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Developing a Serious Game for Enhancing Student Problem-Solving: A Three-Layers Effectiveness Model

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Abstract:	In recent years, serious games have gained popularity among diverse audiences. These games offer an interactive platform for entertainment while also enhancing soft or subject-matter skills. Recognising the importance of problem-solving skills as well as serious games, especially for undergraduate students, this research paper outlines a three-phased study. Phase I involved semi-structured interviews with psychologists, educational scientists, and soft skills trainers to identify strategies for improving students' problem-solving abilities. In Phase II, a narrative serious game was designed and developed based on Mezirow's transformational learning theory. Finally, Phase III evaluated the game's effectiveness and usability among a sample of undergraduate students. High satisfactory scores received both on "Game Experience Questionnaire" and the "System Usability Scale". Reflecting on those high scores and the design and development process of this game, a three-layers model is developed, highlighting the three main factors affecting the effectiveness of serious games. The study's findings have both theoretical and practical implications.
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21st Oct 2024

Editor-in-Chief

Computers & Education: X Reality

Dear Editor-in-Chief,

I am pleased to submit our manuscript, entitled *"Developing a Serious Game for Enhancing Student Problem-Solving: A Three-Layers Effectiveness Model"*, for consideration in Computers & Education: X Reality. This paper explores the design, development, and evaluation of a serious game aimed at improving students' problem-solving skills through a pedagogically grounded approach. We believe this study aligns well with your journal's focus on innovative educational technology and its impact on learning.

Highlights of the paper:

Strong Pedagogical Design: Our study provides a robust example of serious game design led by pedagogical experts. The paper offers a balanced reflection on both the successes and challenges faced throughout the development process, providing valuable insights into serious game creation.

Foundational Pedagogical Theory: A key strength of this work is the integration of a foundational pedagogical theory that underpins the design. This approach demonstrates the benefits of embedding such a theory into the design of serious games, enhancing the educational value of the game.

Strategies for Game Mechanics Development: We propose several pedagogically sound strategies to guide the development of game mechanics, accompanied by a thorough discussion of the associated challenges and successes. These insights can serve as a practical guide for educators and game designers aiming to create effective educational tools.

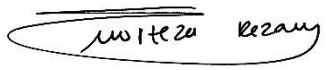
We believe our paper contributes to the growing body of research on serious games, particularly by offering a detailed examination of the Three-Layers Effectiveness Model in supporting problem-solving skill development. The challenges and recommendations discussed may help inform future educational game design.

We confirm that this manuscript is original, has not been published previously, and is not under consideration for publication elsewhere. All authors have approved the manuscript, and there are no conflicts of interest to declare. We look forward to your consideration and would be happy to address any questions or clarifications you may have.

Thank you for considering our submission to Computers & Education: X Reality.

Yours sincerely,

Dr Morteza Rezaei-Zadeh



July 03rd 2024

Re: Declaration of Interest Statement, Paper titled: Developing a Serious Game for Enhancing Student Problem-Solving: A Three-Layers Effectiveness Model

Heliyon Journal,

Dear Sir / Madam,

On behalf of the writers of the paper above, I am writing to declare that there is no financial or other interests related to the paper that (1) could affect or have the perception of affecting the author's objectivity, or (2) could influence or have the perception of influencing the content of the article.

Please let me know if further information is required.

Best Regards,

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Developing a Serious Game for Enhancing Student Problem-Solving: A Three-Layers Effectiveness Model

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Developing a Serious Game for Enhancing Student Problem-Solving: A Three-Layers Effectiveness Model

Abstract

In recent years, serious games have gained popularity among diverse audiences. These games offer an interactive platform for entertainment while also enhancing soft or subject-matter skills. Recognising the importance of problem-solving skills as well as serious games, especially for undergraduate students, this research paper outlines a three-phased study. Phase I involved semi-structured interviews with psychologists, educational scientists, and soft skills trainers to identify strategies for improving students' problem-solving abilities. In Phase II, a narrative serious game was designed and developed based on Mezirow's transformational learning theory. Finally, Phase III evaluated the game's effectiveness and usability among a sample of undergraduate students. High satisfactory scores received both on "Game Experience Questionnaire" and the "System Usability Scale". Reflecting on those high scores and the design and development process of this game, a three-layers model is developed, highlighting the three main factors affecting the effectiveness of serious games. The study's findings have both theoretical and practical implications.

Keywords: Serious Game, Problem Solving, Transformative learning, Game Design and Development.

Introduction

Problem-solving is a vital soft skill highlighted by the World Health Organization. It encompasses identifying issues, understanding root causes, finding solutions, and preventing

complications (Chan & Wu, 2007). Numerous studies emphasize the need for collaborative problem-solving in today's societies (OECD, 2017). However, conventional problem-solving approaches taught in schools often follow rigid formulas, limiting learners' ability to tackle novel problems (Jonassen, Marra & Palmer, 2004). Digital games, when thoughtfully designed, can significantly enhance problem-solving skills (Van Eck, 2006 & Shute, Wang, Greiff, Zhao & Moore, 2016). Such games present complex objectives and scenarios, compelling players to acquire new knowledge and skills to progress (Shute et al., 2016).

