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Digital game-based learning in architecture education: Consolidating visual design principles in freshmen

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Abstract

Using games as educational tools has been a captivating subject in the academic domain. There is an increasing number of digital games designed to support architectural education. This paper introduces a serious game aimed at enhancing basic design knowledge for first-year architecture students. The game focuses on teaching and testing visual design principles such as emphasis, balance, and rhythm. Based on these principles, it allows students to create 2D compositions on a grid pattern by placing and manipulating simple shapes in terms of color, shape, and size. The final composition is evaluated by an artificial intelligence (AI) tool integrated into the game. This AI tool predicts the design principles present in the composition, providing three possible outcomes with associated percentages. The game, currently in the testing phase, has been played by 126 first-year students, and user experience has been assessed through questionnaires, surveys, and basic game metrics. The use of this game to teach visual design principles has proven to be an effective method for engaging students in active learning and enhancing their understanding and application of design concepts. The innovative use of AI to provide real-time feedback and the interactive nature of the game have fostered a deeper, experiential learning process. Additionally, students have proposed various innovative ideas to improve the gaming experience, suggesting potential enhancements that could lead to a more refined and enjoyable gameplay. These insights highlight the potential of digital game-based learning (DGBL) and AI-enhanced tools in creating an engaging and effective educational environment.

Keywords: architectural education, basic design principles, digital game-based learning (DGBL), artificial intelligence (AI), first-year architecture students

1. Introduction

Education should not be strictly adherent to a unidirectional approach. The integration of games as educational resources has received significant attention in academic circles. Games, typically associated with enjoyment, have shown considerable potential to enhance students' learning outcomes within a game-based learning framework (Gros, 2007). Several studies affirm the beneficial effects of incorporating games into education. Chuang et al. (2007) conducted a study involving 108 third-grade university students, providing experimental evidence that video games surpassed computer-assisted education in fostering cognitive growth. Barron's (2015) study compared college students' performance in video game-based learning (using SimCityEdu) with traditional learning methods (lectures/debates), revealing superior knowledge retention and information access among the game-based group. Zhonggen's (2019) study underscored that serious games –designed specifically for educational purposes rather than entertainment, hold the potential to boost players' positive mood and happiness, thereby cultivating favorable attitudes toward academic tasks. In 2020, Coleman and Money discovered that inquiries into 'student-centered digital game-based learning' consistently emphasized elements such as active learning, autonomy development, and increased responsibility and accountability. Furthermore, Oksuz and Cordan's (2022) article demonstrated that enabling players to manipulate the game environment with design tools enhances interaction, promoting experiential and active learning engagement.

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Games inherently possess motivational capabilities, starting from teaching fundamental concepts and aiding in the establishment of a knowledge base. As players progress, the levels and tasks become more complex, encouraging strategic thinking, goal setting, critical analysis, and problem-solving (Westera, 2015). Moreover, games provide a flexible environment, avoiding rigidly predefined problems and solutions, thus accommodating various approaches based on individual differences. Kang et al. (2017) stress that "… open-ended serious games can facilitate students' development of specific skills and improve learning performance through scientific problem-solving." Javid's (2014) study, though non-digital, demonstrated the impact of game-based learning on architecture students, helping them identify connections within design problems to develop unique and integrated solutions. Javid also highlighted that freedom from failure in games correlates with motivation, leading to positive learning outcomes.

This paper presents empirical research on the educational benefits of an open-ended game augmented by artificial intelligence (AI) for students studying art and architecture. While interest in incorporating digital games into architecture education is increasing, current applications are often limited by preset game settings or focus solely on 3D design visualization in simulated environments. The game developed in this study provides students with foundational knowledge of basic design principles and offers opportunities to practice utilizing various elements and implicit rules to create compositions aligned with these principles. This method of learning, utilizing a game with multiple pathways to success and numerous options for player choice and creativity, is crucial for design education and curriculum development.

The originality of this study also lies in its integration with AI technology, allowing students to assess their compositions against predictions made by a machine learning model developed by Demir et al. (2021). This model is proficient at identifying visual design principles evident in artworks, photographs, and contemporary building façades. The incorporation of this AI model offers real-time feedback, facilitating a continuous trial process without the need for constant validation from educators and alleviating concerns about repeated failure. Here the AI-integrated game is expected to aid students by establishing an objective framework for aesthetic analysis grounded in basic design principles, thereby supporting and exploring self-directed learning.

This paper begins with an examination of the current landscape of digital game-based learning (DGBL); including learning models, examples from architecture education, and AI support in game design and development. It then discusses the process of designing a digital game and evaluating its effectiveness as a gaming experience. Following the literature review, the third section provides details on a specific application—an original digital game developed by the authors and voluntarily played by a group of first-year architecture students at Istanbul Technical University (ITU). The paper concludes with the presentation of results and outlines future prospects.

2. Literature Review

2.1. Digital Games and Learning Models

Games provide a platform for students to explore, experiment, and make impactful decisions. Several educational theories support the use of game-based learning, emphasizing its role in fostering active learning and creating meaningful environments where learners can construct knowledge (Harikrishnan et al., 2019). Constructivist Learning Theory (CLT), which suggests that learning is enhanced when students actively engage with phenomena, principles, and practices through pertinent experience-based learning exercises or projects, is one of the most widely used theoretical foundations in research on gamification, serious games, and game-based learning. Pavlik and Pavlik (2024) highlight a practical application of CLT in a classroom setting, where students with minimal technical artistic skills generated visuals emulating a particular painting style using generative AI (DALL-E 2). The integration of AI allowed educators to immerse students in critical analysis of art or art-like materials through an experience-based approach. Similarly, architecture schools utilize experience-based learning to merge abstract concepts with concrete applications, thereby providing students with a holistic and engaging knowledge.

Educational games offer students the chance to experience various scenarios and reflect on their designs, aligning with Experiential Learning Theory (ELT) introduced by David A. Kolb (2015). This theory emphasizes the significance of direct experience and reflection in the learning process (Nadeem et al., 2023). Additionally, Flow Theory describes a state of deep engagement and enjoyment achieved when an individual is fully immersed in an activity, balancing skill level and challenge to prevent anxiety and maintain the flow of the game. Kiili's Experiential Gaming Model (2005) integrates Experiential Learning Theory, Flow Theory, and game design to develop an effective game-based learning framework. This model emphasizes the continuous nature of learning and the importance of appropriate feedback which provides the basis for a continuous process of goal-directed action. It highlights that immediate feedback, coupled with clear goals and challenges tailored to the player's skill level, facilitates meaningful and engaging learning experiences through the sensation of flow.

Video games can be effectively utilized to develop self-directed (incidental) learning (SDL), possessing features conducive for independent learning (Toh & Kirschner, 2020). These games provide a risk-free environment for learners to experiment and fail without real-world consequences. This setting allows learners to progress at their own pace, receiving immediate in-game feedback to enhance various skills and competencies. Li et al. (2024) focused on AI-facilitated SDL, examining how generative AI (ChatGPT) can support and enhance language learning through conversational interaction, personalized feedback, and content generation. Additionally, Shaheen and Fotaris (2023) highlight that digital games implicitly promote reflective learning by encouraging critical thinking, self-awareness, problem-solving skills, and motivation. Reflective learning, characterized by immediate feedback, further supports self-directed learning by enabling students to engage in continuous self-assessment and improvement.

Paciarotti et al. (2021) introduced the 'Learner-Designer Approach' to serious games, which engages students in a process to learn assigned content by actively participating in its design. This new perspective integrates gamification with active learning and social constructivist methods, including project-based learning, self-regulated learning, reciprocal teaching, and cooperative learning. The approach emphasizes metacognitive elements through active monitoring and decision-making. Designers (students) must comprehend, organize, and reason through the learning material to convey it effectively to the players (their fellow students), thereby enhancing their understanding compared to traditional lecturing. Similarly, Örnekoğlu-Selçuk et al. (2024) propose a 'game-design' approach, another way integrating constructivist paradigm into education on a pedagogical basis. This method allows students to design their own games, offering a richer learning experience compared to merely playing games. This concept, referred to as "co-design," transforms students into active producers rather than passive recipients. The 'learning-by-doing' model is emphasized as a fundamental aspect of design education. While designing a game, students engage in higher-order thinking processes, including iterative design, critical thinking, and systemic thinking.

In addition, serious games are studied not only for their learning outcomes (performance) but also for their motivational capacities, which are considered essential for both effective gaming and learning. Hartmann and Gommer (2021) explored student motivation in educational games using Self-Determination Theory (SDT), which posits that individuals' engagement in activities is driven by intrinsic needs for competence, relatedness, and autonomy. Their study indicates that various motivational forms coexist during gameplay, emerging from the interplay of game operativeness (user-friendliness, clarity, technical performance), game attractiveness (challenge, engagement, appearance), and game learning (relevance to course content, educational contribution). The study suggests that designing games for (engineering) education should incorporate diverse mechanics to meet intrinsic human needs and enhance motivational potential. Bertozzi et al. (2024) also referred to the framework of the Self-Determination Theory to investigate psychological factors that may positively and negatively affect motivation in educational contexts and activities. They employed the Self-Report Situational Motivational Scale (SIMS) questionnaire to measure the constructs of intrinsic motivation, identified regulation, external regulation, and amotivation. These constructs were combined into a single motivational score known as the Self-Determination Index (SDI).

