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Proposal for a Game Design Document model for creating educational games to teach computational thinking

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Abstract. *This paper proposes a documentation model for game development to accelerate the growth of educational games that promote computational thinking. Computational thinking is an essential skill in today's world and plays a fundamental role in developing creative solutions and tackling complex problems. Our proposal aims to provide a robust framework for developing educational games that integrate computational thinking concepts in a fun and engaging way. Using this model, we discuss the possibility, effectiveness, and efficiency of using educational games to provide students with a meaningful and enjoyable learning experience related to computational thinking.*

1. Introduction

In the contemporary educational landscape, computational thinking has emerged as a crucial skill, transcending the boundaries of traditional computer science and becoming a fundamental aspect of problem-solving and decision-making in various fields. As technology continues to shape our daily lives, we must equip the next generation of learners with the ability to think algorithmically, analyze data, and approach complex challenges with a computational mindset.

With their immersive and interactive nature, educational games have shown great potential in engaging students and fostering meaningful learning experiences [Wulantari et al. 2023]. By combining entertainment with educational content, games can captivate learners and facilitate knowledge retention dynamically and enjoyably [Frasson et al. 2021]. Leveraging the power of game-based learning, we propose the development of educational games designed explicitly to teach computational thinking.

Computational thinking encompasses problem-solving skills, such as algorithmic thinking, pattern recognition, decomposition, and abstraction [Labusch et al. 2019, Pires et al. 2019, Fernandes 2021]. These skills are crucial for mastering programming and have broader applications in various disciplines, ranging from science and engineering to social sciences and the humanities. Emphasizing computational thinking in education can empower students to become proficient problem solvers and critical thinkers in an ever-evolving digital world.

Despite the recognized significance of computational thinking in contemporary education, integrating it into the curriculum can be challenging. Traditional teaching methods may not fully engage students or make learning enjoyable and memorable [Scrivener 2005]. In this regard, educational games offer an attractive alternative that can enhance students' motivation and create a more dynamic and rewarding learning environment [Haleem et al. 2022, Mohd et al. 2023, Simões et al. 2013, Bernardo et al. 2021].

This proposal aims to introduce a tailored Game Design Document (GDD) model for educational games centered on computational thinking. The model streamlines and accelerates game development while ensuring pedagogically sound content integration. The paper reviews the literature on computational thinking and educational games, presents the GDD template, and discusses its components' contributions to learning. Challenges and limitations are explored, with suggested solutions. By offering a structured framework, this model contributes to educational technology, fostering students' computational thinking abilities and aiding educators and developers in creating engaging learning experiences.

The rest of the paper is organized as follows: Section 2 presents the literature on computational thinking and educational games. Section 3 presents the methodology used in this paper to create the GDD model. Section 4 introduces the proposed GDD model, detailing its essential elements and stages. Section 5 discusses the potential impact of integrating educational games into computational thinking education and addresses possible challenges. Finally, in Section 6, we conclude our proposal and highlight its contributions to educational technology and its potential implications for the future of computational thinking education. As we explore the proposed GDD model for educational games centered on computational thinking, we envision a promising pathway to cultivating the next generation of learners with essential skills to thrive in an increasingly digital world.

2. Literature Review

This chapter provides a comprehensive literature review on integrating computational thinking in educational games. It explores the core concepts of computational thinking, its relevance across disciplines, and its importance in today's world. The potential benefits of educational games for engagement, motivation, and knowledge retention are discussed, along with successful game design models that incorporate computational thinking principles. This review lays the groundwork for the following chapters of the research, offering valuable insights and guidance for the study.

2.1. Computational Thinking: Definitions and Foundations

Computational thinking is a cognitive process that involves breaking down complex problems into smaller, manageable parts and solving them using computational techniques. It encompasses a range of skills, including algorithmic thinking, pattern recognition, abstraction, and decomposition. [Wing 2006] popularized the concept in her seminal paper

"Computational Thinking," emphasizing the importance of computational thinking as a fundamental skill for everyone, not just computer scientists.

