

# The CLG Framework: A Methodical Approach to Designing Educational Video Games

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**Abstract.** This paper introduces the Context Learning Game (CLG) framework, a game design framework developed for educational video games in formal education settings. The CLG framework is structured into three stages: context, learning, and game. The *context* stage establishes general game aspects such as the objectives, target audience, and available resources. The *learning* stage defines formal learning components, including learning theory, content, learning objectives, and learning activities. Finally, the *game* stage encompasses the formal game elements, development, and testing. The stages are hierarchical, with the *context* forming the foundation for the *learning* stage, and both serving as the basis for the *game* stage. The framework aims to integrate concepts from educational video game design, entertainment game design, and educational design while providing a simple iterative workflow. To illustrate the framework's potential, a successful case study of an educational game's design, development, and testing process is presented.

**Keywords:** educational video game, design framework, design model.

## 1 Introduction

Creating educational video games is a challenging activity that requires careful consideration of both the formal aspects of a video game and the educational elements it encompasses. Finding the right balance between these two dimensions can be a difficult task. Consequently, the utilization of comprehensive yet user-friendly frameworks or methodologies becomes essential in guiding the design, development, and testing processes of educational video games.

This paper introduces the Context Learning Game (CLG) framework, a comprehensive design framework for educational video games. The CLG framework specifically focuses on creating engaging and enjoyable educational video games for formal educational settings. Criticism has often been directed towards educational video games for their failure to deliver an enjoyable experience [30]. Additionally, it is known that disguising educational content can lead to negative learning outcomes [30]. To address these concerns, the CLG framework combines concepts and principles from educational game design frameworks and entertainment video game methodologies. The application of entertainment game design principles brings several benefits: (1) it aims to

create an enjoyable experience that meets the player's expectations; (2) it provides mechanisms to systematize the design process; and (3) it incorporates testing as an integral part of the design process.

Additionally, the CLG framework utilizes the alignment principle, which suggests for the alignment of all learning components with a learning theory (as explained in section 2.4), to guide the design process of the educational aspects in video games. The alignment principle offers several benefits during the design process: (1) it enables the creation of theory-based foundations for the learning process; (2) it helps the designer integrate the learning aspects with the game's ludic elements; and (3) it provides a means to assess the players' learning progress and the effectiveness of the video game. The alignment principle ensures that the video game meets the rigorous requirements for use in a formal educational environment.

The CLG framework offers several contributions: (1) it integrates concepts and principles from educational game design, entertainment game design, and educational design into a framework with a simplified structure and workflow; (2) thanks to the learning alignment principle, educational video games developed using the framework will possess the necessary theoretical rigor for implementation in formal educational environments; and (3) it provides guidance on the artifacts (e.g., game documents, reports, prototypes, etc.) that may be developed at each stage of the workflow.

The objective of this paper is to make the CLG framework widely accessible and available for independent use and validation by other researchers. Furthermore, we present a compelling case study of the CLG framework by applying it to a specific game design process discussed in Section 4. While we acknowledge that this case study does not constitute formal validation of the framework, it serves to demonstrate the framework's promising potential. We hope that this example will inspire other researchers and designers to adopt the CLG framework in their own projects.

This paper is organized as follows: Section 2 provides a literature review related to design frameworks for educational video games, design methodologies for entertainment video games, and the alignment principle. In Section 3, we present the CLG framework. Section 4 showcases a successful case study of the CLG framework by presenting a successful educational video game that was designed using it. Section 5 discusses the features and limitations of the framework. Finally, Section 6 concludes the paper, summarizing the key findings and contributions.

## **2 Related Work**

### **2.1 Design and Evaluation Frameworks for Educational Video Games**

This subsection provides a review of six design frameworks for educational video games, forming the foundation of the CLG framework. Each review highlights the features and limitations of the respective framework. Our review focuses exclusively on frameworks specifically designed for serious educational games, excluding those intended for heritage, marketing, or rehabilitation purposes. Additionally, we have

omitted general-purpose serious game design frameworks as they do not emphasize the theoretical foundations of learning.

