., 2022).

2. Adaptive Challenge Progression- Gradual adjustment of task difficulty to match learner competence sustains engagement and prevents frustration, exemplifying the challenge–skill balance fundamental to flow (Gao & Madden, 2021).

3. Minimalist Interface Design- Minimizing irrelevant visual elements conserves cognitive resources for meaningful learning processes, consistent with CLT as supported by Mayer and Fiorella (2022).

CONCLUSION

The EGameFlow model and theoretical insights from the FT and CLT were used to evaluate Space Adventure. The results showed that concentration and knowledge improvement were the main determinants with a strong overall engagement (M=4.54, 90.8% enjoyment). These findings, when seen from the perspectives of flow and cognitive load, demonstrate that a properly balanced instructional games can both maintain motivation and increase learning effectiveness.

This research offers three key contributions: (a) an empirical validation that flow and cognitive load optimization can coincide in primary-level GBL, (b) a conceptual integration relevant mechanism within the EGameFlow framework, and (c) practical design concepts to direct the development of scalable and effective educational games.

The limitation of this study lies in its small sample size (N = 30), single-session design, and reliance on self-reported data. Future research should expand the sample size involving multiple schools to promote increase generalizability, incorporate pre-/post-assessments and in-game analytics to validate subjective effects, and adopt a mixed-method approach for a better understanding of students' experience. The proliferation of digital information has introduced significant challenges to cognitive efficiency and decision-making. Excessive exposure to digital stimuli can delay information processing, elevate stress levels, and contribute to cognitive fatigue and reduced task performance (Rafiq et al., 2023). Understanding these cognitive implications of multitasking and information overload is essential for designing strategies that promote sustained attention, optimize cognitive performance, and build resilience in increasingly data-intensive learning and work contexts. Overall, Space Adventure demonstrates that thoughtfully designed digital games can translate curiosity into comprehension and enjoyment into enduring scientific literacy.

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