Serious Games, as highlighted by Arnab et al. (2015) distinguish themselves by prioritising the pedagogical aspect over the entertainment focus seen in other games. These educational tools, designed for entertainment, are rooted in the transmission of knowledge and instruction. Becker (2021) notes that Serious Games, as a subset, aim to impact various facets, including behavior, attitude, health, and knowledge, achieving a meaningful coexistence of entertainment and learning.

Due to the fact that learners, in the process of digital games, encounter various scenarios in which they must integrate diverse information and analyze different strategies, this action leads to a greater understanding of the causal relationship between decision-making behaviours and the consequences of decisions (Ebner & Holzinger, 2007).

This research aims to enhance the problem-solving skills of students through the design and production of a serious game based on principles and theories of education.

Background and Related Works

In recent years, scattered research has been conducted on the impact of digital games on problem-solving skills. Upon reviewing the literature, it is observed that despite the importance of this skill for students, both in terms of personal life and preparation for entry into the

workforce, the number of studies conducted in this area is limited. These studies could be divided into two main groups. The first group investigated the impact of ordinary games on people's problem solving skill, while the second group tried to design and develop specific game for boosting players' problem solving skill.

Most of the previous studies placed in the first category above. For example, the results of Zhang, Yang and Li (2010) research demonstrated an increase in cognitive abilities, particularly problem-solving skills, after engaging in action video games. The findings of Sanchez and Olivares (2011) also showed an enhancement in collaboration and problem-solving skills among students who participated in mobile-based serious games. Similarly, Akçayır's 2014 study yielded similar results (Akcaoglu, 2014).

Despite the existence of such research, there has been a scarcity of studies leading to the design of games specifically aimed at enhancing problem-solving skills. To the best of knowledge of this study, there are only a few studies including Shih, Shih, Shih, Su and Chuang (2010), Monjelat, Méndez Zaballos and Lacasa (2012), Sanchez and Olivares (2011), and Hwang, Wu and Chen (2012) who tried to design specific serious games for fostering problem solving skill in their players. However, these studies also struggle with some deficiencies, like: 1- failure to engage college students, 2- lack of educational theories and frameworks, 3- minimal exploration of diverse game genres, and 4- insufficient utilisation of qualitative and mixed methods (Rezaei-Zadeh, 2023).

The current study – against the four literature gaps above - aims to design, develop, and test a serious game with the purpose of improving problem solving skills in undergraduate students.

Research methodology

As part of this research, it is aimed to design and develop a problem-solving serious game. Following the software engineering life cycle, we conducted the work in five stages: 1) Problem Identification, 2) Solution Design, 3) Solution Validation, 4) Solution Implementation, and 5) Evaluation of Implementation. Phase I of this study addressed steps 1, 2, and 3, while Phase II focused on step 4, and Phase III on step 5. The research methodology implemented in each of those three phases is elaborated in Table 1.

Table1: Research Methodology of the current study

Software Development Lifecycle	Research Question	Paradigm	Research method	Research Strategy	Participants	Sampling Method	Data Collection Tools	Data Analysis Technique	The Validity of Data
Phase I: Solution Identification	What solutions can foster students' problem-solving ability?	Interpretivism	Qualitative	Phenomenology	Experts in education, psychology, and soft skills	Purposeful sampling; Intensity sampling	Semi-Structured Interview	Colaizzi's Seven-Step Method	- "Expert Review" - "Participant Feedback"
Phase II: Product Design & Development	What processes are in a serious game to improve problem-solving?	Interpretivism	Qualitative	Focus Groups	Experts in education, psychology, and serious game		Brainstorming Method	Constant Comparative Method (CCM)	- "Expert Review" - "Participant Feedback"

Software Development Lifecycle	Research Question	Paradigm	Research method	Research Strategy	Participants	Sampling Method	Data Collection Tools	Data Analysis Technique	The Validity of Data
Phase III: Product Validation and Iteration	How do students perceive the usability and playability of the designed serious game?	Positivism	Quantitative	Survey	Undergraduate Students	Convenience Sampling	1."System Usability Scale" 2."Game Experience Questionnaire"	Descriptive and Inferential Statistics	Expert Review

Each of those three phases mentioned in Table 1 are outlined here.

Phase I: Solutions for fostering students' problem-solving skill:

Semi-structured interviews were conducted with 7 academics and 5 practitioners in the fields of education, psychology, and soft skills until data saturation was reached. The interviewees were selected using the purposive sampling method. All interviews were fully transcribed and coded using the seven-step Colaizzi's method. The codes were cross-checked by two external experts to ensure their reliability and to confirm that no concept was overlooked.