The Four-Dimensional (4D) framework [12] is an assessment tool designed to evaluate the learning potential of educational video games. Its objective is to assist educators in selecting appropriate games and learning strategies that align with their specific learning objectives (LOs) and environment. The framework encompasses four dimensions: *context*, *learners*, *internal representational world*, and *processes of learning*. The *context* dimension considers the learning environment, including historical, political, and economic factors, as well as the availability of resources and the instructor's technical understanding. The *learner* dimension assesses factors such as age, knowledge level, learning background, styles, and preferences. The third dimension focuses on the *internal representational world* of the game, including aspects like mode of representation, interactivity, immersion levels, and fidelity. Lastly, the *processes of learning* dimension evaluates the methods, theories, models, and frameworks that support the learning experience. The main strength of the 4D framework lies in its emphasis on learning aspects and the contextual factors that influence game design. By considering learning theory, content, activities, learner characteristics, and available facilities, the framework enables the creation of games that meet specific learning requirements. However, it does not provide extensive information regarding the design and development of game elements.

The framework introduced by Aleven et al. [2] serves as a tool for analysing and designing educational video games. It consists of three components: (1) learning objectives, (2) the MDA framework (Mechanics, Dynamics, and Aesthetics), and (3) Instructional Design Principles. The first component, *learning objectives*, focuses on defining specific goals to enhance the effectiveness of the learning process. The *MDA framework*, which originally analyses entertainment video games [15], examines games through three layers: *mechanics* (game components such as materials, rules, goals, basic moves, and control options), *dynamics* (player interactions and resulting behaviours), and *aesthetics* (player experiences and emotional responses). The third component, *Instructional Design Principles*, incorporates research-based principles for instructional design. For instance, the framework suggests utilizing principles like the Multi-Media Principles [21], the Cognitive Tutor principles [3], and Gee's 36 principles of game-based learning [13]. The primary strength of the framework lies in its emphasis on learning aspects, as it emphasizes the importance of defining LOs and incorporating relevant learning theories or principles to create effective educational games. However, the framework does not account for the specific contextual factors that influence the learning experience.

The Serious Game Design Assessment (SGDA) framework, designed for evaluating educational video games [24], focuses on six key components: purpose, contents and information, game mechanics, fiction and narrative, aesthetics and graphics, and framing. The *purpose* component assesses the game's objectives and the intended impact on players. The *content and information* component evaluates the information and facts presented within the game. The *game mechanics* component describes the actions and interactions available based on the game's rules and algorithms. The *fiction and narrative* component analyses the fictional elements, such as settings, story, characters, and

problem presented in the game. *Aesthetics and graphics* encompass the audio-visual aspects that materialize the game's content, fiction, framing, setting, and mechanics. The *framing* component considers the target group and their characteristics. The SGDA framework excels in its emphasis on the playful aspects of educational game design and their role in facilitating learning. However, the framework primarily focuses on analysis, neglecting aspects like prototyping and testing in the design process.

The Game for Learning Institute's (G4LI) framework for Game-Based and Playful Learning examines and designs educational video games from a pedagogical and psychological perspective [25]. It emphasizes four foundations: affective, behavioural, cognitive, and socio-cultural. The *cognitive* foundation focuses on processing learning content and cognitive load during gameplay. The framework suggests incorporating learning principles such as situated learning, transfer of learning, scaffolding and feedback, and dynamic assessment. The *motivational* foundation addresses game aspects that promote engagement and continued participation, including intrinsic and extrinsic motivation, individual interests, and goal orientation. The *affective* foundation considers emotions, attitudes, and how game elements can foster positive engagement for learning. The *socio-cultural* foundation focuses on facilitating social interactions and knowledge construction in games. G4LI's framework highlights educational, affective, and social aspects but does not consider contextual factors such as aspects of game design, available resources, and development context.

The GAGE (Goal, Audience, Game, Environment) framework [18] emphasizes four essential categories (goal, audience, game, and environment) along with two optional elements (stakeholders and experience) in educational video game design. The *goal* category defines LOs, content, and instructional methods. The *audience* category considers player characteristics, including demographics and academic information. The *game* category focuses on the logical, functional, and technological aspects of the game. The *environment* category addresses social, physical, and technological factors that may impact gameplay. The *stakeholder* category involves actors involved in design, development, and distribution. The *experience* category encompasses elements added by the designer to enhance player motivation. Deep learning is emphasized, requiring the selection of an appropriate learning theory. The GAGE framework is comprehensive, considering design context, learning aspects, and game elements. However, it lacks specific guidance for the design and development process, such as a workflow or inventory of necessary artifacts.

