Enhancing Programming Learnability for Children Through Video Games

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Abstract: This paper explores the potential of video games as an effective medium for teaching programming concepts to children leveraging gamification principles to enhance engagement. Through the development and testing of an educational game called "Codonia" implementing challenge-based learning and interactive feedback, this research examines how game mechanics support problem-solving and logical thinking. After a qualitative and quantitative study, the results indicate that gamification fosters increased motivation and confidence, suggesting that well-structured educational games can complement or surpass traditional teaching methods. By demonstrating how digital learning environments encourage experimentation and sustained engagement, this study contributes to the broader discourse on innovative educational tools for programming instruction.

Keywords: Gamification, Video games, Edutainment, Learnability, Children, Programming

1. Introduction

The research paper aims to prove games can be a tool for education. Through the power of gamification, adding game mechanics into non-game environments, like a website or teaching management system to increase participation. The goal of gamification is to engage with consumers, employees and partners to inspire collaborate, share and interact (BI WORLDWIDE 2024).

The mobile video game which was created uses gamification elements and was based on two hypotheses that are related to the research questions. First, gamification increases the motivation of learners, and second, gamification increases the self-perceived competence of learners. These two hypotheses motivated the following research questions: Are learners more motivated when learning with a game? (RQ1) Is the self-perceived competence higher with learning with a game? (RQ2) Does gamification have a higher learning outcome than traditional teaching? (RQ3) Through a demo experiment and feedback from a group of participants we can conclude if the game can be further developed for education.

The focus of the research is to see how motivated students will be if they are to study programming through a video game. Using many elements from gamification, a mobile game was created that will get them interested to learn the basics of programming through narratives and challenges. Video games have been viewed as entertainment and a leisurely activity for a long time. Being able to capture the attention of users and teaching new skills. However, now they are seen as a potential learning tool. Researchers have explored new opportunities which will take interactive platforms and use them for an engaging lesson plan. This paper includes unexplored sides of games as a medium for learning, especially when it comes to programming languages.

The study conducted for this research aims to prove that there is positive feedback in using video games to teach the modern brain of the children of this generation. Video games have been used for entertainment providing countless hours of immersive game play. They offer a form of interactive storytelling that can be deeply engaging, and the fun and enjoyment derived from playing games can lead to hours of sustained attention (Harvard Graduate School of Education 2021).

The motivation in RQ1 refers to the players wanting to finish the levels and get to the end of the game, needing to know more about the storyline and still being engaged while playing the game. Self-perceived competence are the players own assessment of their ability to perform a task and achieve goals. In simpler words, it is the confidence that a player has in knowledge and skills in a specific area or task.

Codonia, the educational game we created, aims to be a part of edutainment. A game where children can learn programming through playing a video game. The video game includes a storyline for entertainment, a main objective for motivation, characters who guide the player through the levels and user interface that is easy to understand and navigate.

2. Related Work

Using gamification for teaching and learning has been a n important topic in both academic research and practical applications in schools and at universities for along time now.

"CodeCombat" is an educational game that teaches programming skills through interactive coding challenges. Players write code to control their characters and solve puzzles, learning programming concepts such as variables, loops, and functions along the way (Kapp,2012).

"Classcraft" gamifies the classroom experience by turning learning into an epic adventure. Teachers can customize the game to align with their curriculum, providing incentives for participation and engagement while fostering a collaborative learning environment (Kapp, 2012).

"Foldit" is a puzzle video game that challenges players to solve complex protein-folding problems. The game's competitive elements, leader boards, and collaborative gameplay motivate players to explore different strategies and solutions, leading to breakthroughs in scientific discovery (Kapp, 2012).

Studies have also shown that Scratch helps students develop skills such as abstraction, decomposition, and algorithmic thinking. Studies have reported positive learning outcomes, including increased engagement, motivation, and self-perceived competence among learners who use Scratch (Steward,2023).

A study made for a gamified programming course (Imran, 2022) had 450 registered learners, 374 completed the course, with a 16.88% dropout rate. Participants were divided into three gamification levels: Zero (ZLG), Low (LLG), and High (HLG), with HLG consistently showing higher motivation (5.89), engagement (5.94), and performance (6.71) compared to LLG and ZLG ($p < 0.001$). HLG learners also reported the most significant skill development (7.18) and participation (6.14).