The proposed game in this paper is grounded in constructivist educational theory, emphasizing discovering the knowledge by doing, rather than taking it as it is (Bakan & Bakan, 2018). Students are encouraged to create their own compositions based on design principles by engaging with various scenarios and appropriate game mechanics. Moving beyond simple memorization, the game aims to achieve a deeper understanding through practical activities, embodying experiential learning. The game provides a safe environment for students to experiment and use trial and error, exploring multiple patterns without the fear of penalties, such as losing course points or grades. This approach adapts self-directed learning principles, offering opportunities for experimentation and independent learning. The AI component of the game allows students to engage actively in design tasks by providing real-time feedback and enabling continuous self-assessment. It encourages students to reflect on their work, make adjustments, and learn through doing. This hands-on, iterative process helps students construct their understanding of basic design principles. Additionally, the challenges of creating principle-dominant design patterns, comparison with the AI model's feedback, and aligning with its labeling as the achievement goal are expected to increase intrinsic motivation, enhancing the overall gaming and learning experience.

2.2. DGBL in Architecture Education

In architectural education, commercial games, originally designed without educational priorities, are employed to enhance designing skills and complement theoretical lectures (Taşçı, 2016). Simulation games such as ‘SimCity’ and ‘The Sims’ are commonly utilized, along with role-playing games like ‘Second Life,’ offering interactive experiences that foster user engagement and learning. Strategy games including ‘Civilization,’ ‘Caesar,’ and ‘Age of Empires’ are also integrated into various courses, facilitating discussions on urban and historical contexts through real events and places. For example, in a computer-aided landscape design course, Örnek (2013) substituted mainstream drawing and modeling software with RollerCoaster Tycoon 3 (RCT3). Post-test results from 19 students indicated that RCT3, with its user-friendly interface and effective navigation providing an eye-level view, outperformed CAD software. Despite limitations in design flexibility due to predefined components, the game was evaluated as a time and effort-saving tool for design representation.

Current 3D game engines are also utilized in education, enabling users to navigate ultra-realistic virtual environments from a first-person perspective (Elsamahy, 2017), while incorporating game mechanics and cinematic features. In Redondo et al.’s (2020) study, architecture and urban design students were encouraged to use Unreal and Unity game engines along with head-mounted displays (HMDs) to create interactive virtual environments. The integration of gamification through augmented and immersive visual technologies aimed to enhance spatial engagement by enabling users to manipulate, explore, or modify the virtual surroundings.

On the other hand, an increasing number of studies are focusing on the development of games specifically tailored for architectural education. For instance, Utian (2015) introduced “Space Place Play,” a game in which spatial design and narratives evolve through collaborative processes among players. The game involved 26 postgraduate students in the ‘Cinematic Space’ course within the Master of Architecture program at the University of New South Wales, organized into small groups of three to four students across seven teams. The study aimed to investigate how digital games foster learning and associated outcomes in architectural design. Survey responses from students indicate the game’s positive impact on various aspects, including understanding the spatial design process, the creative use of time, storyboarding, the utilization of films for spatial comprehension, as well as the development of critical thinking and problem-solving skills.

In a study conducted by Şahbaz and Özköse (2018), a 3D first-person computer game titled 'Escape from Haunted Building,' featuring a basic puzzle-solving and thriller-type scenario, was developed to instruct architecture students on historical buildings, specifically focusing on a Greek Bathhouse. 45 undergraduate students from Karabük University's Architecture Department participated in a three-method experiment, divided into equal-sized groups. The first group learned about the historical bathhouse in the classroom using traditional course materials; the second group visited the building on-site, while the last group engaged with the game developed for the study. Post-questionnaire results pertaining to architectural details, building construction, and architectural style suggested that playing the game enhanced students' knowledge about the building, with the exception of the building construction category.

Goli et al. (2022) introduced a serious open-ended game, 'GaoDe,' which engages students through a multi-modal natural user interface, involving gesture and speech recognition. In a familiar CAD environment, students could simulate the design process of various iconic buildings, gaining hands-on experience with the complexities involved. GaoDe fosters an environment where there are no strict or predetermined correct or incorrect answers, promoting a more open and exploratory learning atmosphere without fear of failure. In a design studio attended by 41 first-year architecture students, feedback on the game's utility, learning improvement, and satisfaction was collected. Participants strongly agreed on the game's ease of use and effective interactivity during the design process. GaoDe was acknowledged for its potential to boost motivation and support continuous engagement in design activities through user-friendly gameplay.

In a designed workshop, Babacan Çörekci (2023) explored the impact of game-based learning on the comprehension of design processes and time management among second-year interior architecture students. 'Miro boards' served as both the gaming and design interface. The game included tasks for students to complete within specified timeframes, requiring knowledge of architectural structures such as construction dates, heights, and lengths. Participants, acting as clients or end users, evaluated the process, assigning scores and prizes in end-of-day appraisals. This gamified approach aimed to foster various learning outcomes, including multitasking skills, attention to details, and self-confidence. To sum up, incorporating DGBL into design encompasses various aspects, including the design process, knowledge acquisition, collaborative practices, and the development of management and communicative skills.

Our study aims to instruct architecture students in 'visual design principles' through a digital game, with the potential to benefit first-year architecture education in academic institutions. Specifically to our topic, in the context of basic design education, Coşkun and Çağdaş (2022) recently developed a game module where students become active players and experience their compositions within the game universe. The multiplayer, interactive, digital, and open-ended environments provided by the games allowed for various scenarios in basic design education. Within this framework, students explored fundamental design principles such as balance, rhythm, and proportion through specific geometric forms and color selections within a game structure. Compared to traditional practices, it was observed that students could express themselves better with predefined elements and rules in the design exercise. The study concluded that the digital 3D game environment is significant for encouraging the development of different representations and allowing students to revisit and refine design outputs repeatedly.

2.3. AI Enhanced Games in Education

AI techniques have been employed in DGBL in order to improve player engagement and learning outcomes (Hammedi et al., 2020). Sun et al. (2023) review intelligent game-based learning environments, which integrate commercial game technologies with AI methods from intelligent tutoring systems (ITS) and intelligent narrative features. These ITS-integrated games aim to replicate human tutors by assessing player responses in real-time and providing appropriate feedback and guidance (Chen & Chang, 2024). The combination of gamification techniques and dynamic AI support offers personalized learning experiences (Romero et al., 2024). AI plays a crucial role in tailoring the educational journey to each student's unique needs and preferences. For example, AI algorithms can analyze a student's progress, learning style, and interests, and then suggest 'personalized exploration paths' based on their progress and preferences (Perlaza Rodríguez et al., 2024). This approach keeps students engaged and ensures they receive the most relevant and practical learning experiences.

McLaren and Nguyen (2023) conceptualized the role of digital games in "Artificial Intelligence in Education (AIED)" in two ways; (1) games that employ AI within their operation and interaction with players, and (2) games that have been developed and/or extended using AI techniques. They also defined four major ways in which AI has been utilized in the context of learning games: where AI is used to perform real-time adaptation during gameplay, AI-powered interactive dashboards or recommendations are featured, AI-driven non-player characters are employed, and AI is used for post-game analysis rather than in gameplay or game mechanics.

AI-driven interactive learning methods are also used to evaluate the quality of art and design teaching because they provide objective evaluation and can be automated, saving time and resources (Fan & Li, 2023). AI can function as a virtual tutor, offering adaptive cues and supplemental resources when students encounter obstacles during their design challenges. It offers performance analysis and individualized feedback to enhance problem-solving skills. Ahmed et al. (2023) found that AI-supported serious simulation games transform urban planning education into an immersive and experiential journey, empowering students to become proactive urban planners capable of anticipating and addressing the complex challenges of creating sustainable, resilient, and livable cities. These games leverage AI to create more realistic and engaging learning experiences, providing students with personalized feedback and support. Le and Kim (2023) utilized a deep learning model to predict daylight performance in a cubic building game environment. Since especially first-year students (users) often find simulation techniques challenging, a game-based platform is a promising alternative, making analysis more engaging and accessible to students of all skill levels. This initial project aims to develop for larger building layouts with more floors in a shared virtual space.

Our research uniquely integrates a customized AI model into an open-ended game for basic design education, enabling real-time identification of student compositions. This fosters self-assessment and offers a tailored learning experience for first-year architecture students, which is not targeted in the existing design literature. The immediate AI-generated feedback allows students to iteratively improve their designs, significantly advancing traditional and digital methods while promoting creativity and independent problem-solving skills.

2.4. Digital Game Design and Assessment of Gaming Experience

Video games can be categorized into four main aspects according to Schell (2008): Mechanics, Story, Aesthetics, and Technology. Some aspects are more apparent to players than others; with aesthetics being the most visible, and technology being the least visible. Game mechanics comprise the general rules and procedures, while the story involves the sequence of events, which may be linear, branching, or non-existent. Aesthetics pertain to the visual and sensory aspects of the game, often influenced by the underlying technology. Together with story and mechanics, aesthetics establish a relationship between the player and the game. Technology dictates the systems utilized for gameplay, including the chosen game engine, texture quality, and programming language. It serves as the medium for delivering the story, executing mechanics, and housing aesthetics.

The transition of a game from the designer's concept to the player involves several stages. In the Pre-production phase, activities such as planning, visual scenario drafting, game design, and early prototyping take place, encompassing all steps before moving into production. A critical outcome of this stage is the game design document (GDD), deemed the "blueprint" of game development (Baldwin, 2005). This reference document, though varying across game genres, must comprehensively address all aspects and tasks leading to the final product. Typically, a GDD includes sections such as overview (description, genre, target audience), gameplay and mechanics, story, characters, game world, levels, interface (visual, auditory, and control), technical content, art design, and management (budget, timeline, risk analysis, etc.).