Medina-Medina et al. [23] propose four key axes that guide the design process of an effective educational video game: (1) integrating the educational team throughout the design and development stages, (2) incorporating educational aspects into the game elements, (3) utilizing an engaging narrative for learning, and (4) implementing an assessment system within the game. The framework places particular emphasis on learning and assessment aspects, increasing the likelihood of meeting educational requirements. However, it does not extensively address the ludic elements of the educational video game, such as game mechanics, levels, and challenges, nor does it provide specific guidelines for their design.

## 2.2 Game Design Methodologies for Entertainment Video Games

The Iterative Design methodology for games emphasizes playtesting and prototyping [29]. It advocates making game design decisions based on previous experiences gathered through game testing. As players' experiences are hard to predict, early testing with players is vital to increase the chance of success. Thus, game designers focus on developing an early prototype, primarily addressing key aspects like the game system, mechanics, and player interactions. Aesthetics (visual art, sound, music, etc.) are added in later iterations. The designer conducts playtesting, evaluates the results, modifies the game system based on insights, and repeats the process multiple times until the game is considered ready for delivery.

The Player-Centric framework proposes that game designers should focus on a representative player when designing their games [1]. According to this framework, a successful game should (1) entertain the player and (2) fulfil the player's expectations and desires. To implement this methodology, designers need to conduct audience research or envision an ideal player. The representative player archetype should include information about the player's gaming preferences, likes, dislikes, and motivations. Using this player profile, designers can make informed design decisions that align with the player's expectations, increasing the chances of matching the players' capabilities and limitations [14]. The Player-Centric framework follows a three-stage approach for video game design: (1) concept, (2) elaboration, and (3) tuning [1]. However, we believe that the Iterative Design methodology offers a more effective development approach.

## 2.3 Game Design Documents

A game design document is a proposal, plan, or record of a game, consisting of a description of its concept and main aspects. It serves two fundamental purposes: communication and guidance. In essence, it informs others about the game's content while ensuring consistency among all team members involved in the video game's development concerning its main concept [27]. During its early stages, the game design document is subject to continuous criticism and feedback, allowing many design concerns to be resolved at this stage.

The structure of a game design document can vary from one designer to another; however, the aims are similar. According to T. Ryan [27, 28], there are four types of game design documents: (1) game concept; (2) game proposal; (3) game functional specifications; and (4) game technical specifications. Each document serves a distinct purpose and is built upon the foundation of the previous one.

A different classification is proposed by Adams [1], who defines nine types of game design documents: (1) high concept document; (2) game treatment document; (3) character design document; (4) world design document; (5) user interface design document; (6) story and level progression document; (7) on-screen text and audio dialog scripts; and (8) game script. It is not necessary to create all of them, and some can be combined into a single document. Adams suggests that game designers should write these documents for five reasons: (1) to record design decisions; (2) to transform ideas into

specific plans; (3) to communicate the game concepts and guide the development stages of the game; (4) to set contractual obligations; and (5) to find funding.

## 2.4 Alignment Principle

When designing a learning experience (e.g., lessons, simulations, learning tools, etc.), it is necessary to define the LOs, learning activities, and assessment methods [7]. However, according to the alignment principle, these learning components must be aligned with a learning theory that defines how people learn [22]. Adopting a learning theory helps in selecting pedagogical methods that support the learning assumptions. An excellent example of the alignment principle is constructive alignment [7], which involves framing all learning elements within the constructivist paradigm. Constructive alignment is based on the idea that individuals construct their knowledge. As a result, to achieve the LOs, learning experiences must employ pedagogical methods and activities that promote active learning. Additionally, assessment methods should evaluate the construction of knowledge through active learning.

The adoption of alignment principles offers three main advantages: (1) it systematizes the design of learning experiences, which is essential in formal education; (2) it guides the consistent definition of pedagogical methods, learning activities, and assessment methods aligned with theory-based learning assumptions; and (3) it provides the theoretical foundations to critically evaluate the success or failure of the designed experience.