Numerous studies have explored the application of computational thinking in various fields. For instance, computational thinking has been instrumental in modeling and simulating complex systems in science and engineering, aiding researchers in understanding and predicting natural phenomena [Lee et al. 2020]. In the context of the social sciences, computational thinking has been utilized for data analysis [Kafai and Proctor 2022], allowing researchers to gain insights from large datasets and identify patterns and trends.

[Denning and Tedre 2019] explains that computational thinking is not a set of concepts for programming; it is a way of thinking that is honed through practice: the mental abilities to design computations to do jobs for us and to explain and interpret the world as a complex of information processes. [Angeli and Giannakos 2020] addresses the growing attention to developing students' knowledge about designing computational solutions to problems, algorithmic thinking, and understanding fundamental computer science concepts. [Kong and Abelson 2019] present a comprehensive guide that covers all important aspects of computational thinking education. It provides an in-depth discussion of computational thinking, including perceiving computational thinking practices as ways of mapping models from data and process abstraction.

Some researchers present diverse viewpoints on computational literacy and thinking. [Li et al. 2020] emphasizes the benefits of computational literacy in daily life, advocating for its promotion among high school students. [Caeli and Yadav 2020] highlights unplugged approaches as valuable tools for developing computational thinking skills. On the other hand, [Nardelli 2019] questions the need for considering computational thinking as a separate subject and emphasizes teaching computing itself. Overall, the articles underscore the significance of computational thinking in various domains and its importance in preparing students for a digital society.

Computational thinking is a crucial cognitive process applicable across various fields beyond computer science. Studies have shown its enhancement through practice, empowering individuals to address real-world challenges. Both unplugged approaches and digital tools are valuable for developing this skill, with teachers playing a vital role. Emphasizing the teaching of computing as a foundational discipline with transversal value is crucial, preparing the next generation for success in a data-driven digital society.

2.2. Educational Games: Potentials and Benefits in the Learning Process

Educational games, often called serious games or educational simulations, have gained considerable attention in recent years as effective tools for teaching and learning. These games go beyond pure entertainment and are designed with specific academic goals [Czauderna and Guardiola 2019]. They leverage gamification elements to engage learners actively and promote knowledge acquisition in a fun and interactive manner. Research has demonstrated that educational games can improve learning outcomes and increase student motivation [Lin et al. 2023]. By creating an immersive and enjoyable learning environment, games can enhance students' retention of information and foster a positive attitude toward learning. Furthermore, games offer a safe space for experimentation and exploration [Lalicic and Weber-Sabil 2022], allowing learners to make mistakes without fear of real-world consequences [McGarr 2021], promoting a growth mindset and a willingness to take risks in their learning journey [Lee et al. 2021].

[Maatuk et al. 2022] presents how the COVID-19 pandemic forced educational institutions worldwide to adopt e-learning as an alternative to traditional methods. This study explores the challenges and opportunities of e-learning from the perspective of students and instructors at a public university during the pandemic. Results show widespread adoption of e-learning with benefits such as greater access to resources and flexibility, but challenges remain, including internet quality and financial constraints. Pedagogically, learners' characteristics and motivations are vital in selecting appropriate e-learning strategies. Technical support, training, and infrastructure improvements are crucial to successfully implementing e-learning. Recommendations include providing Internet access, modern electronic libraries, classrooms dedicated to e-learning, and regular faculty training. Understanding learners' needs and motivations is critical to increasing the effectiveness of e-learning during and after emergencies.

About mobile learning, [Bernacki et al. 2020] present a collection that involves the use of personal electronic devices for learning in various contexts. The articles explore how mobile technologies affect the learning process and outcomes, provide new learning opportunities, and gather valuable data to understand learning better. It emphasizes integrating mobile learning with broader learning theories and highlights the benefits and challenges of mobile devices in education. The authors propose a research agenda to support the value of mobile devices as a learning and observation platform.