Phase II: Designing and developing a serious game for fostering students' problem-solving skill:

Two focus groups involving 15 academics and practitioners, specialised in education, psychology, and serious game design, were conducted. Their discussions were transcribed and coded using the Constant Comparative Method (CCM). The game mechanics were collaboratively conceptualised during these sessions, and Unity software was used for game development.

Phase III: Assessing the game's usability in enhancing students' problem-solving skills:

During this phase, 20 undergraduate students from Shahid Beheshti University were selected via convenience sampling. After playing the game and in order to validate and assess the game's usability, they completed two questionnaires as follows:

- **System Usability Scale**

The "System Usability Scale," developed by Brooke (1996), comprises 10 items. Conducted by end-users, this test helps identify system deficiencies and opportunities for improvement. Responses, on a Likert scale, range from completely disagree (1) to completely agree (5). The test result is a numerical value between one and a hundred, calculated using the following formula:

$$Score=((Q1-1)+(Q3-1)+(Q5-1)+(Q7-1)+(Q9-1)+(5-Q2)+(5-Q4)+(5-Q6)+(5-Q8)+(5-Q10))*2.5$$

Formula 1: The method for calculating the System Usability

The score derived from the formula indicates the level of system usability, interpreted based on Table 2.

Table 2: Interpretation of System Usability Levels

Usability Level	Score
The best possible	Greater than 85.5
Excellent	Greater than 71.4 and less than or equal to 85.5
Good	Greater than 50.9 and less than or equal to 71.4
Acceptable	Greater than 35.7 and less than or equal to 50.9

Poor	Greater than 20.3 and less than or equal to 35.7
Very bad	Greater than 12.5 and less than or equal to 20.3
The Worst Possible	Less than or equal to 12.5

- **The Game Experience Questionnaire**

The Game Experience Questionnaire, developed and validated by Ijsselsteijn at Eindhoven University, evaluates user experience during interaction with a digital game (IJsselsteijn, de Kort & Poels, 2013). It comprises statements regarding the user's experience during gameplay, capturing their feelings throughout the session. Players indicate their agreement level with each statement using a scale of five levels: (0) Not at all, (1) Very little, (2) Somewhat, (3) A lot, (4) Very much. In this study, the original questionnaire with 33 statements is employed, analysing user experience across seven dimensions (Table 3). Component scores are derived from the average scores of their respective items.

Table 3: Game Experience Questionnaire Dimensions

Dimensions	Phrases
Competence	Items: 2, 10, 15, 17, 21
Sensory and Imaginative Immersion	Items: 3, 12, 18, 19, 27, 30
Flow	Items: 5, 13, 25, 28, 31
Tension/Annoyance	Items: 22, 24, 29
Challenge	Items: 11, 23, 26, 32, 33
Negative affect	Items: 7, 8, 9, 16

Negative affect	Items: 1, 4, 6, 14, 20

Findings

The study's findings are structured into three phases corresponding to the three research questions: Phase 1: Solutions for enhancing students' problem-solving skill. Phase 2: Design and development of a serious game for fostering students' problem-solving skills. Phase 3: Evaluation of the developed game for enhancing students' problem-solving skills. Each phase is summarised below.

Phase 1: Solutions for enhancing students' problem-solving skill

In addition to conducting and analysing interviews, relevant research literature was reviewed to explore how students' problem-solving skill can be cultivated. Table 4 summarises the 15 solutions.

Table 4: Solutions for cultivating students' problem solving skill

No.	Solution	Source	
		Interview	Literature
1	Strengthening students' internal locus of control	*	
2	Teaching problem identification methods to students	*	*
3	Enhancing students' responsibility and accountability	*	
4	Having a coach	*	
5	Promoting students' positive mindset	*	*
6	Promoting solution-focused approach in students over emotion-focused approach	*	

No.	Solution	Source	
		Interview	Literature
7	Teaching out-of-box thinking to students	*	
8	Promoting students' reflective thinking	*	*
9	Helping students to learn from their mistakes and successes	*	
10	Training students about creative thinking techniques	*	*
11	Teaching lateral thinking to students	*	
12	Promoting students' collective thinking	*	
13	Helping students to recognise and rectify their cognitive errors	*	*
14	Fostering students' holistic thinking	*	
15	Training students about idea evaluation	*	*

These solutions establish the theoretical foundation for the game being designed and developed in this study. They serve three key purposes:

1- Informed Decision-Making: Guiding decisions related to the game mechanics developed in the next stage of this study.

2- Objective Alignment: Ensuring game mechanics align with the primary goal of fostering students' problem-solving skill.

3- Educational Enhancement: Elevating the educational value of the game.

In the upcoming phase, these solutions will be put into practice to design the game mechanics, aligning with the study's objective of enhancing students' problem-solving abilities.

