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Competition and Collaboration: A Multi-Modal Analysis of Cognitive Load and Behavior Patterns in Game-based Learning

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1. Introduction

Digital game-based learning(DGBL) is increasingly recognized as an effective approach for enhancing learners' motivation, engagement and learning performance in various disciplines (Barz et al., 2024; Camacho-Sánchez et al., 2023). Competition and collaboration are critical factors within DGBL environments for the purpose of improving learners' performance(Lin & Hou, 2024; Wang & Huang, 2023). Although these mechanisms in DGBL have demonstrated great potential in education, it often demands higher levels of mental engagement because DGBL environments often present learners with highly realistic and interactive interfaces and these complex elements can sometimes overwhelm the cognitive capacity of learners, leading to an increased cognitive load (Sweller, 2022). To address these challenges, recent advancements in technologies that capture process-based physiological data have provided new avenues for understanding and analyzing cognitive states during learning activities (Ayres et al., 2021; Vanneste et al., 2021). These technologies enable researchers to gather detailed, real-time data on learners' cognitive load and engagement, offering a more comprehensive view of the learning process (Vanneste et al., 2021).

This study aims to delve into investigating cognitive load and behavioral patterns from both physiological and self-reported perspectives in individual context against those in competitive and collaborative settings. By employing multi-modal learning analytics, which integrates data from various sources, the study seeks to provide a comprehensive understanding of how these different learning environments impact students' mental processing and behavioral patterns.

2. Literature Review

2.1 Cognitive Load Theory in DGBL

Sweller(1988) originally proposed Cognitive Load Theory (CLT), a framework describing the demands placed on working memory during the learning process. CLT identifies three types of cognitive load: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. While intrinsic load is inherent to the learning material, extraneous and germane loads can be influenced by the design of the learning experience (Sweller, 1988; Sweller et al., 1998). In DGBL, previous research indicated that the findings on cognitive load are inconclusive, potentially due to the use of different educational features across various types of games in the literature (Kahyaoğlu Erdoğmuş & Kurt, 2023).However, subjective mental effort rating scales may not accurately measure the cognitive load (Paas & van Merrienboer, 1994). Therefore, additional physiological measurements are necessary.

2.2 Mechanisms in Digital Game-Based Learning (DGBL)

2.2.1 Individual Mechanisms in DGBL

Individual learning in DGBL refers to scenarios where learners engage with the content at their own pace without the influence or interference of peers (Obery et al., 2021). One significant advantage of individual learning environments is the reduction in cognitive load related to social interactions and coordination, which can sometimes overwhelm learners in collaborative settings (Schellens & Valcke, 2005).

2.2.2 Competitive Mechanism in DGBL

Digital game-based learning (DGBL) often integrates competition as a key element to enhance learner motivation and engagement. Competition motivates individuals to master the game by assessing their abilities through real-time peer comparisons (Morschheuser et al., 2019). Research has shown that competition plays a critical role in fostering positive motivational outcomes, such as enjoyment, engagement, performance (Liao et al., 2019; Sun et al., 2022; Sung & Hwang, 2018), flow experiences (Dindar, 2018), and future gaming intentions (Ryan et al., 2006). However, competition can also impose a higher cognitive load, especially on learners who may not thrive in high-pressure environments, the constant comparison with peers can lead to stress, anxiety, and even disengagement (Yang et al., 2020).

2.2.3 Collaborative Mechanism in DGBL

Collaborative learning environments in DGBL involve multiple learners working together to achieve shared objectives, which can lead to deeper cognitive engagement, enhanced problem-solving abilities, and better retention of knowledge compared to individual learning scenarios (Yang et al., 2024). However, the success of collaborative DGBL is contingent upon the effective management of group dynamics. Poorly structured collaborative environments can lead to issues such as social loafing, where some group members rely on others to carry the cognitive burden, resulting in unequal participation and diminished learning outcomes (Hwang et al., 2012). Furthermore, the effectiveness of collaboration is influenced by factors such as group composition, prior knowledge, and the level of cohesion among group members (Yang et al., 2020). Ensuring that all participants are actively engaged and contributing meaningfully is critical to the success of collaborative learning in DGBL.