Educational games have become powerful tools for teaching and learning, engaging learners through gamification and promoting improved outcomes and motivation. They create immersive, enjoyable environments that foster information retention and a positive attitude toward education, encouraging a growth mindset. Additionally, the COVID-19 pandemic accelerated e-learning adoption worldwide, offering flexibility and resource access but facing challenges like internet quality and financial constraints. Recognizing learners' characteristics and motivations is crucial for effective e-learning, requiring technical support, training, and infrastructure improvements. Mobile learning with personal devices offers real-time data and enhances learning understanding, requiring integration with broader learning theories for its full potential. Overall, the combination of educational games, e-learning, and mobile learning provides opportunities to enhance education, improve experiences, and prepare learners for the future's challenges.

2.3. Related Experiences: Models of Game Design for Teaching Computational Thinking

Several studies have explored integrating computational thinking concepts into educational games [Pires et al. 2019, Fernandes 2021]. These experiences have demonstrated the potential of game-based learning to enhance students' computational thinking skills [Hooshyar et al. 2021]. Some researchers have developed games that require players to solve puzzles by applying computational thinking principles [Jiang et al. 2019, Agbo et al. 2021], such as designing algorithms or debugging code.

Game design frameworks have also been proposed, focusing on effectively incorporating computational thinking concepts into the game mechanics, narrative, and user interface [Jiang et al. 2019, Akkaya and Akpinar 2022, Wu and Richards 2011, Leonard et al. 2018]. These models emphasize the importance of aligning the game's content with specific learning objectives to ensure the educational value of the experience.

Despite the promising results of these endeavors, there is still ample room for further exploration and refinement. By building upon existing research and experiences, our proposed GDD model seeks to provide a comprehensive and practical guide for creating educational games that facilitate the development of computational thinking skills.

The literature reveals the significance of computational thinking as a crucial skill for learners across various domains. It highlights the potential of educational games in fostering computational thinking abilities, motivating learners, and providing an engaging and effective learning environment. By examining related experiences and research in this area, we can lay the foundation for a robust GDD model that will empower educators and game developers to create innovative and impactful educational games for teaching computational thinking.

3. Methodology

This chapter presents the methodology employed to develop a comprehensive GDD model to create educational games focused on teaching computational thinking. For this, we outline the essential elements that must be incorporated into the GDD, encompassing educational objectives, target audience, game mechanics, narrative, characters, interface, challenges, teacher support resources, and evaluation methods. By defining these elements, we seek to ensure that subsequent stages of game development align with the intended educational outcomes, facilitating a structured and intentional design process.

The proposed GDD model follows a well-organized structure, guiding the development of the educational game from conception to implementation. We discuss the various sections of the document, starting with an overview of the game's educational goals and outlining the specific computational thinking skills the game aims to promote. In addition, we delve into the document's structure and content, including detailed descriptions of the target audience, game mechanics, narrative elements, and the game's visual interface. We explore the challenges and puzzles designed to reinforce computational thinking concepts and the resources provided for teachers to integrate the game seamlessly into their educational practices. Adhering to this methodological approach, we seek to facilitate the creation of engaging and effective educational games that cultivate computational thinking skills in students, preparing them for the challenges of the digital age.

The methodology employed in this research involves the development of a comprehensive GDD model tailored specifically for creating educational games aimed at teaching computational thinking. To begin with, we identify and define the essential elements that must be included in the GDD to ensure a holistic and pedagogically effective game development process. These elements encompass various aspects, such as educational objectives, target audience, game mechanics, narrative, characters, game interface, challenges, teacher support resources, and assessment methods. By clearly defining these elements, we ensure that subsequent stages of game development align with the intended educational outcomes.

The proposed GDD follows a structured format that systematically organizes the components essential for creating an educational game focused on computational thinking. The document begins with an overview of the game's educational objectives, outlining the specific computational thinking skills to be addressed. Subsequently, we delineate the target audience and academic level, ensuring that the game content is appropriately tailored to meet the learners' needs and cognitive abilities. The game mechanics and dynamics section elucidates the interactive elements and rules that will engage and challenge the players while fostering computational thinking abilities. The narrative, characters, and environments are detailed to create an immersive and cohesive experience that complements the educational content.