Phase 2: Design and development of a serious game for fostering students' problem-solving skill

The game designed by the current study is a 2D educational game developed using Unity Game Engine for Android and iOS. The genre of the game is narrative adventure, and the purpose of the game is to foster students' problem solving skill.

A. Game's Characters

In the game, there are two main characters: Yasaman, the protagonist, and Almas, her diary, who serves as her coach. Yasaman is a college student facing life challenges that cause her mental distress and hinder her problem-solving abilities. She's somewhat introverted, sensitive, and prone to quick-tempered reactions. She often compares herself to others, striving for perfection, and has a competitive streak. Despite this, she is organized and enjoys reading and the arts. Almas, her diary, plays the role of a supportive coach, guiding Yasaman through her problems based on the events she records in her life.

B. Game's Theoretical Foundation

Mezirow's theory of transformative learning serves as the primary theoretical foundation for game design. The learning process consists of 10 stages (Mezirow, 2003). Initially, individuals confront a dilemma challenging their mental assumptions, where past experiences fail to provide solutions. Next, they engage in critical self-reflection, experiencing emotions like guilt or anxiety, which catalyse learning. Stage three involves critically evaluating existing evidence and assumptions, fostering rational discourse. Critical reflection is pivotal in transformative learning. In stage four, the problem is acknowledged and shared with others, who provide feedback.

Stage five involves exploring new solutions and actions for addressing the dilemma. In stage six, planning is done for implementing these solutions. Stage seven entails acquiring the necessary knowledge, skills, or resources for executing the plan. In stage eight, the individual attempts to enact new roles, actions, or solutions and re-evaluates them. Stage nine confirms the competence of the new roles and solutions. Finally, in the integration stage, the individual applies the newly gained roles and solutions to similar life problems. See Figure 1 for a summary of the transformative learning stages.

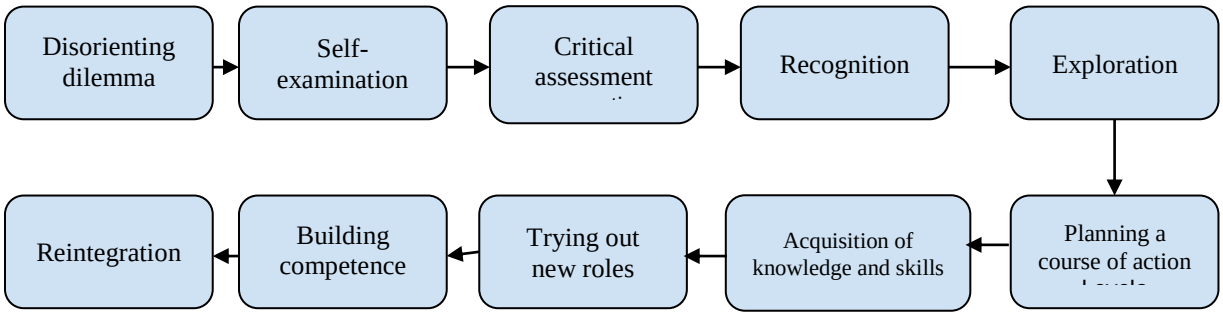

Figure 1. Ten Stages of Transformative Learning Theory

Mezirow suggests that achieving transformative learning doesn't always require going through all these stages, and they can be experienced in a random order. In the game design, the first seven phases of Mezirow's transformative learning theory have been integrated (see Table 5).

C. Game’s Narration and Levels

The game's storyline is divided into three chapters, each comprising separate scenes where events unfold. Figure 2 provides an overview flowchart of the game's structure.