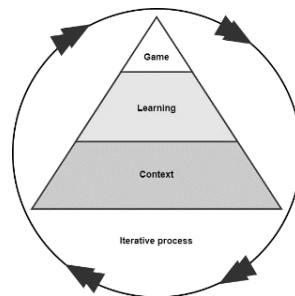
## 3 The Context Learning Game Framework

The CLG framework suggests dividing the design process for educational video games into three stages: (1) context, (2) learning, and (3) game (see Fig 1). Each stage addresses a critical aspect of the video game design process. The framework follows a hierarchical structure, where each stage serves as the foundation for the next, becoming more specialized and complex. Specifically, the context stage forms the basis for the learning stage, and together, they form the foundation for the game stage. Additionally, the CLG framework emphasizes an iterative design process, represented graphically as a circular pattern of arrows around the pyramid. The following subsections provide detailed explanations of each stage in the framework.

### 3.1 The Context Stage

The *context* stage forms the foundation of the pyramid and must be prioritized. Effective design necessitates a thorough comprehension of the problem at hand. To properly understand the problem, designers must analyse and define key contextual elements relevant to the development and utilization of the designed object. For example, designers should consider the individuals responsible for designing and developing the object, the intended users of the tool, available design and development resources, and the intended usage environment. Through a comprehensive analysis and definition of

the context, designers can identify strengths and constraints that may impact the design process and subsequent design decisions. By understanding the context, designers can enhance the likelihood of finding an optimal solution to the problem at hand.



**Fig. 1.** The CLG framework and its stages.

During the *context* stage, the game designer analyzes the problem at hand, which involves designing an educational video game, as well as the available resources to address the problem. The following list describes some context aspects that designers may contemplate:

1. The *purpose and scope* set the primary objectives and scope of the educational video game. This section offers a concise overview of the intended functions, content coverage, project scale, and desired final presentation of the game. Its purpose is to provide guidance for future design expectations and decisions. Defining this aspect requires close collaboration between the designer and relevant stakeholders involved in the game's development. A clear definition of the purpose and scope of the video game facilitates the establishment of essential elements within the context, learning, and game stages.
2. The *educational environment* encompasses the specific type of learning setting in which the educational experiences will occur. Designers should also consider internal regulations, organizational culture, and political factors that may impact subsequent design decisions. Furthermore, the educational environment considers whether it is a formal environment, such as a high school or university, or an informal setting, such as a student's home.
3. The *target audience* should cover key characteristics of the players/learners who will engage with the game. Essential aspects include demographic data, academic level, and gaming experience. This information proves valuable for defining both the learning aspects (e.g., learning theory, covered content, LOs, etc.) and the game aspects (e.g., game genre, aesthetics, narrative, challenge difficulty, etc.). An effective approach to gaining a deeper understanding of the target audience and guiding design decisions is the creation of personas as suggested in [9, 10]. Personas are profiles that represent anticipated players/learners.
4. The *facilities and equipment* section defines the specific location where the educational video game will be played, such as a classroom, laboratory, home, outdoor space, etc. It also summarizes the available equipment for playing the game, such as

high-end computers, low-end computers, tablets, smartphones, etc. This information proves valuable for making appropriate decisions regarding the learning aspects, game aspects (e.g., user interface, aesthetics, input mechanisms, etc.), and the game's technological requirements.

5. *Deadlines* are a crucial consideration. Time restrictions have a significant impact on various design decisions, including the complexity of the game, the number of levels and challenges, and the quality of the graphics. It is essential to account for deadlines as they influence the overall design process and determine the achievable scope within the given timeframe.
6. *Design and development team*. This aspect addresses the human resources available for designing and developing the solution. The composition of the team will determine its strengths and limitations, which should be carefully considered before commencing a project, as they will influence subsequent decisions. Moreover, designers should identify potential collaborators who are not part of the core team but can contribute to the project, such as illustrators, graphic designers, game developers, subject matter experts, teachers, researchers, etc.
7. *Budget and development tools*. This section considers the financial resources and development tools available for designing and developing the educational video game. Development tools encompass hardware, software, information sources, assets (such as 3D models, animations, scripts, etc.), and equipment required for producing multimedia content. It is essential to consider the budgetary constraints and the availability of development tools to make informed decisions throughout the design and development process.