The second stage is the Production phase, wherein prototypes undergo a comprehensive transformation into a fully developed game (Dalmau, 2004). This stage involves activities: modeling the game world, rendering, coding/programming, incorporating visual-audio effects, and designing the user interface. Game coding can be accomplished through an existing game engine or by creating a new one, often requiring proficiency in different programming languages such as C++ or Python, and the implementation of AI algorithms for additional functionalities. As the production phase nears completion, the testing phase is initiated to scrutinize every aspect of the game, identifying and addressing any bugs. Subsequently, the pre-launch phase focuses on advertising, generating anticipation, and building hype among the general audience. This step is typically less relevant for serious games. Finally, the launch phase marks the game's release for play, followed by the discovery of unforeseen bugs and additional problem-solving. Post-launch, ongoing attention from the game designers, including collecting player feedback, plays a crucial role in determining the life expectancy of the game.

Considering that the primary objective of any game is to be enjoyable, providing surprises, challenges, and opportunities for skill application, as well as delivering a hedonic experience at the end, the evaluation of user experience (UX) in games and interactive environments has been a longstanding practice. UX evaluation methods can be implemented at various stages of the design and development lifecycle, and they can be categorized as follows (Bernhaupt, 2015):

- User-oriented methods, spanning from concept to post-production phases, encompass a range of techniques including Focus Groups, Interviews, Observations, PIFF and CEGE questionnaires, Play-testing, Physiological UX evaluation, and Experiments including game controller evaluation.
- The methods based on user data enable automated testing or analysis. Game metrics, which are interpretable measures derived from raw telemetry data, involve logging player interactions, positions in the game world, camera angles, and all data related to gameplay interaction processes, including time spent playing and session length.
- Expert-driven approaches include Game Approachability Principles (GAP), which offers valuable guidelines for game designers to create better tutorials during the conceptual design phase. Heuristic evaluation, another expert-based inspection method, follows recognized and established usability principles.
- Game-specific strategies address the distinctive requirements of game developers by concentrating on techniques and standards for evaluation processes designed for diverse game genres, including social games and exertion games.

3. Case: "VDP Mania" Game

3.1. Basic Design Course at ITU and Its Application in the Game

Introductory architecture courses play a critical role in shaping the path of architecture students as they progress toward becoming professional architects. According to Farivarsadri (2001), these initial educational experiences are pivotal, providing not only fundamental skills and essential design knowledge but also shaping students' ideas about their future roles and responsibilities. Among these courses, the Basic Design course holds particular significance by acquainting freshman students with both the conceptual and practical aspects of creativity (Makaklı & Özker, 2016). This course typically encourages students to create 2D and 3D compositions focusing on design principles and elements (Boucharenc, 2006; Gungor & Yorgancıoğlu 2019; Uluçay 2023).

At ITU, the first-year curriculum includes a set of courses known as the "Foundation Studio," (Temel Eğitim Stüdyosu: TES) which is mandatory for students across all five majors within the

Faculty of Architecture. This collective initiative aims to instill fundamental concepts related to design, which students are expected to apply throughout their undergraduate studies. The Foundation Studio consists of three main courses: Project (PR), Visual Communication (VC), and Basic Design & Visual Arts (BD-VA). BD-VA, similar to its counterparts in other Turkish architecture schools, is a studio-based course designed to facilitate students in exploring, discussing, and interpreting basic design issues rooted in visual design principles. ITU's BD-VA course covers basic design elements such as point, line, surface, and form; and design principles (including gestalt principles) like repetition, rhythm, balance, harmony, contrast, and continuity; all organized in both 2D and 3D works. It explores the concept of space, scale, proportion, color, texture, and light; addresses visual perception; and analyzes patterns in both natural and man-made environments.

Visual design principles (VDPs), evident across various forms of art disciplines (Fichner-Rathus, 2011), pertain to design principles taught in basic design courses within architectural curricula. VDPs involve systematic methods that utilize design components to create a perceptual structure aiding visual processing (Puhalla, 2011). These principles include unity, proportion, contrast, repetition, movement, harmony, balance, rhythm, and emphasis (Landa, 2010). Exploring VDPs within 2D and 3D compositions is a subject in basic design courses, including first-year BD-VA courses at the ITU Faculty of Architecture. In the BD-VA course during the 2019-2020 Fall Semester (TES 113E Section 5, the first author was one of the tutors), two weeks were dedicated to the project "Pattern-ing 1." In this project, students were tasked with abstracting shapes from letters, dance figures, maps, etc., and then using and modifying these shapes to create either a 2D composition or a 2.5D low relief. They were instructed to adhere to three fundamental VDPs: emphasis (achieved through color, shape, or isolation), balance (symmetrical, asymmetrical, and crystallographic), and rhythm (regular, progressive, and flowing/movement). Another two weeks were allocated to the project "Pattern-ing 2," where students were asked to work with 3D forms, starting from solid geometry and then altering them in terms of size and shape at various levels such as vertex, face, and edges. Once again, VDPs remained central to the development of unique compositional ideas. Examples from students' works of both Project 1 and 2 are provided in Figure 1.

Building upon the findings of Salem and Dündar (2019), which highlight a growing interest in exploring digital technologies in basic design education, this study aims to integrate digital game-based learning of VDPs as a standalone resource in first-year architecture education. The proposed game incorporates a VDP-detecting AI into its system, providing self-feedback and flexibility for students to access it at any time and from anywhere. This innovative learning approach is expected to aid students in understanding and consolidating the design concepts. The game targets three VDPs: emphasis via color, isolation, or shape; crystallographic balance; and progressive rhythm, all conforming to AI classification.

Emphasis involves creating dominant elements within a composition. Lauer and Pentak (2011) describe it as a 'focal point' that "attracts attention and encourages the viewer to look closer" (p.56). Color emphasis occurs when an element with a contrasting or distinct color is used in a composition. Isolation achieves emphasis by positioning an element separately from others in the composition. Shape emphasis is employed when a uniquely shaped element stands out in form or scale within the composition.

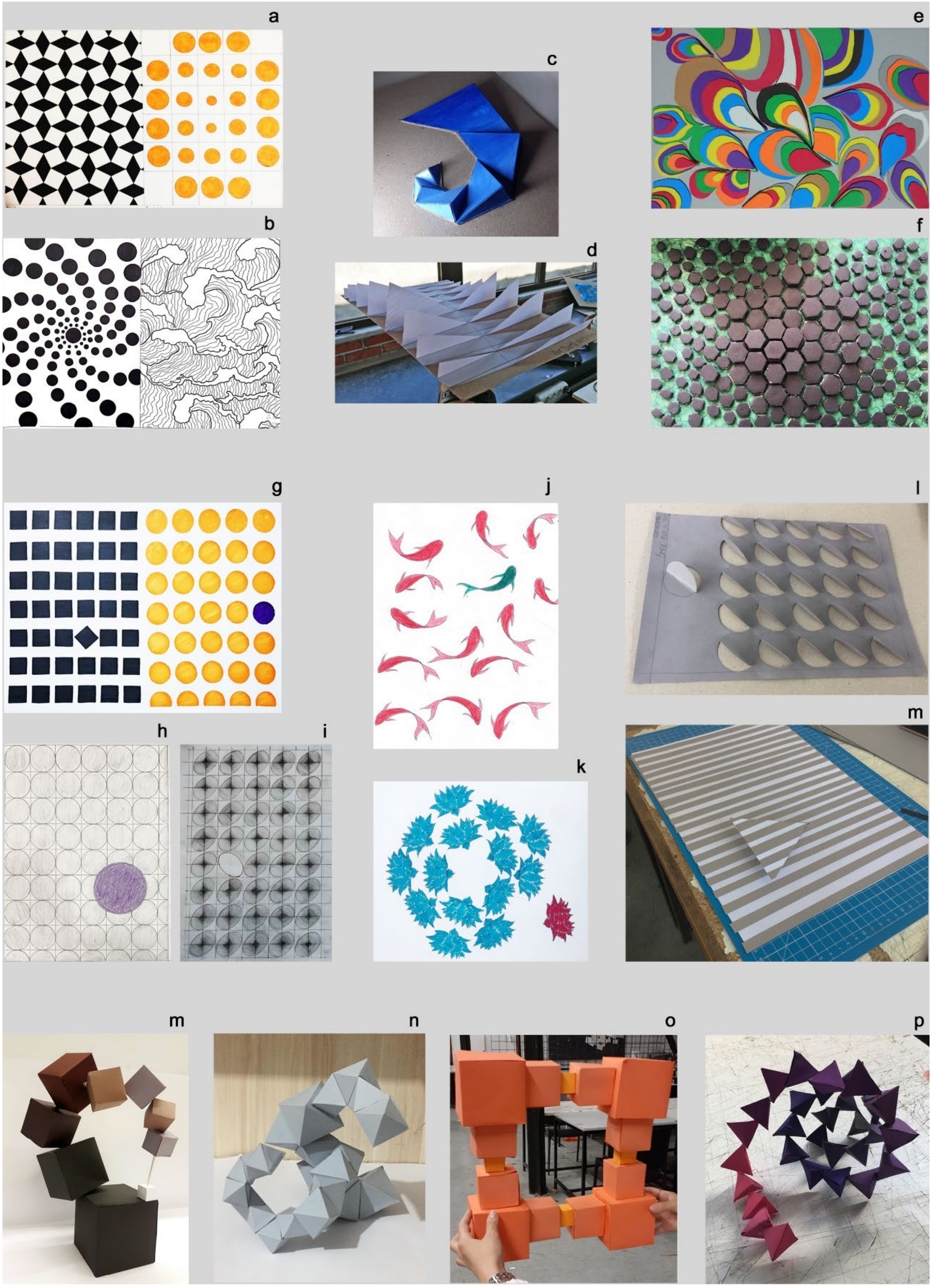

Figure 1 Works by (a) Yusuf Ziya Özaltın (b) Hatice Akgür (c) Hande Beril Küçükler (d) Uğur Dertli (e) Şeyma Kaya (f) Umut Sacalar (g) Didem Kılıç (h) Ege Ayaksız (i) Songül Özyurt (j) Zeynep Yaren Karabulut (k) Aybüke Yarbasan (l) Ömer Ruhlukürkçü (m) Güleycan Genç (n) Hüseyin Can Çiçek (o) Berzan Sönmez (p) Ayşe Nur Yılmaz (r) Güleycan Genç