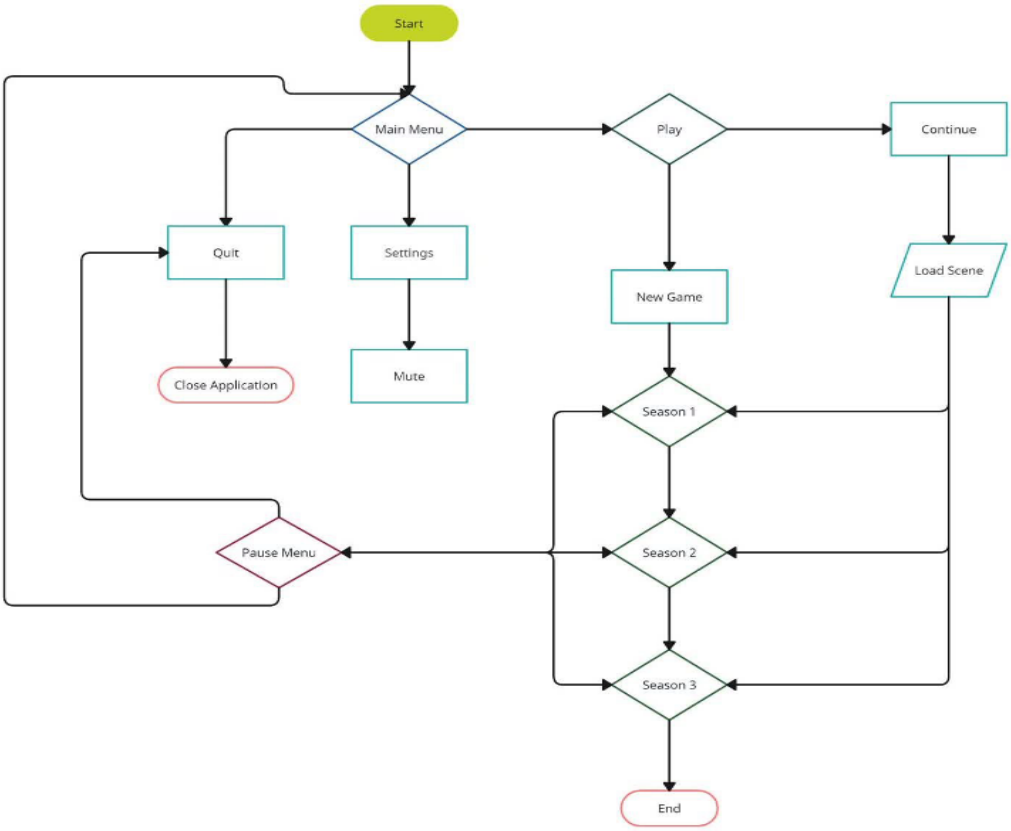

Figure 2. Flowchart of the General Structure of the Game

In line with the game's goal of teaching problem-solving principles through transformative learning theory, each chapter aligns with both the "Problem-Solving Phases" and the "Phases of Transformative Learning Theory." In the first chapter, "Winter," the character faces a problem, grapples with negative emotions, evaluates the situation, and acknowledges the problem's existence. Moving to the second chapter, "Spring," the character embarks on discovering and evaluating potential solutions to address the problem. Lastly, in the third chapter, "Summer," the character focuses on planning the implementation of chosen solutions while acquiring the necessary knowledge and skills to execute the plan effectively.

The character progresses through the phases of Mezirow's theory via in-game events through the three chapters above, which prompt conversations with the coach, interactions with others, or internal dialogues.

Simultaneously, the character faces various problem-solving challenges throughout the game's storyline. Yasaman copes with these challenges by documenting daily events in her diary each night. The diary, acting as her coach, reflects her emotions and experiences, and facilitating conversations, where Almas assists Yasaman. These conversations raise the character's awareness of the challenges, and with the coach's guidance, she comprehends and resolves them. The third component, treatments or solutions, plays a crucial role in helping the character overcome these challenges. Table 5 outlines the relationship among these three components and the arrangement of the game scenes.

Table 5: Integration of Transformative Learning Phases, Problem-solving Needs, and Solutions

Seasons	Scenes	Phases of Transformative Learning	Problem-solving Needs	Solutions
Chapter 1 (Winter - Awareness)	Scene 1	–	–	–
	Scene 2	–	–	–
	Scene 3	Phase 1 (Disorienting dilemma)	External locus of control	The Whys 5 Technique
	Scene 4	Phase 2 (Self-examination)	Weakness in controlling unpleasant emotions	The ABC Technique
	Scene 5	–	–	–
	Scene 6	–	Emulating experiences from others	The What Technique

Seasons	Scenes	Phases of Transformative Learning	Problem-solving Needs	Solutions
	Scene 7	–	–	–
	Scene 8	Phases 3 and 4 (Critical assessment and Recognition)	–	–
Chapter 2 (Spring - Effort)	Scene 1	–	–	–
	Scene 2	Phase 5 (Exploration)	Weakness in creating effective solutions	The Ideal Future Technique
			Recognizing and addressing internal and external limitations	Coach Companionship - Limitless Thinking
			Neglecting the use of tools and resources in problem-solving	Coach Companionship
			Weakness in decision-making and selecting appropriate solutions	The PMI Technique
Chapter 3 (Summer - Blossoming)	Scene 1	—	–	–
	Scene 2	Phases 6 and 7 (Critical assessment and Acquiring Knowledge and Skill)	–	–
	Scene 3	Phases 6 and 7 (Critical assessment and Acquiring Knowledge and Skill)	–	–

Phase 3: Evaluation of the developed game for enhancing students' problem-solving skill

To validate the game as part of the third step of the software design cycle (Product Validation), an assessment was carried out from the perspective of undergraduate students as the game's

target audiences. Two tools were utilised for this purpose: the "Game Experience Questionnaire" and the "System Usability Scale."

Game Experience Test Results

The Game Experience Questionnaire evaluates the player's experience across seven dimensions: Competence, Immersion, Flow, Tension, Challenge, Negative affect, and Positive affect. Results for each dimension are presented separately.