All the elements described above should be documented in a concise report and reviewed by the relevant stakeholders for potential adjustments. This report serves to provide the designer with a comprehensive understanding of the project context aligned with the stakeholders' perspectives. Such knowledge of the game context will facilitate informed decision-making in subsequent stages. By considering these factors, the chances of designing a successful educational video game are significantly enhanced.

### 3.2 The Learning Stage

The *learning* stage, situated in the middle of the pyramid, builds upon the foundation established in the *context* stage and serves as the basis for the *game* stage. Its objective is to define essential elements such as the learning theory, content, LOs, pedagogical approaches, learning activities, and assessment methodologies. The learning aspects should be carefully aligned with the elements established in the context stage. For example, the designer must choose a suitable learning theory that resonates with the target population, select appropriate content and LOs based on the background and knowledge level of the audience, and design learning activities that are suitable for the academic environment and facilities outlined in the context stage.

The *learning* stage must warrant the alignment principle. It requires a careful alignment and integration of the learning objective, learning activities, and assessment



methods with the chosen learning theory. The following list outlines key aspects that need to be defined within the learning stage:

1. The *learning theory* serves as the foundation for understanding how the target population learns. It provides a systematic and validated approach to comprehending human learning processes, and it should guide the selection of LOs, pedagogical approaches, and learning activities within the educational video game. Moreover, a learning theory offers a framework for discussing and evaluating the effectiveness of the game as an educational tool.
2. *Content and learning objectives*. The content encompasses the skills or knowledge that the learner is intended to acquire. The LOs specify the scope and desired level of mastery that the learner should attain upon successful completion of the educational video game. It is crucial for the LOs to be clearly stated and measurable. Established taxonomies of LOs, such as Bloom's taxonomy [4] or the SOLO taxonomy [7], can provide valuable guidance in formulating the LOs.
3. The *pedagogical approaches* refer to the methods employed to teach knowledge or skills, such as scaffolding or problem-based learning. These approaches are typically aligned with the underlying learning assumptions defined by the learning theory.
4. The *learning activities* includes the tasks and exercises that learners are required to undertake to achieve the LOs. These activities should align with the learning assumptions, address the LOs, and effectively implement the chosen pedagogical approaches. Furthermore, it is crucial for the designer to consider that these learning activities will be translated into ludic activities.
5. *Assessment* refers to a systematic approach for measuring the extent to which students have achieved the LOs. Typically, this involves developing an assessment tool or protocol specifically designed for the purpose. The assessment should align with the chosen learning theory and the LOs. Additionally, it should possess a comparable level of difficulty to the learning activities and demonstrate the practical applicability of the acquired skills or knowledge beyond the context of the video game. Additionally, the assessment plays a significant role in evaluating the overall efficacy of the educational video game.

At the conclusion of this stage, the game designer should have prepared a comprehensive document encompassing all the learning components. It is important for all the aspects to undergo a thorough review by stakeholders and validation by subject matter experts. This document will serve as a guiding resource for subsequent decisions made during the game stage, particularly in relation to game mechanics, rules, and narrative development.

### **3.3 The Game Stage**

The game stage, situated at the pinnacle of the pyramid, is constrained by the contextual and learning requirements defined in the preceding stages. The primary objective of this stage is to design and develop an engaging and enjoyable educational video game. It is divided into three iterative and intertwined substages: (1) game design, (2) development, and (3) testing, each producing its own corresponding artifact. In the game

design substage, the game designer defines and describes the key elements of the educational video game in a game design document. As soon as possible, the designer should jump into the development substage that entails the creation of an initial prototype for initial evaluation and validation. The testing substage involves evaluating the prototypes, encompassing aspects such as engagement, enjoyment, user experience, and learning efficacy. Following game testing, the designer may revisit previous substages of the game stage or prior stages of the framework to modify sections that do not meet the video game's requirements or return to the development subsection to increase the game prototype's features.