The game interface is meticulously designed to facilitate intuitive interaction and seamless gameplay, ensuring learners can fully engage with the computational challenges presented. Moreover, we outline the various challenges and puzzles players will encounter throughout the game, each designed to reinforce specific computational thinking concepts. To support educators in integrating the game into their teaching practices, the document includes teacher support resources, such as guidelines, lesson plans, and assessment tools. Finally, we propose an evaluation and feedback mechanism to assess the game's effectiveness in achieving the desired educational objectives. The methodology also systematically details the stages involved in developing the educational game. These stages cover concept conception, prototyping, design iteration, content creation, programming, and testing. During the concept conception phase, we generate creative ideas that align with the defined elements of the GDD. Prototyping allows us to create a basic version of the game document to assess its initial viability.

Design iteration involves refining the game's aesthetics, mechanics, and user experience based on feedback and testing. Content creation encompasses developing educational materials, challenges, and narrative elements to incorporate computational thinking concepts seamlessly within the game.

In summary, the methodology consists of a) evaluating game design development research and GDD, both for entertainment games and serious games, and, when possible, applying to teaching computational thinking; b) writing the first version of the document; c) evaluation and discussion of the document by computing professors and game developers; d) refinement of the first version and new evaluation until the document is not subject to improvements. This comprehensive methodology serves as the backbone of our proposed GDD template, enabling the creation of educational games that effectively promote computational thinking skills among students in an engaging and meaningful way.

4. GDD Model for Computational Thinking Educational Games

This chapter presents the proposed GDD model specifically tailored for developing educational games that focus on teaching computational thinking. With the growing importance of computational thinking as a vital skill for learners across diverse domains, this model aims to harness the potential of educational games to create engaging and effective learning experiences. Each section of the GDD is carefully crafted to align with the intended educational objectives, ensuring that computational thinking concepts are seamlessly integrated into the gameplay. By following this model, educators and game developers can collaboratively create purposeful and pedagogically sound educational games that nurture computational thinking abilities in learners.

Educational games have emerged as powerful tools for cultivating computational thinking skills in learners. To facilitate the systematic development of educational games with a focus on computational thinking, we propose a comprehensive GDD model. This model is a structured guide for game designers, educators, and developers to create immersive and pedagogically effective games that integrate computational thinking concepts seamlessly.

Educational Objectives of the Game: The basis of our GDD template is clearly defining the game's educational objectives. This section of the GDD should describe the specific computational thinking skills to be addressed, such as algorithmic thinking, pattern recognition, problem abstraction, and decomposition. Each objective is tailored to match the desired educational level and align with established curriculum standards. By defining precise educational goals, the game design process becomes purpose-driven, ensuring that the game experience serves as a means to achieve meaningful learning outcomes.

Target Audience and Educational Level: Understanding the target audience is essential to create engaging and relevant educational games. In this section, we identify the specific demographic characteristics of the players, such as age group, academic level, and prior knowledge of computational thinking concepts. By tailoring the game content to match the cognitive abilities and interests of the intended audience, we enhance the game's accessibility and potential impact on learning outcomes. Moreover, this section provides insight into the appropriate educational level for which the game is designed, allowing educators to integrate it seamlessly into their teaching strategies.

Game Mechanics and Dynamics: The game mechanics and dynamics are the core elements that govern the interactive and challenging aspects of the game. This document section outlines the rules, interactions, and mechanisms players will encounter throughout the gameplay. By carefully designing game mechanics that align with the identified educational objectives, we ensure that players engage in activities that foster computational thinking skills. The game's dynamics refer to how these mechanics interact and evolve, providing a dynamic and captivating gameplay experience that sustains learners' interest and motivation.