***The user's gaming experience in the dimension of "Competence"**

The dimension of "Competence" in the player's game experience answers the question of how players assess their ability and performance in the game. To address this question, a one-sample t-test was employed.

Table 6: One-Sample t-test Results in the Competence Dimension

Number	Average	Standard deviation	T-Value	Degrees of freedom	P-Value	Mean Difference
20	2.23	0.368	2.79	19	0.012	0.2300

Based on the results of the one-sample t-test, the test's significance level (0.012=Sig) is considered significant. This is because the observed mean (2.23) is greater than the theoretical mean (2). This result indicates that players' performance in playing the game is average, and the game's difficulty level is balanced. In other words, the game is neither too difficult to discourage players nor too easy to lack challenges. However, desirability does not necessarily imply excellence, and the game can be further improved in this aspect.

***The user's gaming experience in the dimension of "Immersion"**

Additionally, in the dimension of "Immersion" (Sensory and Imaginative), it illustrates how immersed players are in the game world from a sensory and imaginative perspective. To answer this question, a one-sample parametric t-test has been utilized.

Table 7: One-Sample t-test Results in the Immersion Dimension

Number	Average	Standard deviation	T-Value	Degrees of freedom	P-Value	Mean Difference
20	2.46	0.434	4.80	19	0.00	0.466

Based on the results of the one-sample t-test, the test's significance level (0.000=Sig) is considered significant. This is because the observed mean (2.46) is greater than the theoretical mean (2). This result suggests that players find the storyline and game environment enjoyable and pleasant.

***The user's gaming experience in the dimension of "Flow"**

Additionally, in the dimension of "Flow", it shows how much players have focused on the game's storyline and flow. To address this question, a one-sample parametric t-test has been used.

Table 8: One-Sample t-test Results in the Flow Dimension

Number	Average	Standard deviation	T-Value	Degrees of freedom	P-Value	Mean Difference
20	2.1	0.508	0.879	19	0.390	0.100

Based on the results of the one-sample t-test, the test's significance level (p = 0.390=Sig) is not significant. This is because the observed mean (2.1) is equal to the theoretical mean (2). This result indicates that players were relatively engaged during gameplay, but this engagement might not be as desirable as expected, suggesting there is room for improvement in the game experience.

***The user's gaming experience in the dimension of "Tension"**

The dimension of "Tension" addresses whether the game has caused discomfort or distress to the players. To answer this question, a non-parametric Binomial test has been used.

Table 9: Results of the Binomial Test in the Tension Dimension

Dimension of Gaming Experience	Category	Number	Observed Percentage	Ratio	P-Value
Tension	<=2	20	1.00	0.50	0.0
	>2	0	0		
	All	20	1.00		

The results of the Binomial test indicate a significant level of significance (000/0=Sig). This suggests that most users selected the options "never" or "rarely" in response to questions related to this dimension. Because they chose these two options, their ratio fell into the smaller or equal to 2 categories, indicating that their level of experience was less than average. Consequently,

considering the ratio being less than or equal to 2, players have not experienced significant stress, and their stress level during the game has been below average.

***The user experience in the dimension of "challenge"**

The dimension of "challenge" indicates the player's perception of the challenges presented to them and their level of difficulty or ease. To assess this dimension, a parametric one-sample t-test was employed.

Table 10: Results of the One-Sample t-test in the Challenge Dimension

Number	Average	Standard deviation	T-Value	Degrees of freedom	P-Value	Mean Difference
20	0.960	0.358	-12.95	19	0.00	-1.04

Based on the results of the one-sample t-test, the test's significance level (000/0=Sig) has been established. This outcome indicates that the game was not particularly challenging for the players, and their level of challenge during the game was below average. This experience is not desirable since the presence of challenges is one of the fundamental elements of games. Therefore, it would be better for the game to be more challenging for the players and to enhance the level of challenge in this dimension.

***User gaming experience in the dimension of "Negative affect"**

The "Negative Affect" dimension reflects the negative feelings or perceptions that players have about the game. As shown in Table 11, this dimension was evaluated using a non-parametric Binomial test.

Table 11: Results of the Non-Parametric Binomial Test in the Negative Affect Dimension

Dimension of Gaming Experience	Category	Number	Observed Percentage	Ratio	P-Value
Tension	<=2	20	1.00	0.50	0.0
	>2	0	0		
	All	20	1.00		

The results of the Binomial test confirmed a significance level of p=0.000. Given that the ratio is less than 2, it can be inferred that the game did not negatively impact the players. The negative impact on their experience was significantly below average, which is a desirable outcome.

***The user's gaming experience in the "Positive Affect" dimension**

The "Positive Affect" dimension reflects the positive and pleasant feelings that players have towards the game. As shown in Table 14, this dimension was evaluated using a parametric one-sample t-test.