The game stage, positioned at the pinnacle of the pyramid, is influenced by the contextual and learning requirements defined in the preceding stages. The primary objective of this stage is to design and develop an engaging and enjoyable educational video game. It comprises three iterative and intertwined substages: (1) game design, (2) development, and (3) testing, each generating its own corresponding artifact. In the game design substage, the game designer defines and describes the essential elements of the educational video game in a game design document. Rapidly, the game designer should transition to the development substage to create an initial prototype for preliminary evaluation and validation. The testing substage involves evaluating the prototypes, considering aspects such as engagement, enjoyment, user experience, and learning efficacy. After game testing, the designer may revisit previous substages of the game stage or prior stages of the framework to modify sections that fail to meet the video game's requirements or return to the development subsection to enhance the features of the game prototype.

**The Game Design Substage.** The primary objective of the game design substage is to define various game elements, including game mechanics, challenges, story, aesthetics, user interface, and game world. This substage necessitates close collaboration with subject matter experts and stakeholders. To ensure effective management and communication of design decisions, designers can utilize game design documents. These documents serve as a cost-effective tool for defining and visualizing the core concepts of the game, enabling designers to identify any flaws and make swift corrections. During the process of creating the game design document, designers may also conduct minor research and prototyping tasks to explore concepts that could be incorporated into the document.

The game design substage is constrained by the context and learning aspects. The designer must align the game elements with the target audience, available resources, learning theories, content, pedagogical approaches, LOs, and learning activities. Collaborating with subject matter experts and stakeholders is crucial to ensure the accurate definition of these aspects. They should review and validate the design decisions made by the design team.

When considering the learning aspects, the designer must effectively transform the learning activities into engaging ludic activities using game elements such as game mechanics, challenges, narrative, game world, and rules. It is essential for the game design document to clearly demonstrate the alignment between the LOs, learning activities, and ludic activities. To facilitate this mapping between the learning and game aspects,

the designer can utilize frameworks like the Game Mechanics Learning Mechanics framework [5].

Concerning the entertainment aspects, the designer should consider the factors that contribute to making a video game enjoyable, including challenges, fantasy, curiosity, control, competition, and social features [8, 19, 20]. These elements enhance intrinsic motivation and player engagement, both of which are desirable qualities for facilitating learning [16].

The game design substage should be efficient to allow for rapid prototyping, as many design decisions may evolve throughout the process. However, it remains crucial to maintain a set of game design documents that captures and tracks all design decisions, enabling effective communication within the design and development team. This document serves as a reference point and facilitates collaboration, ensuring that everyone is aligned and informed throughout the iterative design process.

**The Game Development Substage.** Meeting all the requirements of an educational video game is a challenging task that needs continuous testing. Hence, early prototyping plays a fundamental role. By gradually building and testing initial versions of game prototypes, designers can gather valuable feedback from players and subject matter experts to validate the game's effectiveness. If the prototype meets the desired requirements, the development team can proceed with implementing more advanced versions of the game, refining it further until it meets all specifications. In cases where the prototype falls short of the requirements, the designer should revisit the game design substage or previous stages of the framework for necessary adjustments and improvements.

The initial prototype should be a small, playable version of the game. It does not need to be a fully polished but should effectively demonstrate the core concept, game mechanics, and the main learning aspects. The primary objective of the game prototype is to conduct testing. Consequently, a cost-effective and efficient development tool is essential before proceeding to create the final version of the game. Depending on the team's capabilities, the development team can opt for paper-based prototypes or digital prototypes. The choice of prototype medium should align with the team's resources and expertise.

At the end of the first iteration of the development substage, the design and development team should have a functional prototype of the game. This prototype will be utilized for subsequent testing and will serve as a foundation for refining future iterations of the game prototype as well as the final version of the game.

**The Testing Substage.** The validation and testing process is essential to determine whether the educational video game meets the required standards. As soon as the first prototype is implemented, the testing substage begins.

The validation process is essential to ensure that the video game effectively delivers the intended contents and teaching methods. Subject matter experts, educators, and stakeholders play crucial roles in this stage. Validation can be formal or informal. Also, various qualitative or quantitative research methods can be employed for validation.

The development team should carefully choose the most suitable option based on their specific context and skills.

Game testing should evaluate the learning efficacy and factors related to the use of the video game, including usability, user experience, usefulness, and instructional aspects. It should be performed on a sample with the same characteristics as the target population. Like the validation process, testing can be formal or informal, employing qualitative or quantitative methods.