The "Stack Game" (Dicheva and Hodge, 2018) is an educational game designed to help students understand the Stack data structure in a Data Structures course. The game challenges students to use stacks for solving problems such as converting arithmetic expressions from infix to postfix notation and evaluating postfix expressions.

"Sleuth" is a gamified platform designed for teaching introductory programming through interactive code puzzles, using a detective-themed narrative to engage students. The platform is currently used for online and campus-based teaching with around 1200 active students at any given time (Katan and Anstead, 2020).

3. Gamification Basics

To grasp how the concept of video games can further aid education into a more advanced era, we need to understand the basics of gamification. What is the motivation behind gamification? Are we trying to get users to aimlessly be addicted to games? Is there any result? Well, gamification aims to increase user engagement. This encourages them to spend more time completing tasks and challenges without noticing the time passing.

According to Karl Kapp gamification is a careful and considered application of game thinking to solving problems and encourage learning using all the elements of games that are appropriate (Kapp, K.M. 2012). The motivation is creating fun and addicting elements from game mechanics and applying them to real-world applications. In other words, take programming and make it gamified. With the same building blocks or component that are used in video games, we can create an educational platform that will not feel like studying. With the power of gamification, any lesson can turn into a competition with yourself or your peers.

Game mechanics are designed to increase user engagement for games that do not necessarily have anything to do with gaming. They enhance the gaming experience for users. These are the elements that can fit every kind of user personality depending on what they aim to do in a game. Each of these items have their own game elements that help with engagement, motivation, and loyalty:

- Points and rewards
- Challenges and quests
- Feedback
- Leader boards
- Storytelling and narrative
- Social interaction
- Customization
- Unlockable items

Poorly applied game design elements, however, may undermine these basic psychological needs by the over justification effect or through negative effects of competition. Educators must, therefore, clearly understand the benefits and pitfalls of gamification in curricular design, take a thoughtful approach when integrating game design elements, and consider the types of learners and overarching learning objectives (Rutledge et al. 2018). If you do not apply gamification properly it can lead to over justification and the negative effects of competition.

Over justification effect occurs when you offer too many rewards or incentives to a player who was already interested in completing the task. This can cause them to change their motivation from enjoying the game to now playing it for a completely different reason. That is, adding game design elements to increase extrinsic motivation, motivation that you get from outside sources, can have an adverse impact on learners who already started with a strong intrinsic motivation, self-motivation.

Reading research papers that talk about how to teach programming can be a fascinating topic. Researchers often deep dive into topics that have to do with development. *Algorithmic Development* is where the focus is creating new algorithms to solve problems in a more efficient way. Developing new programming languages or improving the ones that exist. Creating a more structured and secure language that is also more powerful. Researchers also often talk about Artificial Intelligence. *Artificial Intelligence* who concentrates on developing new models and techniques. Finding a way to make Artificial Intelligence more human-like. Studying how the users interact with the software so it's more effective and intuitive with its answers.

These topics are being also studied through different methods. Conducting experiments and conducting case studies. Testing new approaches to validate their effectiveness. Collaborating with other experts in fields like linguistics to innovate a new programming language foundation.

The question arises how does researching "how to teach programming?" differentiate from how we actually teach programming in schools? The lesson plan needs to be thoroughly written for each step of the difficulty level. It should progress naturally, without feeling like they took a big leap from learning how to walk. The levels that were played in the demo were simple, easy to understand although they would not uphold in the long run. Because this was supposed to be an introduction, easy concepts were chosen. Meaning, to continue developing Codonia more challenging levels have to be introduced through each stage.

To create a successful lesson plan these are the six steps that need implementing into the levels as they progress to harder terms and definitions.

- Clear learning objective
- Progression system
- Immediate feedback
- Long-term feedback
- Social interaction
- Rewards and recognition

Each of these steps are counted as milestones as to how much the game has progressed itself. Clear learning objectives are the basis of our learning step. We can imagine an empty Lego plate that will be used to build upon. The learning objectives must be defined in a simple manner, without adding any unnecessary steps.

4. Codonia: The Game

Our video game "Codonia" has been created in the Godot Game Engine using its embedded language GDScript. It is intended to be a mobile game, although it can also be played on a laptop with a touch screen. The design is simple, which ensures children to have a clear understanding of what each element's purpose is. The levels are created in-between cut-scenes and dialogue scenes. Before they start to play the game, there had to be a storyline that would get them interested in continuing.