Table 12: Results of the One-Sample t-test in the Positive Affect Dimension

Number	Average	Standard deviation	T-Value	Degrees of freedom	P-Value	Mean Difference
20	2.1	0.431	1.76	19	0.94	0.170

The one-sample t-test results indicate a significance level of p=0.094, which is not statistically significant, as the observed mean (2.1) equals the theoretical mean (2). A score of 2 suggests a relatively favourable perception of the positive impact dimension in users' gaming experience. This indicates that players experienced a positive impact and had good feelings during gameplay. However, there is still room for improvement in the game.

Results of the game usability test

To evaluate the game's usability from the users' perspective, students completed the System Usability Scale (SUS) questionnaire. This scale measures the usability or ease of use of a system. The game's usability level is then interpreted based on the results of this test.

Table 13: Scores of Each User in the System Usability Test

Sample	Test Score	Sample	Test Score
One	77.5	Eleven	62.5
Two	50	Twelve	80
Three	82.5	Thirteen	80
Four	60	Fourteen	75
Five	77.5	Fifteen	72.5
Six	82.5	Sixteen	67.5
Seven	80	Seventeen	67.5
Eight	70	Eighteen	87.5
Nine	75	Nineteen	82.5
Ten	80	Twenty	85

Sample	Test Score	Sample	Test Score
Total 74.75			

As depicted in Table 15, the overall score obtained from the system usability test is 74.75, which, based on the scoring guidelines, falls within the "Excellent" range. Consequently, the usability level of the designed game in this study has been assessed as excellent.

Conclusion

The current study first explores 15 theoretical solutions for boosting students' problem-solving ability. Then, those theoretical solutions alongside Meziro's Transformative Learning theory were used to design and develop a serious game for helping students to be better problem-solvers. Developing the game as a product of this study differs it from most of the previous studies in this area. Most of the serious game studies focused on the theoretical aspects of these games and explored the 'potential' impacts Most of the serious game studies focused on the theoretical aspects of these games and explored the 'potential' impacts (Papanastasiou, Drigas & Skianis, 2017), applications (Ma, Oikonomou & Jain, 2011) and considerations (DaCosta & Kinsell, 2022) of these games. But the current study goes further and developed an 'actual' serious game. This product-based perspective in the serious game studies is necessary for exploring the 'actual' impacts, applications, and considerations of these games. applications (Ma et al., 2011), and considerations (DaCosta and Kinsell, 2022) of these games.

Finally, the "Game Experience Questionnaire" and the "System Usability Scale" were used to assess the effectiveness and ease of use of the game. Overall, the game received very satisfactory scores in all dimensions of the two tests above. This huge success of being highly evaluated by the game players triggers an important question of 'why this game is very well received by its

players?' Looking more closely at the design and development process of the game, we have three potential responses to this important question.

First, the design and development of this game is supported by a theory. The game targets students' problem-solving ability. Therefore, it's important having a theoretical framework which is in line with this target. Transformative learning is a learning theory which mentions that learning happen in a cycle comprising ten stages starting from a dilemma. In other words, the whole learning process is based on solving a dilemma. This theory is very close to the target of this game which wants to improve students' problem-solving ability. Unfortunately, most of the serious games do not have a theory which works as a foundational framework which directs the design process of the game (Vakilian, Rezaeizadeh & Abolghasemi, 2018).

Second, the game is built based on a diverse range of pedagogical subject-matter solutions for developing students' problem-solving skill. While those solutions are theoretical solutions, they are being used to design the mechanics, challenges, rewards, and characteristics of the game. There are two key-words which make those solutions as effective guidelines for designing the serious game: "Pedagogical", and "Subject-matter".

"Pedagogical" refers to the methods and principles of teaching. In the context of game design, this means integrating instructional strategies that are known to enhance learning and retention (Rezaei-Zadeh, 2023). Pedagogical solutions ensure that the game not only entertains but also educates, by incorporating elements such as scaffolding, formative feedback, and differentiated instruction. These methods help to engage students at different levels of ability and understanding, fostering a more inclusive learning environment (Barari, RezaeiZadeh, Khorasani & Alami, 2022). For instance, scaffolding can be used in the game to gradually increase the difficulty of challenges, providing players with the support they need to develop their skills

progressively. Formative feedback within the game mechanics can guide players through their learning journey, offering immediate insights into their progress and areas needing improvement (Kasani, Mourkani, Seraji, RezaeiZadeh, Aghazadeh & Abedi, 2023). Differentiated instruction allows the game to cater to various learning styles and paces, making it accessible and effective for a diverse student population. This is in line with the findings of (Rezaei-Zadeh et al., 2023) and (Alikahni, RezaeiZadeh, & Vahidi-Asl, 2018). who mention that without pedagogy, serious games are void solutions.