3.1 Research Gap

While extensive research has explored the effects of competitive and collaborative learning environments in DGBL, there is a notable gap in understanding how these environments compare to individual learning scenarios. Specifically, how does individual versus competitive and individual versus collaborative mechanisms differentially impact cognitive load, engagement, and learning outcomes? By addressing these research gaps, the study aims to provide a comprehensive understanding of how different learning mechanisms in DGBL influence cognitive load and learning behavioral patterns, ultimately informing the design of more personalized and effective educational games.

4.Proposed Research Work

4.1 Research Questions

1. How do competitive and collaborative game-based learning environments compare against individual learning environments in terms of cognitive load?

2. What are the behavioral patterns observed in learners within individual versus competitive and individual versus collaborative DGBL environments?
3. How can physiological data predict cognitive load in individual, competitive, and collaborative DGBL environments?

5.Research Methodology

5.1 Participants

The study aims to recruit 30 pairs of participants who meet specific inclusion and exclusion criteria (shown in the Table 1 below) to ensure the reliability of the results.

Table 1 Criteria of Participants

Criteria	Categories	Details
Inclusion Criteria	Age	21-40 years
	Gender	Male or Female
	Vision	Normal vision or corrected vision (no color blindness)
	Handedness	Right-handed
	Language Proficiency	Proficient in the English language
Exclusion Criteria	Handedness	Left-handed
	Vision	Visual impairments and/or color blindness
	Medical History	History of psychological or neurological disorders
	Medical Conditions	Recent injuries, surgeries, and/or implants at the head or scalp

5.2 Game Design

The game is set in a neuroscience lab where a virus outbreak has occurred, creating a high-stakes environment that requires players to apply their knowledge of sensorimotor processes to survive. The experimental protocol and game conditions are outlined below:

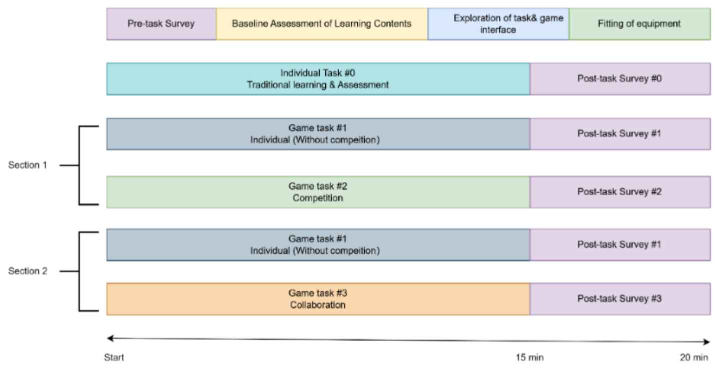

Figure 1 Outline of experimental protocol and game conditions

6. Data Collection and Analysis

To address the research questions, this study will employ a comprehensive multi-modal learning analytics approach. Data will be collected through the following methods:

Table 2 Description of Data Collection and Analysis

Research Questions	Data Collection	Data Analysis
Q1: How do competitive and collaborative game-based learning environments compare to individual learning environments in terms of cognitive load?	Eye-tracker: Capture gaze patterns, fixation duration, and saccades Electrodermal Activity (EDA): Measure skin conductance responses to detect arousal and stress levels In-Game Behavioral Logs: the time spent on tasks, the sequence of actions, and the frequency of specific behaviors. Verbal Interactions: Audio recordings of verbal interactions between players Survey/Questionnaires: Cognitive load instrument(Hwang et al., 2013) The ARCS motivation scale (Keller,1987a; 1987b) Technology Acceptance Scale (Davis, 1989) Learning emotion questionnaire (Samsudin & Chng, 2015)	Descriptive Statistics Time-Series Analysis Inferential Statistics Content Analysis
RQ2: What are the behavioral patterns observed in learners within individual versus competitive and individual versus collaborative DGBL environments?		Descriptive Statistics, Time-Series Analysis Thematic Analysis
RQ3: How can physiological data predict cognitive load in individual, competitive, and collaborative DGBL environments?		Correlation Analysis, Regression Analysis Thematic Analysis

7. Contribution of the Proposed Research

This proposal will significantly contribute to digital game-based learning (DGBL) by examining the effects of individual, competitive, and collaborative mechanisms on cognitive load and behavior. Using multi-modal learning analytics, including physiological data like electrodermal activity (EDA) and eye-tracking, it will provide detailed insights into how learners engage and process information. The findings will guide the design of balanced and effective learning environments, optimizing engagement and performance. Additionally, the study will enhance Cognitive Load Theory (CLT) by offering new strategies for managing cognitive load in immersive digital learning settings.

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