To provide players with a purpose to continue engaging with the game, a narrative was created focusing on a fictional kingdom named Codonia. This kingdom was ruled by their queen, Ada, who had been captured by an evil villain, Nullify. The children are introduced to their objective early in the level, so they get a basis of what their mission is. While working on the demo, additional attention was given to the different types of elements we can add so the interaction does not feel repetitive.

The game is in 2.5D and some of the levels even being top-down. A 2.5D game is a two-and-a-half dimensional game. This design technique is used to add a bit of depth to a video game. While your character can move

through a 3D environment, their only options are going up, down, left, right. The environment is set in layers, so each object in the game has its own position in the world.

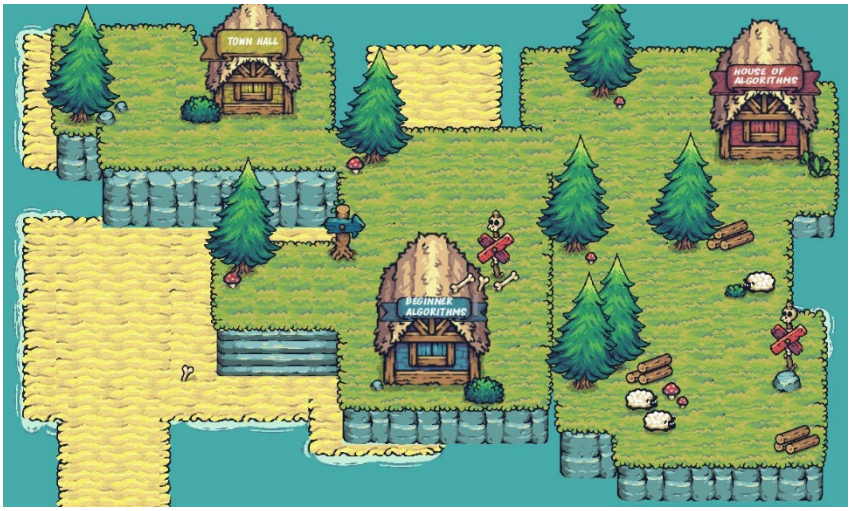

Figure 1: Codonia level design

Codonia has three different layers of tiles. To create an illusion of a 3D game, on top of the water there are individual islands of sand. The sand is the foundation for the real platform that the players will use. The third tile, which was accessible, is the ground. The stacking of different layers gave the perception of depth. Although, to be able to have the player move around the map, smaller islands were created to connect with bridges. One of the levels includes getting answers correct in a quiz to be able to show hidden bridges. Even though there is a sense of freedom when playing the game, it cannot be completed without finishing the objective.

A good example is one of the Algorithm levels where character is stuck in a forest with a lot of trees, with no road in sight. They must depend on a list of step-by-step instructions they found on a sign that give the way out. The instructions clearly state how many steps they need to take toward a direction to be able to navigate the forest. In gamification positive reinforcement is crucial. The psychology of every player is different although the main component that makes them keep playing is the thought of finishing the game. One way to make sure that the students who are playing these educational games do not get discouraged enough to leave the game, is to give them explanations.

Educational games should not have that kind of outcome since we want to motivate children to get involved, nevertheless, they need to know that there are repercussions. Giving an explanation to the player why they answered wrong is part of a feedback with a consequence. It shows the player that that they cannot guess answers while trying to finish the level. It gives them a sense of responsibility for the towers. Through narrative we are connecting the players to the characters on the screen. If something were to happen to the towers or a character in the game, the player needs to understand the consequences of their actions. This in a way forces the players to take the game seriously to not concurrently restart the level. This negative feedback also needs to have a positive effect on their psyche.

Immediate feedback follows after a wrong answer is pressed. In one level design, there are trolls that are waiting for a command. The command, in our case is answering the questions through a quiz, will tell the troll to either not react or destroy a tower. This is the kind of feedback that makes it thrilling for kids to remember the right answer by repeating the level every time they fail answering the questions correctly, in our case by memorization. As the questions are simple, “What is GDScript used in?” and the only answer would be “Godot”, memorization is acceptable.