Story and Narrative: Narrative and storytelling play a crucial role in immersing players in the game world. In this part of the document, we craft a captivating and relevant story that complements the game's educational content. The narrative serves as a backdrop to contextualize the challenges and puzzles presented to the players, creating an engaging and coherent game experience. A compelling story enhances player engagement and provides a memorable and meaningful context for reinforcing computational thinking concepts.

Characters and Environments: Characters and environments contribute to the overall atmosphere and experience of the game. In this field, we design characters representing diverse roles and perspectives, making the game relatable and inclusive. The game environments are carefully crafted to align with the narrative and support the gameplay challenges. By creating a visually appealing and immersive world, learners are motivated to actively explore and interact with the game's content.

Game Interface: The game interface serves as the primary point of interaction between players and the game world. We design an intuitive, user-friendly interface in this document space that facilitates seamless gameplay. The interface is crafted to be visually appealing and navigable, providing players with a smooth and enjoyable experience. A well-designed interface ensures that learners can focus on the computational challenges presented without being impeded by unnecessary complexities.

Challenges and Puzzles Central to the educational experience, this section outlines the various challenges and puzzles strategically designed to reinforce computational thinking skills. Each challenge is thoughtfully crafted to align with specific educational objectives and progressively increases in complexity as players advance through the game. By presenting learners with engaging and intellectually stimulating problems, we encourage them to apply computational thinking techniques creatively and critically.

Teacher Support Resources: Educators play a vital role in effectively integrating the game into the classroom. In this section, we provide teacher support resources, including guidelines, lesson plans, and supplementary materials, to facilitate seamlessly incorporating the game into the educational curriculum. These resources empower educators to leverage the game's full potential and ensure that learners' experiences extend beyond the game environment into the classroom.

Evaluation and Feedback: Evaluating the effectiveness of the educational game is crucial to assess its impact on learning outcomes. This section outlines the evaluation methods and feedback mechanisms employed to gauge learners' progress and comprehension. By gathering quantitative and qualitative data on the game's educational impact, we can identify areas for improvement and continuously enhance the game's pedagogical efficacy.

The proposed GDD model is a comprehensive blueprint for creating educational games that effectively cultivate computational thinking skills. By integrating each element systematically, we strive to develop games that captivate learners, foster computational thinking abilities, and empower them to thrive in a technology-driven world.

5. Discussion

The proposed GDD model presents a structured and comprehensive approach to creating educational games for teaching computational thinking. The model's feasibility lies in its systematic organization of essential elements, ensuring that each component aligns with the educational objectives and target audience. By providing a clear roadmap for game developers and educators, the model enhances the efficiency and effectiveness of the game development process. Furthermore, the model's applicability extends to various educational contexts, from formal classroom settings to informal learning environments and online platforms. Its adaptability allows for customization based on specific educational goals, curriculum standards, and learner needs, making it a versatile tool for creating tailored educational games.

5.1. Contributions and Potential Benefits of Using the Model

Adopting the proposed GDD model holds several significant contributions to the field of educational technology and computational thinking education. Firstly, it provides a cohesive framework that integrates pedagogical objectives with game design principles, fostering a harmonious blend of learning and play. The model's emphasis on specific computational thinking skills ensures a targeted approach, enabling learners to develop a deep understanding of fundamental concepts.

Secondly, the model's potential benefits are manifold. By leveraging the engaging nature of educational games, the proposed model has the potential to captivate learners' interest and motivation. This heightened engagement translates to increased knowledge retention and enhanced problem-solving abilities. Furthermore, as learners progress through the game's challenges and puzzles, they build resilience, critical thinking skills, and an inclination toward a growth mindset.

Moreover, the model can foster a positive and collaborative learning environment. Multiplayer and cooperative elements can be integrated into the game's mechanics, encouraging students to collaborate, communicate, and solve problems collectively. This social aspect of gameplay promotes teamwork and communication skills, valuable assets in both academic and real-world settings.