Balance in composition refers to achieving visual equilibrium. Arntson (2011) defines it as "two forces of equal strength that pull in opposite directions, or by multiple forces pulling in different directions whose strengths offset each other" (p.64). Crystallographic (mosaic) balance is about arrangement of a large number of elements, incorporating variations in color, size, or shape throughout the composition. Despite appearing chaotic and diverse in nature, an image employing this principle achieves an overall effect of a calm and uniform whole. Rhythm involves creating repetition in elements, colors, forms, positive and negative spaces, and textures. According to Landa (2010), rhythm is "a sequence of visual elements at prescribed intervals" that develops "a coherent visual flow" from one element to another (p.35). Progressive rhythm refers to the gradual hierarchical change in a group of recurring elements within the composition, such as squares increasing slightly in size or a square transitioning into a circle over several frames. Figure 2 exhibits several examples belonging to the relevant VDP classes used in the AI model.

Figure 2 Sample images from the photography dataset. Taken originally from Demir et al. (2021)

3.2. VDP Detecting AI Model

The AI model employed within the game has been developed in the research conducted by Demir et al. (2021) and has been approved for use in this game. As part of the model development process, researchers initially created a computer-generated dataset to detect nine VDPs in images. This synthetic dataset comprises basic geometric shapes and a patchwork of simple images with backgrounds. To address the complexity of the task, datasets were then prepared from various domains. For the photography dataset, the majority of images were sourced from stock image websites such as iStock and the 500px collection of Getty Images. For the art dataset, 23 contemporary art museum online databases were examined for the selection of both analogue and digital paintings, prints, works on paper, graphic art, and posters. Additionally, architectural data featuring facades with evident utilization of VDPs was downloaded from two primary web applications: Instagram and ArchDaily. Approximately 100,000 images were collected for the photography dataset, 91,800 images for the art dataset, and 90,736 images for the architecture dataset (totaling 282,536 images) to be inspected and annotated in the final phase. A web application facilitated the data annotation process. The platform stores data and provides a selection interface, through which experts identify the most apparent VDPs and assign labels accordingly. The curated final dataset consists of 23,825 labeled images.

The researchers used PyTorch (Paszke et al., 2019) as the deep learning framework for all experiments. During the optimization process for supervised classification, they utilized EfficientNet-B7, pretrained on ImageNet, without freezing any layer parameters. Given that a visual composition typically encompasses multiple principles, they adopted an approach of evaluating the top three accuracy scores rather than solely relying on the highest accuracy score of the computer model. This methodology enables the assessment of secondary and tertiary predictions of the data. The model's top three scoring classes are highly likely to include the correct labels compared to considering only the top score label. Across all experiments, the top accuracy ranged from 56% to 77%, while the top three accuracies ranged from 80% to 93%. Further elucidation on the technical integration of the model into the gaming platform is provided in Section 3.3.2.

The learning-based model's principal and solitary input comprises the cumulative knowledge extracted from a vast collection of meticulously curated products in art and architecture, along with their annotations by expert designers. This extensive dataset of real products allows the AI model to perform objective evaluations. This capacity is advantageous for both learners and educators as it ensures fair and consistent assessments. For learners, it means receiving unbiased feedback on their designs. For educators, it provides valuable insights to refine their teaching strategies based on objective data. The AI model, adept at detecting VDPs, exhibits the capability to identify compositions generated by users within the game environment. This real-time analysis helps students understand their mistakes and make necessary adjustments promptly, enhancing their learning experience.

We can cite the limitations of the AI model used in the game as follows. The model is not designed to adapt to different student skill levels. While it can offer detailed feedback, it does not differentiate between beginners and more experienced students. Additionally, the lack of generative features limits the model's ability to make suggestions or improvements related to the compositions. The accuracy and effectiveness of the AI model are heavily dependent on the quality and diversity of the training data. Currently, the data encompass certain art objects from a specific time period and are limited to nine design principles. This limitation means that the model may not fully capture the variety and evolution of design styles over time.

3.3. Creation of the Game

A simple casual game was aimed that would aid students in learning VDPs through various steps. All game icons were sourced from freepik.com. The game's design was chosen to be 2D, aligning with the AI's training on images. The game's intended platforms were identified as Windows PC and MAC. Its genre can be classified as a serious game. The target audience, established at the outset of the research, comprises architecture freshmen students. The decision to utilize the 'Unity Editor, 2021' as the game engine stemmed from its reputation for being beginner-friendly in the gaming industry, combined with the authors' prior experience with the software.

3.3.1. Game Mechanics & Controls

The game is navigated solely through mouse inputs. Upon launching, players encounter a welcome screen presenting four options: START, LEARN, ABOUT, and QUIT (refer to Figure 3). Clicking on the LEARN button directs users to the "LEARN Menu," which lists the VDP names along with respective buttons. Each button leads to a dedicated screen providing detailed information about the corresponding VDP, accompanied by three images illustrating examples of its application. Selecting the ABOUT button reveals additional options: Feedback and Article. The Feedback button directs users to a questionnaire, while the Article button provides access to the scholarly article serving as the basis for the AI model. Lastly, clicking on the QUIT button exits the game and closes the application.

The game commences upon the player pressing the START button. Upon initiation, the player is presented with the option to choose between two game modes. The first mode is the QUIZ game mode. In this mode, players are presented with three pictures and tasked with selecting the correct one corresponding to the given VDP task (refer to Figure 4). Each correct answer earns the player a point. To enhance player engagement, a score-based approach has been integrated. Displaying the player's score provides extrinsic motivation in the form of a reward, encouraging continued participation and interaction with the game.

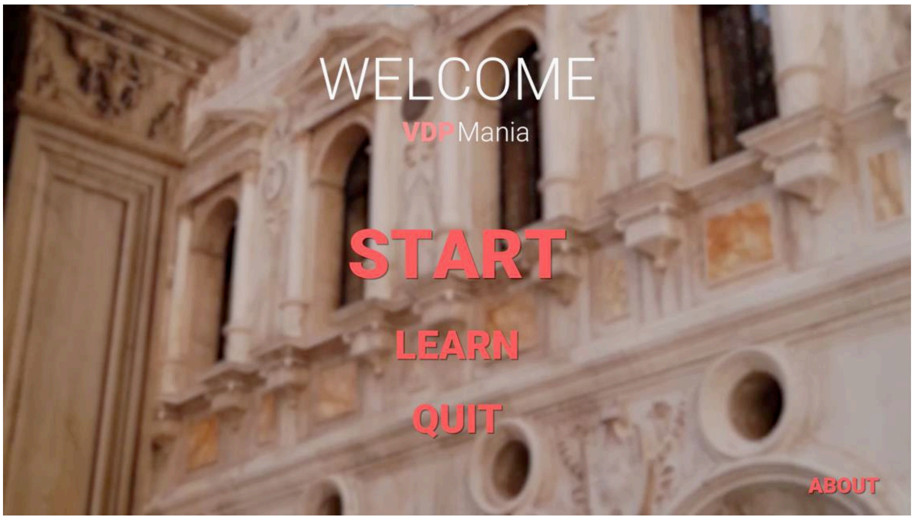

Figure 3 The "Welcome Screen" of the game

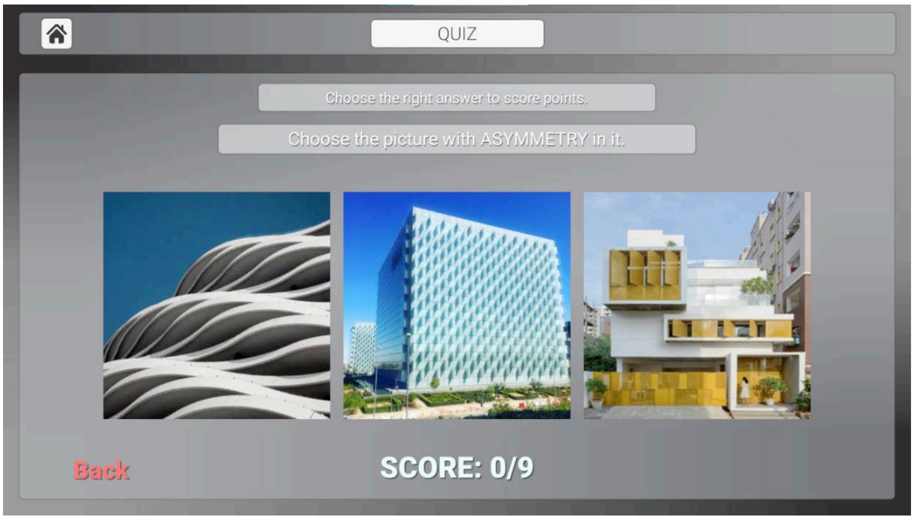

Figure 4 Quiz game mode

In the CREATE section within the "START Menu," players are presented with a task outlining which VDP(s) must be adhered to in the composition to achieve a higher score. A column displays various tools for creation: materials (objects and shapes for addition), delete, rotation, color change, color saturation change, and scale change. Each button in the game is labeled with text explaining its respective function. The main portion of the screen is dedicated to a grid, serving as the canvas for composition creation (Figure 5). Shapes and objects can be moved around the grid via mouse button drag-and-drop, with automatic snapping to the nearest grid slot upon release. New elements can be continually added to the grid, while unwanted elements can be deleted through a dropdown menu on the right-hand side. Once players have completed their composition in accordance with the objective displayed, they must press SUBMIT. Upon submission, a screenshot of their composition is captured and sent to the AI model. Following image processing, VDP class ratings generated by the AI are displayed on the screen. Players have the option to either retry or return to the main menu, with respective buttons displayed alongside their score.