At the end of the testing stage, the designer should have prepared a report describing the methods used to collect data, the results of the evaluation, an analysis of the data, and a discussion of the findings. The report should highlight the strengths of the game as well as any gaming and learning concerns that need to be addressed. Additionally, it may identify unexpected player behaviours.

## 4 Case Study

This section provides an example of the CLG framework's application, showing its potential. It showcases the design, development, and testing process of *DS-Hacker*, an educational video game aimed at teaching binary search tree (BST) data structures to higher education students. The focus is on the CLG's workflow used to successfully design and develop the game.

The *context* stage covered aspects such as purpose, objectives, learning environment, target population, resources, and location. Additionally, a review of game engines and assets was conducted, including sound effects, particle effects, scripts, and 3D models. The objective was to find a development environment suitable for rapid prototyping and offering high asset quality. Three game engines, Godot, Unreal Engine, and Unity were tested and reviewed. Unity was ultimately chosen for several reasons: (1) it offers a free licensing option suitable for academic purposes, (2) it provides a comprehensive and well-documented library for 3D development, (3) Unity's Asset Store contains quality assets and tools for fast prototyping, and (4) the developer was proficient in Unity.

In the *learning* stage, all the pedagogical aspects were defined. Firstly, Kolb's experiential learning theory (KELT) [17] was chosen due to its resemblance to the game cycle of video games [31]. KELT suggests that learning is a holistic process where individuals construct and reconstruct knowledge based on their experiences. After selecting the learning theory, the contents and LOs were determined, following the guidelines for undergraduate degree programs developed by the Association for Computing Machinery [6]. The LOs covered BST introductory concepts and algorithms, considering the knowledge level of the target audience. An analogy-based pedagogical approach was chosen to facilitate learning, as it allows the construction of new knowledge using familiar knowledge [11]. Then, learning activities were drafted to be translated into ludic activities and aligned with the defined learning aspects. For assessment, a BST conceptual knowledge test was developed. All these learning components were included in the game design document.

The *design* and *development* process of *DS-Hacker* suffered three major iterations with several modifications. In the game design substage, elements such as game genre, theme, aesthetics, mechanics, levels, challenges, goals, narrative, and game world were defined. The action-adventure genre was selected for its inclusion of physical and cognitive challenges [1], making it suitable for learning conceptual and procedural knowledge. Additionally, its reliance on narrative elements facilitates conveying conceptual knowledge. As for the theme and visual aesthetics, the science fiction (cyberpunk) theme was chosen for its relevance to computer science elements and the superior quality of available assets compared to other themes.

Regarding the narrative and game world, they were designed to convey the learning content. The game story revolves around a robot created to hack a corrupt corporation's data centre, structured as a BST, and reflecting the BST data structure. To overcome challenges, players must learn about BST concepts presented through the game's story and dialogue system.

Regarding levels and challenges, each level focuses on one or two LOs and includes an appropriate number of game challenges or activities matching the learning activities. The challenges serve to practice BST concepts taught in the game story, comprising cognitive puzzles and navigation tasks through the game world.

After completing the game design document, the *development* substage commenced. The first digital prototype consisted of six levels and covered five LOs, with an in-game tutorial explaining game mechanics and controllers using text. A complete description of the game can be found in [26].

During the *testing* substage, the first prototype underwent informal validation by two Algorithms and Data Structures professors at Trinity College Dublin. They provided feedback on content, data structure representation, user interface (UI), and playability. Based on the results, minor changes were made to the UI (navigation map, dialogue system, and menus) and the organization of the game world to better reflect the BST model. The second prototype was also made available in English and Spanish.

To assess the second prototype's effectiveness, a pilot experiment was conducted with thirty-two engineering students from Universidad de Costa Rica. The pre-test post-test experiment evaluated learning gains, perceived learning, clarity of contents, intrinsic motivation, usability, user experience, usefulness, and presentation of instructions. The results showed increased learning gains and motivation among students, but some pedagogical and playability problems hindered the learning process.

To address the observed obstacles, the framework stages were revisited and modified. Changes were made in the context, where the target audience and technological resources were adjusted. Initially, it was assumed students had high video game proficiency, but the pilot experiment revealed some struggled with game controls. Also, the available computer power in laboratories fell short of expectations, leading to performance and user experience issues during the pilot experiment.