5.2. Limitations and Challenges to Consider

While the proposed model offers numerous advantages, it also presents limitations and challenges. Game development, even with a well-structured document, requires significant resources in terms of time, expertise, and budget. Not all educational institutions or educators may have the necessary resources to undertake such endeavors. Additionally, the model's success heavily relies on the quality of game design and the integration of pedagogical content. Ensuring the game effectively reinforces computational thinking concepts requires rigorous testing and iterative design processes.

Moreover, implementing educational games in traditional educational settings may encounter resistance or skepticism from educators or administrators unfamiliar with their benefits. Convincing stakeholders of the value and potential impact of educational games on learning outcomes may require advocacy and evidence-based research.

5.3. Possible Adaptations and Customizations of the Model

The proposed GDD model can be adapted and customized to suit diverse educational contexts, age groups, and subject areas. Educators and game developers can modify the game mechanics, challenges, and narrative elements to align with specific curricular goals and learning objectives. Additionally, the model can be tailored for learners with varying levels of computational thinking proficiency, allowing for differentiated instruction and individualized learning experiences.

Furthermore, the model's flexibility allows for the incorporation of emerging technologies, such as virtual reality or augmented reality, to enhance the immersive and interactive aspects of the game. The integration of these technologies can provide learners with unique and engaging experiences, further augmenting the game's educational impact.

In conclusion, the discussion on the proposed GDD model reveals its potential to revolutionize computational thinking education through innovative and engaging educational games. While addressing challenges and limitations, the model's adaptability and potential benefits underscore its significance as a valuable tool in promoting computational thinking skills and preparing learners for success in an ever-evolving digital world.

6. Conclusion

This article set out to propose a GDD model tailored for developing educational games focused on teaching computational thinking. The primary objective was to provide a structured framework that integrates pedagogical objectives with game design principles, aiming to create engaging and effective educational games. The proposed model sought to foster computational thinking skills in learners, preparing them for the challenges of the digital age while nurturing creativity, critical thinking, and problem-solving abilities.

The discussions surrounding the proposed GDD model highlighted its feasibility, applicability, and potential benefits. The model ensured a purpose-driven and efficient game development process by systematically defining the educational objectives, target audience, game mechanics, narrative, characters, and challenges. The model's contributions include fostering a harmonious blend of learning and play, promoting engagement, and enhancing knowledge retention. Furthermore, integrating multiplayer and cooperative elements can encourage collaborative learning and communication among students.

Nevertheless, the discussions also acknowledged the challenges and limitations, such as resource constraints and the need for rigorous testing and iterative design. Convincing stakeholders of the value and impact of educational games may require advocacy and evidence-based research.

The proposed GDD model holds promise for future implementations and adaptations in various educational contexts. Educators and game developers can customize the model to suit specific curricular goals, age groups, and subject areas, fostering personalized learning experiences. Moreover, integrating emerging technologies, such as virtual or augmented reality, can enhance the game's immersive and interactive aspects, captivating learners with novel and engaging experiences.

To strengthen the implementation of the model, future research should focus on conducting rigorous studies to measure the game's impact on computational thinking skills and learning outcomes. Evidence-based research can validate the effectiveness of educational games and contribute to broader acceptance and adoption among educators and institutions. This GDD model proposal is not limited in itself. Ideally, as future work, the document will be applied to creating games for teaching computational thinking so that we can validate through case studies and not just by evaluating professionals. This way, extracting more relevant data from students, teachers, and game developers will be possible.

In addition, another future work that will follow immediately after this one is the modification of this GDD to create games that teach computer programming through computational thinking concepts based on the categorization of these games and the creation of different templates for each type of category.

In conclusion, the proposed GDD model represents a significant step towards cultivating computational thinking skills in learners through educational games. This model paves the way for innovative and impactful educational experiences by promoting engagement, critical thinking, and problem-solving abilities. As educational technology continues to evolve, embracing and refining such models will undoubtedly empower learners to thrive in an ever-changing digital landscape.

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