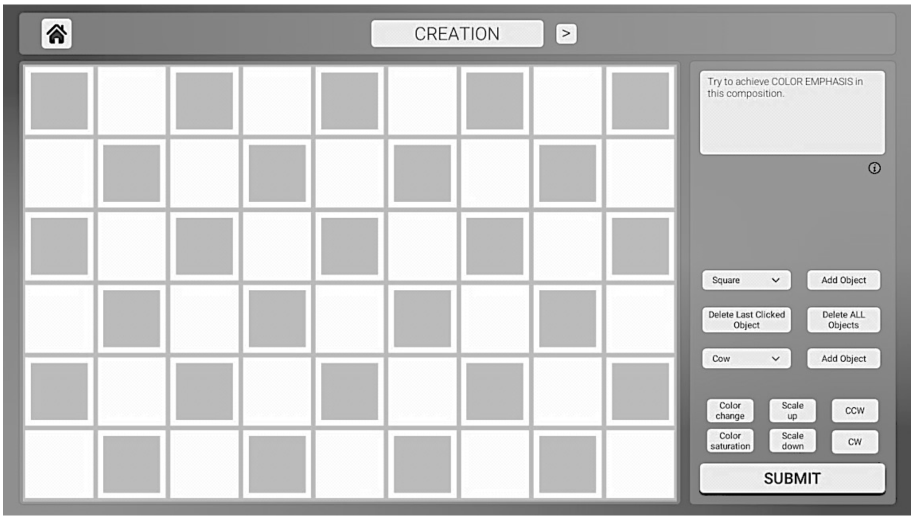

Figure 5 Creation section of the game

A tutorial video detailing the gameplay mechanics was prepared and accompanied by a QR code for easy access. Additionally, a flowchart outlining the sequential steps taken by the player during gameplay was created. These supplementary materials are available from Karakaya (2023).

3.3.2. Integration of AI

The integration of the machine learning model into the game is facilitated through Python. The AI operates on an image provided to it, which, in the context of the game, comprises compositions generated by students in the CREATE section. A screenshot of the student's creation is captured and stored in the game's data path. The image's path is then passed to the transforms.Compose() function of the Torchvision library to prepare the image for input into the model. Torchvision offers numerous common image transformations within the torchvision.transforms module. The image is resized to match the dimensions of the images used for training the model, ensuring uniformity in size. Subsequently, normalization is conducted using the mean and standard deviation values obtained during model training. Following this, the model is loaded using the parameters acquired during training. The eval() function from the PyTorch library is utilized to record the model's output for the new image. Upon passing the output through the torch.sigmoid() function, probabilities are obtained for each category. By utilizing the torch.topk() function with a parameter k set to 3, the three categories with the highest probabilities are extracted. Subsequently, the top three categories, along with their corresponding probability values, are written to an output file. Earlier, the category names were defined as: [“symmetric”, “color”, “progressive”, “regular”, “crystallographic”, “flowing”, “isolation”, “shape”, “asymmetric”].

Once the Python code completes execution, an output text file containing the results is generated in the game's data path. These results indicate the VDPs present in the student's composition as evaluated by the AI. A C# script, created via the Unity Editor, reads this text file and incorporates the results into the game, displaying them on the score screen at the end of the CREATE section. As the Unity Editor exclusively supports JAVA or C#, the steps involving the Python code cannot be directly implemented into the game. To address this challenge, all aspects of the Python code for the AI were packaged into a single .exe file. This file format is compatible only with computers operating on Windows systems, thereby restricting the game's accessibility to computers with iOS operating systems, as a constraint for the experiments. Despite the relatively small size of all other assets used in the game, packaging all libraries into a single file significantly increased the game's size, resulting in a final product size of 543 megabytes.

3.4. Evaluation Criteria

This study employs several methods to comprehensively assess the holistic gaming experience, including aspects such as overall quality, usability, enjoyment, narrative flow, technical performance, and player satisfaction. Questionnaires or surveys serve as main instruments for eliciting subjective evaluations concerning various facets of gameplay. The CEGE-Q ("Core Elements of the Gaming Experience-Questionnaire," given in Appendix-1) emerged as the most suitable user-centric methodology for this research due to its conciseness and manageable length, consisting of 38 items. It is notably succinct compared to the extensive 163-item "Presence-Involvement-Flow Framework" (PIFF) scale (Takatalo et al., 2015), which is a psychological research framework to study experiences in digital games. The CEGE Model, introduced by Calvillo-Gámez et al. (2015), draws upon the realms of 'video games' and 'puppetry' to engender enjoyment within players. Video game components are game-play and environment. Game-play outlines the core mechanics, rules, and storyline of the game. The environment pertains to the game's presentation, including its visual and auditory elements. Puppetry refers to the player's interaction with the video game. Puppetry describes how the player engages with the game, leading to the game's outcome based on the player's actions. This interaction is influenced by three factors: control, ownership, and facilitators.

Observable variables associated with these elements (such as scenario and rules for game-play, or graphics and sound for environment) are considered as items in the questionnaire context. Constructed with 38 items distributed across 10 scales (refer to Table 1), the CEGE-Q underwent modifications in this study, involving the removal of items 10-12, 19, 23-25, 27, 28, and 30-32, which pertained to aspects like achieving victory in the game, sound effects, and musical accompaniment. Consequently, the questionnaire was refined to include a total of 26 items. Participants rated each item on a 7-point Likert scale to indicate their opinions, attitudes, and feelings about their gaming experiences. This scale was chosen for its ease of use and ability to simplify working with quantitative data, allowing straightforward conclusions, reports, and graphs from the responses.

Table 1 The Items in the Questionnaire Belongs to Different Scales, Calvillo-Gámez et al. (2015)

Items	Scale 1	Scale 2
1, 4, 5	Enjoyment	-
2, 3	Frustration	-
6–38	CEGE	-
6–12, 38	Puppetry	Control
13–18	Puppetry	Facilitators
19–24	Puppetry	Ownership
25	Puppetry	Control/Ownership
26–31	Video-Game	Environment
32–37	Video-Game	Game-Play

Students are provided with additional open-ended follow-up surveys pertaining to the educational objectives of the game, integration of artificial intelligence, and subjective feedback concerning gameplay. They are listed as:

- S1: Did the preceding sections of the game (educational and quiz segments) provide supportive contributions to the subsequent design phase?
- S2: How did you find the artificial intelligence module's predictions on the composition you generated in the design phase? Was this feedback enjoyable? Did it motivate you to explore alternative patterns?
- S3: Did the game support your learning or enhancement of basic visual design principles?
- S4: What were the features you liked and disliked in the game? (Including technical aspects of the game)

- S5: Were there things you wanted to do in the game but couldn't due to the constraints of the game's storyline and mechanics? If so, what were they?
- S6: Is there any other topic you would like to address regarding game development and further improvement?

Moreover, two game metrics are employed in this study to enhance understanding of gameplay dynamics. Due to the inability to establish suitable hooks in the game engine for logging user data, students were queried about their playtime and duration spent in the game. These metrics offer a quantitative measure of players' overall commitment to the game. They can also map patterns of usage; such as whether players tend to engage in shorter, more frequent sessions or longer, less frequent sessions. CEGE-Q and other game-specific questions were web based structured by using Google Forms and accessible through the MAIN MENU: ABOUT section in the game.

3.5. Experiment

Testing a game during its developmental phase is crucial for ensuring the successful delivery of a high-quality software product. This examination takes the form of "beta testing," wherein the game is made accessible to a select group of external users who represent the target audience. Game testing experiment is structured as follows:

Objective:

The experiment was designed to evaluate the effectiveness of the AI-supported game in enhancing students' understanding of basic design principles. Beta testers play a pivotal role by providing valuable feedback and identifying issues or areas requiring improvement.

Participant Selection:

We recruited participants from a cohort of first-year architecture students enrolled in the 2023-24 Spring Semester ITU, Faculty of Architecture mandatory course "Introduction to Architectural Design Computing." Prior knowledge of design principles was not a requirement for participation. To assist students who might be unfamiliar with these concepts, we included an explanatory section within the game (see Section 3.3.1). Most of the selected students had also completed 'Foundation Studio' courses, including 'Basic Design and Visual Arts,' during the preceding Fall Semester. These courses provided them with experience in understanding and applying design elements and principles in both 2D and 3D formats.