In terms of learning aspects, content and LOs were reduced, and a clearer explanation of the Binary Search Tree data structure was added, accompanied by explanatory images for better understanding.

Game components suffered four modifications: (1) a tutorial level was included to teach game mechanics; (2) the dialogue system and content were updated; (3) level

goals were divided into smaller sets of challenges; and (4) in-game signages were added for player guidance. Additionally, graphic quality was lowered to accommodate computers with lower specifications.

The final version of the video game was evaluated with students from Universidad de Costa Rica and Universidad de Colombia. Results demonstrated its effectiveness, as players increased their learning gains and intrinsic motivation. A full description of the evaluation is available in [26].

## 5 Discussion

The CLG framework unifies educational game design, entertainment video game design, and pedagogical design into a simple, easy-to-use workflow, systematically addressing learning and gaming aspects.

The framework is structured into three stages, providing an iterative design process. Each stage focuses on specific aspects that serve as the foundation for subsequent stages. Design decisions are documented using artifacts like design documents, reports, or prototypes, supporting communication, criticism, and modifications. The iterative nature of the framework allows for problem-solving and validation.

In terms of learning, the CLG framework employs the alignment principle, supporting learning and formal education environments. It helps define LOs, assessment methods, and evaluation criteria for the video game's efficacy. Furthermore, the framework recommends documenting the learning aspects to guide future design decisions and ensure the video game meets learning requirements.

For the *game* stage, the framework enables the balance between learning and enjoyable game elements. The *game design* substage facilitates systematic definition, criticism, and modification of video game components through design documents, aligning them with learning requirements. Rapid prototyping and multiple iterations are recommended to achieve a balance between learning, fun, and engagement. The *testing* substage assesses the video game's performance against requirements, identifying and correcting issues in subsequent iterations.

Additionally, Table 1 lists the design aspects addressed by the CLG framework and indicates which frameworks or methodologies (reviewed in section 2) consider those aspects. Through this, we aim to demonstrate our commitment to integrating the educational and entertainment design concepts and the comprehensiveness of our framework.

Concerning the limitations, the framework has not been validated extensively. As shown in the previous section, we have shown a successful case study by applying it in one educational video game, proving the framework potential. However, it is necessary to develop more educational video games to test the efficacy of the framework. These educational video games should have different purposes, target audiences, learning goals, genres, etc. to validate the flexibility of the framework. Additionally, the CLG framework's process and workflow have not been compared with other frameworks' workflow. This makes it difficult for designers and development teams to visualize the strengths and limitations of our framework. However, as mentioned in the introduction,

the aim of this paper is to make widely available, such that it can be used and validated independently by other researchers. We expect that other researchers find the CLG framework valuable and use it for their further designs.

**Table 1.** List of aspects considered by the CLG framework, and the design frameworks and methodologies reviewed in section 2.1 and 2.2.

	CLG Framework	4D Framework [12]	Aleven et al. Framework [2]	SGDA [24]	G4LI Framework [25]	GAGE [18]	Medina et al. Framework [23]	Iterative Design [29]	Player-Centric Design [1]
Purpose & scope	X	X		X		X		X	X
Educational environment	X	X				X			
Target audience	X	X		X		X		X	X
Facilities & equipment	X	X				X			
Deadlines	X					X			
Team	X					X	X		
Budget & tools	X					X			
Learning theory	X	X	X		X	X	X		
Content	X	X	X	X		X	X		
Learning objectives	X	X	X			X	X		
Pedagogical approach	X					X			
Learning activities	X	X							
Assessment	X						X		
Game design*	X	X	X	X	X	X	X	X	X
Development	X							X	X
Testing	X							X	X
* Game design includes the definition of game elements such as rules, game mechanics, game world, levels, challenges, narrative elements, characters, user interface, etc.									

## 6 Conclusion

This paper has presented the CLG framework, which focuses on creating fun and engaging educational video games while ensuring the fulfillment of learning requirements. The case study presented in this study showcased its potential. Its straightforward structure and workflow make it easy to follow. We believe that game designers will find the CLG framework valuable, as it facilitates the design and development of high-quality, effective educational video games.

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