"Subject-matter" pertains to the specific content or topics that the game addresses. Effective game design requires a deep understanding of the subject matter to ensure that the educational content is accurate, relevant, and aligned with curriculum standards. Subject-matter expertise allows the game to present information in a way that is both engaging and educationally sound (Davari, Vahidi-Asl, Alikhani, & RezaeiZadeh, 2020). This involves creating scenarios and challenges that reflect real-world applications of the subject, thus enhancing the relevance and applicability of the learning experience (Mohammadinasab, Mazaheri, Reazaeizade & Heydari, 2020). For example, a game designed to teach mathematics might include puzzles that require the application of algebraic concepts to solve real-life problems. This not only reinforces the theoretical knowledge but also helps students see the practical value of what they are learning. Subject-matter alignment ensures that the educational objectives of the game are met, making the learning experience both meaningful and measurable.

Third, the usability (ease of use) of the game designed and developed by this study was so high. This high usability is crucial for the game's effectiveness in boosting students' problem-solving skills because it ensures that students can navigate the game intuitively, without unnecessary frustration or confusion. When a game is easy to use, students can focus more on the learning

objectives and the problem-solving challenges presented, rather than struggling with the game's interface (Chenari, Rezaeizadeh & Bandali, 2022). This seamless interaction fosters a more engaging and immersive learning experience, allowing students to fully concentrate on applying their critical thinking and analytical skills. Furthermore, high usability reduces the cognitive load associated with learning new game mechanics, enabling students to devote more mental resources to understanding and solving the problems within the game (Yanez-Gomez, Cascado-Caballero & Sevillano, 2017). By prioritising usability, the game not only becomes more accessible to a wider range of students but also maximizes its potential as an effective educational tool.

These three factors and their impact on the effectiveness of the game developed by this study are summarised in Figure 3.

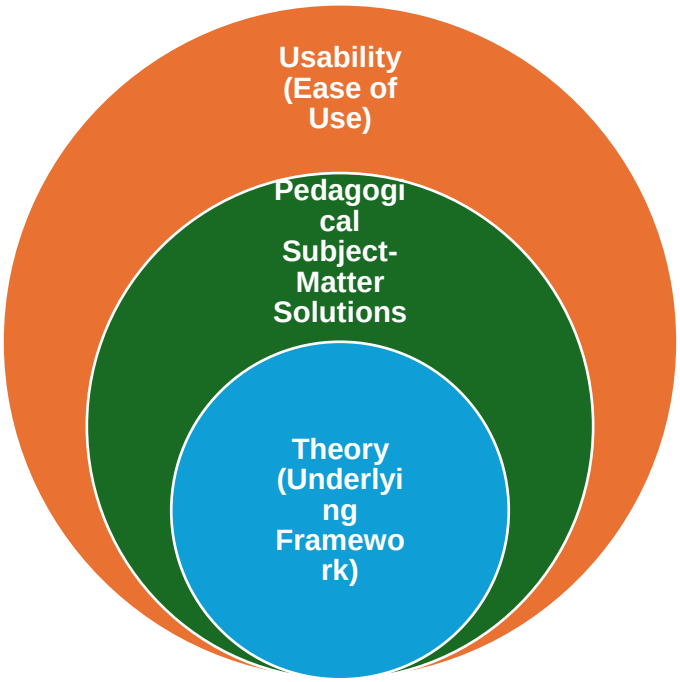

Figure 3. The three layers model of the factors affecting serious games' effectiveness

This image illustrates a layered framework for the design and development of a serious game aimed at boosting students' problem-solving skills. It is composed of three concentric circles, each representing a different component that contributes to the game's effectiveness. Here's an interpretation of each layer:

Core Layer - Theory (Underlying Framework):

This innermost circle represents the theoretical foundation or underlying framework of the game. It includes the educational theories, principles, and research that inform the game's design. This could involve cognitive theories, constructivist approaches, or specific problem-solving methodologies that guide how the game facilitates learning and skill development.

Middle Layer - Pedagogical Subject-Matter Solutions:

The circle surrounding the core represents the pedagogical subject-matter solutions. These solutions are derived from the core theoretical framework and involve the practical application of developmental methods and content-specific strategies. This layer focuses on integrating effective instructional techniques and subject-specific content into the game, ensuring that the educational material is both engaging and pedagogically sound. It encompasses how the theoretical concepts are translated into game mechanics, challenges, characters, rewards, and learning activities.

Outer Layer - Usability (Ease of Use):

The outermost orange circle highlights the importance of usability or ease of use. This layer ensures that the game is user-friendly, intuitive, and accessible, allowing students to engage with the game without encountering usability issues. High usability is crucial as it enables players to

focus on learning and problem-solving rather than struggling with the game's interface. This layer ensures that the educational and theoretical elements are effectively delivered through a well-designed, easy-to-navigate user experience.

The diagram emphasises that while the theoretical framework provides the foundation, the practical implementation through pedagogical solutions is essential, and the overall effectiveness is significantly enhanced by ensuring high usability. Each layer builds on the previous one, creating a comprehensive approach to designing a serious game that successfully boosts students' problem-solving skills.

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