A total of 126 freshmen students (89 female and 37 male) agreed to participate in the game testing and subsequent questionnaire. The participants' ages ranged from 18 to 22 years old. It was emphasized that all data, including participant responses, would remain anonymous and solely used for the purposes of the study. Considering the straightforward mechanics and controls of the game, the gaming experience was not a decisive factor in participant selection.

Intervention (Game play):

The experiment commenced within the classroom setting, with students receiving both verbal and written briefings detailing the procedures for downloading and installing the game documents. The QR code, serving as a tutorial for the game, was distributed to the students. This preparatory phase was overseen by both authors and two instructors of the course, who addressed any inquiries pertaining to the process. Following the introduction session, participants were instructed to individually play the game during class time, utilizing their personal computers. They were apprised that the game was not constrained by time limits and could be continued at their discretion, albeit with a requirement to submit their findings and responses within a one-week timeframe. Those using MAC computers running iOS were advised to utilize a device with a Windows operating system or access one of the computers in the faculty's laboratory.

Data collection:

The gaming session of the experiment entails two distinct phases: design and pre-design (learn and quiz) phases. Upon completion of pre-design phase, students are tasked with generating three compositions that reflect three VDPs: emphasis (involving color, isolation, or shape), crystallographic balance, and progressive rhythm. Upon completion of each composition, students are prompted to capture a screenshot, inclusive of AI predictions, and subsequently upload them to a cloud folder opened by the administrator. Students are directed to arrange each output image on a Miro board, categorizing them by VDP, thereby creating a collective presentation of all productions. Examples of student work for each group, focusing on emphasis, rhythm, and balance, are given in Figure 6, 7, and 8 respectively.

For collecting behavioral metrics, the records of students' gameplay interactions were gathered, including the amount of time spent on tasks and the frequency of tool usage. These metrics help in quantitatively understanding engagement levels. After completing the game, students were asked to fill out surveys that included both Likert-scale CEGE questions and six additional interview-like questions about their experiences. These surveys provide subjective data and valuable insights related to the students' perceptions of the game.

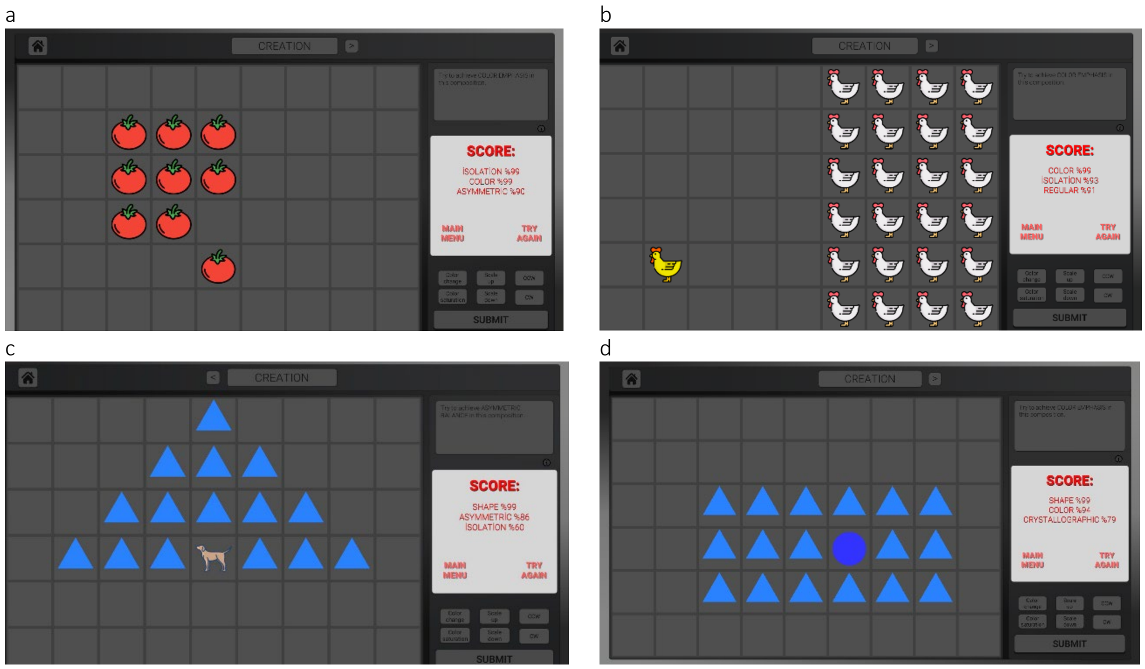

Figure 6 Emphasis (Isolation, color and shape) works by (a) E. B. (b) A. Y. (c) G. A. (d) S. A.

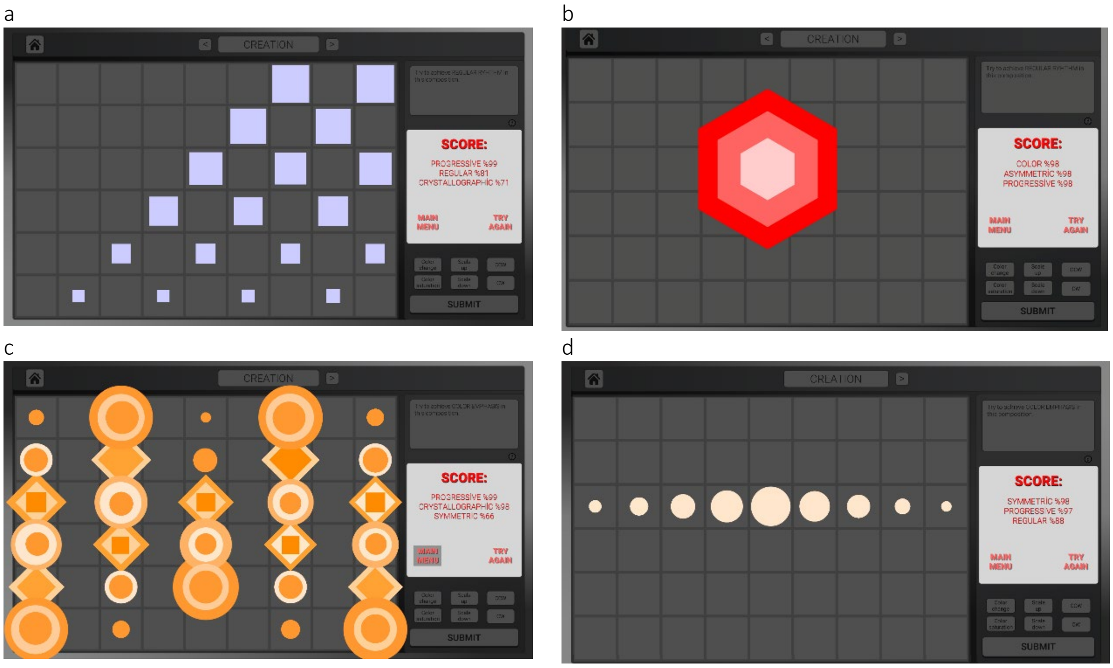

Figure 7 Progressive rhythm works by (a) B. S. Ö. (b) N. Y. (c) Z. B. (d) E. B. K.

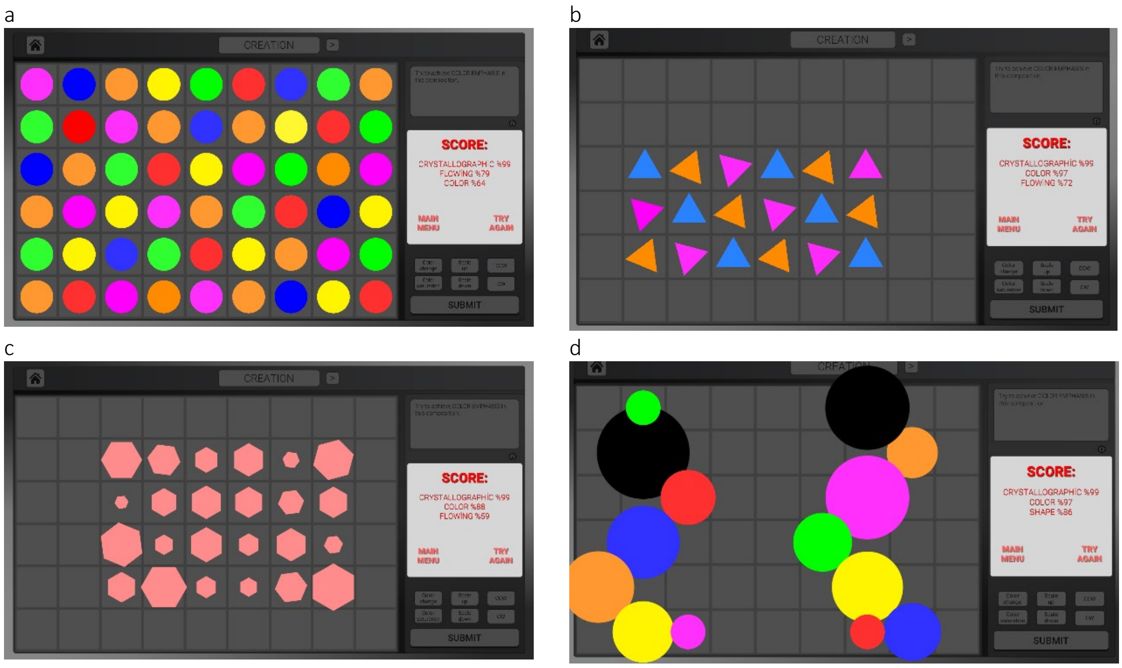

Figure 8 Crystallographic balance works by (a) S. A. (b) E. D. (c) D. A. (d) Y. S. M.

3.6. Data Analysis and Results

Upon examining the metrics, it becomes apparent that, on average, students remained engaged in the game for approximately one hour, with reported minimum and maximum playing times of 33 and 85 minutes, respectively. This data furnishes us with a reliable estimate of the game's duration, accommodating variances in play styles and strategies. Such insights are instrumental in planning game sessions efficiently, enabling us to gauge the time required for players to create a composition while maintaining immersion without becoming overly prolonged. Notably, 79% of participants completed the game with only one play, while the remainder participated two or more times. This suggests that the majority of students can feasibly accomplish all tasks within a single session without waning interest. Given the game's goal achievement nature, a high frequency of logins may not necessarily directly correlate with strong engagement in the game.

When examining the first five questions of the CEGE-Q, specifically addressing ‘enjoyment’ and ‘frustration’ scales, the distribution of ratings is illustrated in Figure 9. Questions 1 and 4 exhibit a significant alignment, with half of the participants expressing enjoyment through higher Likert values, while 25% selected values in the middle range, and the remaining 25% opted for lower values. Similarly, for Question 2, only 19% of students (24 out of 126) agreed that they experienced frustration at the conclusion. Our analysis indicates that students who enjoyed the game were more likely to engage deeply with the material, suggesting a positive correlation between enjoyment and educational quality.

The remaining items of the CEGE-Q, focusing on aspects related to video-game and puppetry, can be synthesized as follows: in the context of the ‘puppetry: control’ scale group, students expressed that they could remember the inputs provided by the controllers (Q-8, mean: 5.2); alongside an affirmation of clear visibility of necessary on-screen elements during gameplay (Q-9, mean: 4.96), and a recall of the actions performed in the game (Q-38, mean: 5.02). Question 14, associated with the ‘puppetry: facilitators’ category, revealed a consensus regarding the game’s graphical simplicity (mean: 5.17). For Question 29, which belongs to ‘video-game: environment’ scale, students conveyed that the graphical elements of the game were consistent with the scenario depicted (mean: 5.17). Lastly, the question about ‘video-game: game-play’ (Q-33) scale showed that most participants understood the rules of the game, with an average score of 6.

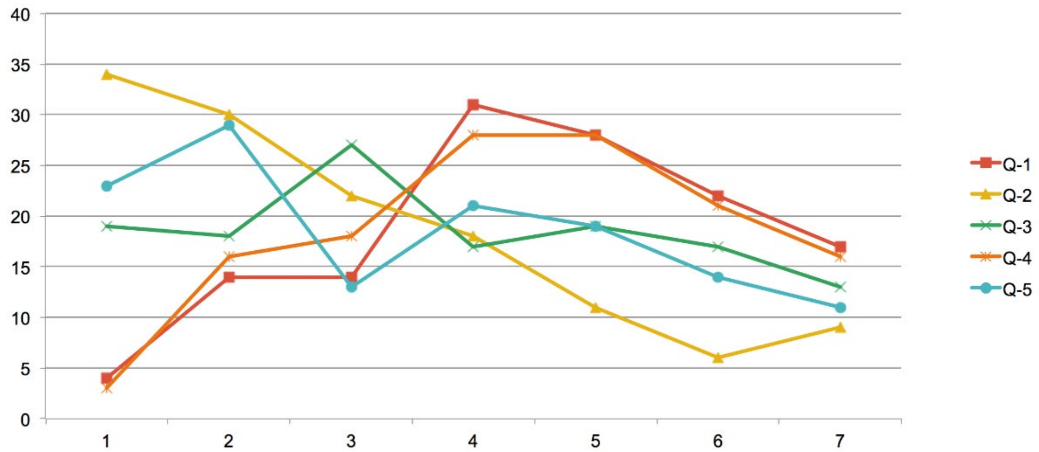

Figure 9 Distribution of the scores for first five questions

The open-ended game-specific questions provide valuable insights into participants’ experiences. Regarding the query labeled S1, addressing the supportive elements of preceding game sections, a mere 9 out of 126 respondents noted minimal or no contribution. Conversely, the majority expressed strong affirmation, citing an array of concrete examples and commending the visually stimulating elements. They emphasized the educational component as being helpful, descriptive, informative, and conducive to a better understanding of the concepts. Additionally, some participants appreciated the convenience of accessing information within the game interface without exiting. Some players mentioned they revisited instructions and consulted learning materials before designing, underscoring the reinforcing effect of prior knowledge on successful game completion.

In regards to the Question: S2, the AI component in the game received highly positive evaluations from a significant majority of participants (78%). They found this aspect to be both accurate and effectively functional, as well as entertaining, adding an enjoyable dimension to the game. While for some, liking the AI did not provide enough motivation to sustain prolonged engagement, for the majority, it sparked greater ambition to generate new compositions and continuously strive for improvement. Several respondents expressed excitement and pleasure in awaiting the AI-generated results. Feedback often aligned with expectations, reinforcing feelings of success upon achieving desired outcomes. Conversely, instances of surprise arose when the AI produced unanticipated results, prompting participants to reconsider their approach. They also learned from their 'mistakes' when the result possibilities appeared on the screen. Some comments referred to the capabilities of AI, including attempts to test it and observe how its responses changed when the pattern changed. Overall, the AI integration not only enhanced enjoyment but also fostered innovative thinking and experimentation. During the experiment, only 11 students were undecided, and 18 expressed negativity toward the inclusion of AI. Their reasons were largely linked to AI's inaccurate classification and shortcomes in explaining the rationale behind its choices. The errors of AI could stem from the algorithm's inability to fully grasp complex design nuances. The impact of these inaccuracies includes potential student frustration and misguidance. Future improvements may involve refining the training data and incorporating more sophisticated AI techniques to enhance accuracy. A few students found the feedback of AI model overly predictable, describing it as 'boring' in that regard.

Questioning the educational purpose of the game (S3) yielded highly positive results from participants, with 110 students affirming its efficiency. Many acknowledged that the game facilitated learning, understanding, and retention, particularly in enhancing their VDPs especially "*by applying*." Some students compared it to a self-assessment tool, describing it as a way to "*test myself*." Some answers highlighted the active engagement and participation fostered by the game:

"I can't say that I learned it in this way, but it helped me improve my creativity in this field."

"Yes. It is a good practice to learn well."

"Yes it made me use them whilst thinking about them not just passively use them.

"Yes, I think practical training is always more teachable."

"Yes it improved. It was a kind of brain training. It was fun trying to find a way with different alternatives within certain limits."

Some responses indicated the potential for the game to assume a supportive role in the basic design course, portraying it as an assistant tool:

"Yes, it supported. It enabled me to make memorable and reinforce what I had learned in depth in the basic designs of the previous semester."

"Yes, we had previously created such compositions from papers in the basic design homework. This game has become much more practical with artificial intelligence."

The critical feedback regarding S3 was also informative. 9 students expressed uncertainty, and 11 held negative views about the educational purpose of the game. One participant remarked that the game seemed inadequate for architecture students, particularly those focused on visual design, adding, "*I believe it would be more beneficial for other disciplines to grasp basic visual design concepts*." Two other students found the game unnecessary and overly simplistic for similar reasons. Additionally, one student stated that relying solely on a 2D grid to learn these principles would not be sufficient. Recognizing the limitations of a solely 2D platform, we aim to incorporate 3D design exercises in future versions. We also plan to enhance the game's complexity and add features that challenge students more effectively.

We also surveyed students about their likes and dislikes regarding the game (S4). The findings are summarized in Table 2, categorizing responses based on game design components. The largest number of negative comments revolve around technical issues, particularly bugs related to object interactions and responsiveness. These bugs significantly impact the gameplay experience and require attention for user satisfaction. Students expressed a desire for more intuitive and user-friendly controls, as well as additional keys for common actions. Future updates will focus on enhancing the control scheme to make the game more accessible.

Table 2 Coding Analysis of the S4 Data Obtained from the Participants

concepts of game design	number of students	(a) negative comments
bug	18	new object sticks to another object/ overlapping/ lack of layering
bug	16	not responding immediately/ slow/ crush/ freezing LAG
bug & mechanics	16	not easily place shape on the grid/ can not move objects freely
controls	8	need easier commands
graphics	8	few shapes (not variety in shape)
controls	6	adding simple control keys of copy, paste and undo
UI	5	accidentally clicking 'Deleting all' button (too close to the 'add a new object' button)
controls	4	being fully control of the game; controller was not sufficient
graphics	4	color variation; using a color spectrum and select among
bug	3	not detecting the objects clicked on, but select one another
bug	3	wait for AI responses/ results of AI
graphics	3	grid limitation
UI	3	better visual display and interface
level design	3	saving option, the game only works once every time
level design	3	trying again the same composition after the results come back
bug	2	difficulties in downloading
game mechanics	2	getting difficulty in changing size, color, direction etc.
controls	1	move an objects by a click instead of carrying it
graphics	1	size limitation
game mechanics	1	not remembering the last color setting of shape
game mechanics	1	incapable of selecting multiple objects for change
UI	1	understanding the selection (like a frame appearing)
concepts of game design	**number of students**	**(b) positive comments**
story and narrative	10	the idea behind the game (the aim; its logic; visual thinking)
story and narrative	10	sufficient examples and the pre-game information and quiz part
game mechanics	9	simple and understandable (commands and movements)
game mechanics	7	color or Size or orientation change
graphics	7	having options, different features
story and narrative	6	AI part
UI	6	Interface easy, plain
graphics	4	funny icons and shapes
story and narrative	4	like the idea of creating something on your own
game mechanics	2	creating compositions by using simple geometric shapes
graphics	2	grid system and layout

Feedback on graphics highlights concerns such as the limited variety of shapes, constraints in color options, and restrictions on size. Enhancing graphic quality and providing more customization options will be prioritized to make the game more visually appealing and creative. Various issues related to game mechanics were mentioned, including difficulty in changing object properties (size, color, direction), inability to remember settings, and challenges in selecting multiple objects for modification. Addressing these concerns in future versions will streamline the gameplay experience and make it more efficient for users. Several students highlighted problems with accidental actions (such as unintentionally deleting objects) due to the current UI design. This indicates that the UI may not be intuitive or responsive enough. Refining the UI will help prevent these issues and improve overall usability. Finally, incorporating features like progress saving in level design can make the gameplay experience more engaging.

In terms of positive feedback, players have expressed appreciation for several aspects of the game. They value the underlying concept, as well as the provision of adequate examples and pre-game information. The AI aspect has also been recognized as a noteworthy component. Players emphasize the simplicity and clarity of the game mechanics, alongside the ability to create compositions using simple geometric shapes. The graphics have been well-received, attributed to the presence of appealing icons and shapes. The inclusion of a grid system and layout was also positively remarked upon for effectively managing visual clarity and organization. Additionally, the user interface is commended for its ease of use, facilitating overall accessibility and navigation within the game.

Regarding S5, which asked users about anything they wished to perform in the game but were unable to due to its design constraints, we observed some similar responses to those in S4. However, there were also distinctive comments, which offered innovative and suggestive insights. Primarily, participants expressed dissatisfaction with the 'limited space' of the grid, both in terms of being unable to work within a larger area and not being able to place objects at any point within the frame. This limitation hindered their ability to create desired compositions and restricted their design freedom. One participant noted, *"I couldn't work completely free because the shapes were placed at the exact central points. I could have gone through a more disorganized layout."* Some participants had remarkable requests within the game, including the following ideas:

"I wish I could move from 2D drawing to 3D."

"… maybe, I wish I make more curvy designs"

"I would liked to create new objects (shapes) with myself"

"Yes. There was nothing we could add as a background."

All of these refer to the students' expectation for more freedom within the game, akin to that found in 2D/3D design software. This entails shapes being able to perform more actions than just rotating and resizing; as one student articulated: *"I would like to be able to change more properties of shapes, such as stretching one side of a square to make it a trapezoid."* They seek greater ease in manipulating forms, including the ability to move them freely, duplicate them, and even array them, similar to functionalities available in many digital drawing tools they are accustomed to, such as AutoCAD. A comment pertained to the desire for more precise control over objects: *"When we want to enlarge objects, we can change their size by entering numbers instead of pressing constantly because I had a hard time getting them to the same size."* Implementing more advanced shape modification capabilities, and bringing the game interface closer to the current CAD tools in the future reconstruction of this game can attract more users and continue accustomed design-making behavior.

The final question (S6), inviting participants to write about any other issues they would like to mention regarding game development and potential improvements, also yielded fruitful comments. Students suggested adding different levels and increasing the game's difficulty, as well as expanding the quiz session. One student proposed the inclusion of a time limit as a challenge and pressure for the user, which could enhance gameplay. Another student suggested adding music: *"maybe the game can include some specific music, for every single stage."* Finally, there were requests for more architectural information and additional building features, and the implementation of design patterns in 3D format.

4. Conclusion

Within the field of architecture education, there exists a promising space for game developers and researchers to introduce novel approaches by integrating elements of serious games and game-based learning. This study introduces a new digital game, currently in the testing phase, targeting first-year architecture students. It aims at a reinforcement of their basic design knowledge through creation of simple 2D compositions embodying specific visual design principles. The compositions crafted within the game are then assessed by an AI model capable of predicting the underlying design principles. This AI model draws from a separate body of research, having been trained on thousands of labeled art objects, photographs, and architectural views. By leveraging this technology, students are offered self-learning capabilities, enabling them to critique their work autonomously without the immediate presence of an instructor.

After elaborating the game's planning and production stages, this paper proceeded with a testing phase employing a series of user experience methodologies. The overall findings, derived from 126 first-year architecture students, indicate a strong positive response towards various aspects of the game, ranging from AI integration to usability. They particularly appreciated the underlying concept of utilizing Digital Game-Based Learning (DGBL) in architectural education, focusing on basic design principles. Detailed feedback was collected through a game-specific survey, which highlighted issues such as bugs and limitations in game mechanics, graphics, and user interface (UI). Addressing these concerns is essential for improving satisfaction and retention rates. In achieving self-directed learning, we can highlight that the AI component was found motivating by students for sustaining prolonged engagement. They generated compositions, took feedback, and re-generated new ones to get accurate predictions. They also learned from their mistakes by reflecting on the AI's responses. This interactive nature of the game promoted a deeper, experiential learning process. Moreover, the game allowed students to explore multiple patterns quickly, free from class settings and course requirements. Aligned with constructivist learning theory, the game facilitated understanding and direct experiences, particularly enhancing students' knowledge of visual design principles (VDPs) by "applying" them in practice. Students appreciated this hands-on participation, not just passively learning design principles but actively using them. Additionally, students suggested adding features to increase the challenge, such as time limits and varying difficulty levels. Implementing a scoring system as a reward mechanism, based on AI results, could enhance the game experience. These suggestions relate to the game's motivational potential and could be included into future versions. Depending on Self-Determination Theory, we could measure student motivation through a new experimental setting in further research, gaining further insights into their willingness to engage in gameplay.

In the agenda for further studies to develop and refine this game, several enhancements are planned. One proposed mechanism involves enabling students to capture and upload photos corresponding to requested design principles, which would then be evaluated by AI. Additionally, various interactive game modes may be incorporated to enhance enjoyment during educational sessions. The potential for a mobile app version is also promising, offering opportunities to integrate augmented reality for real-time manipulation of scenes. This would introduce new control mechanisms, such as touchscreens instead of mouse input, potentially improving usability. In response to student feedback, the AI component could be expanded beyond mere 'label' provision to actively generate revised compositions based on identified principles. While implementing this generative aspect will require additional technical work, visual representations such as heatmaps could be consulted to elucidate how AI detects principles within images, indicating the specific features influencing its predictions.

The game-related experiments in this research could benefit from enhancements. Integrating behavioral and game metrics with synchronized physiological sensor data could provide a more comprehensive understanding of the player experience. It's important to consider tracking login patterns to identify any recurring trends, such as semester-based patterns, which could offer valuable insights into user engagement over time.

The game still requires conducting experience testing across various institutions and for diverse skill level students to gather broader feedback and identify potential improvements. Additionally performing longitudinal studies to evaluate game's impact on students learning through the proceeding years of education will be a feedback for educational basis.

The game can be adapted and evaluated in various educational and research context. The game is devised to incorporate into different course curriculums as a supplementary tool, also compare learning outcomes with traditional methods. The game inherits a capacity for cross-disciplinary applications, such as in visual arts, engineering and computer science, to assess it effectiveness in different learning environments.

The game developed in this research is planned to be available through an open-access platform, allowing other educators and researchers to use it. This will facilitate wider adoption and potential improvements by the community. In conclusion, while educational games in architecture face numerous challenges in achieving high-quality, stable products in the market, the underlying motive and ultimate goal aspire to cultivate a more engaged, interactive, and enjoyable learning environment within architecture schools.

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Appendix-1:

Core Elements of the Gaming Experience Questionnaire (CEGE-Q):

1. I enjoyed playing the game
2. I was frustrated at the end of the game
3. I was frustrated whilst playing the game
4. I liked the game
5. I would play this game again
6. I was in control of the game
7. The controllers responded as I expected
8. I remember the actions the controllers performed
9. I was able to see in the screen everything I needed during the game
10. * The point of view of the game that I had spoiled my gaming
11. I knew what I was supposed to do to win the game
12. * There was time when I was doing nothing in the game
13. I liked the way the game look
14. The graphics of the game were plain
15. * I do not like this type of game
16. I like to spend a lot of time playing this game
17. * I got bored playing this time
18. * I usually do not choose this type of game
19. * I did not have a strategy to win the game
20. The game kept constantly motivating me to keep playing
21. I felt what was happening in the game was my own doing
22. I challenged myself even if the game did not require it
23. I played with my own rules
24. * I felt guilty for the actions in the game
25. I knew how to manipulate the game to move forward
26. The graphics were appropriate for the type of game
27. The sound effects of the game were appropriate
28. * I did not like the music of the game
29. The graphics of the game were related to the scenario
30. The graphics and sound effects of the game were related
31. The sound of the game affected the way I was playing
32. * The game was unfair
33. I understood the rules of the game
34. The game was challenging
35. The game was difficult
36. The scenario of the game was interesting
37. * I did not like the scenario of the game
38. I knew all the actions that could be performed in the game

* Denotes items that are negatively worded.

Reliability of CEGE-Q:

The Cronbach alpha for the whole questionnaire is 0.794 and for the CEGE scale is 0.803.

Resume

Asli Cekmis is an Assist. Prof. Dr. in the Department of Architecture at Istanbul Technical University (ITU). She teaches in the graduate programs of Architectural Design Computing, and Game & Interaction Technologies. Her research focuses on soft computing methods and AI applications in building design. She also teaches undergraduate courses, including 'Basic Design and Visual Arts,' to first-year students in the ITU Faculty of Architecture.

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