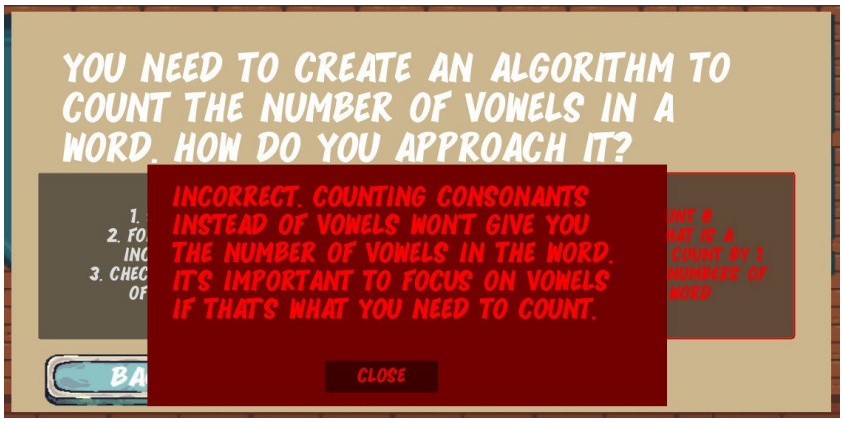

Figure 2: Example of immediate feedback

Meanwhile, *long-term feedback* is the opposite of *immediate feedback*. They do not get to see their behaviour right after playing a level. This is data that is accumulated throughout the game and would be shown in different scenarios. The first scenario would be after the player has finished a chapter which would be equal to one lesson plan, around ten levels for each lesson plan, they get a detailed summary on their performance.

he words they missed the most, the objectives where they made the most mistakes and a suggestion on which levels they can replay. It is anticipated that the children will be able to play and focus in a more calming manner knowing in the end they get feedback that will help them in the future. It takes away one less worry of trying to remember the checkpoints of their less highly performed levels.

The dialogue would explain what they need to do including a piece of information about the characters or introducing the villain early on to give the children motive to continue playing. There was limited time to prove why this thesis could work, the experiment had to be harder.

The children only had one shot in understanding the concept, solving the problems and re-iterating what they had learned. This realization would set for those children who would try to skip a conversation and get perplexed. Next level they performed better, paying higher attention to the dialogue and the tasks.

5. Evaluation

To evaluate the effectiveness, a qualitative and quantitative study was carried out that included twenty-five participants. The focus was on their feedback on what makes the game more enjoyable to play while keeping the learning elements. The questionnaire focused on the enjoyment level, learning, game play, motivation, difficulty, excitement, and interest.

A *Binomial test* is a statistical test that determines if the proportion of success in a binary outcome. This outcome is compared to the hypothesized proportion. In this study there are only two outcomes that can be possible, either a success or a failure. The steps that determine a binomial test are shown in *Table 1.*

Table 1:Binomial Hypothesis

Step	Details
Define the Hypothesis	Null Hypothesis (H_0): The proportion of successes is equal to the hypothesized value (p_0). Alternative Hypothesis (H_1): The proportion of successes is not equal to the hypothesized value (p_0).
Collect the Data	Count the number of successes (x) and the number of trials (n).
Calculate the Test Statistic	The test statistic in a binomial test is based on the binomial distribution.
Determine the p-Value	The p-value is the probability of obtaining a result as extreme or more extreme than the observed value under the null hypothesis. It is calculated using the binomial probability formula or statistical software.
Compare the p-Value to the Significance Level (α)	If the p-value is less than the significance level (commonly α = 0.05), reject the null hypothesis. Otherwise, fail to reject the null hypothesis.

Since the questions were multiple-choice answers, the analysis implemented a binomial test using Python. A custom was created that counted “strongly agree” with “agree” as positive feedback and “strongly disagree” with “disagree” as negative feedback (see *Table 2*). The focus is on having one scale, either they agree or disagree with the demo, eliminating neutralization.

Table 2: Survey responses

Question	Positive Responses	Negative Responses
I feel confident about understanding Algorithms after playing the game	25	0
I can explain what an Algorithm is in my own words	25	0
I feel confident about understanding Loops after playing the game	23	2
I can explain what a Loop is in my own words	19	6
I found the game to be engaging	25	0
The game did not keep my interest while playing	4	21
I will likely play the game if more levels come out	22	3
I felt excited while playing the game	24	1

Since it was important for me to get high-precision answers, the reliability measurement ensured that the responses were consistent across all different types of questions. This helps identify whether those who respond truly understand the topic of the question and the question itself. Another important reason is reducing biased responses.

If everything is positively phrased, the children will go through each question without a second thought. Prioritizing the effectiveness of the video game rather than getting positive feedback ensured its content was thoroughly designed and implemented to justify those responses. The script took each answer individually and ran a test. This way we can count exactly which part of the demo failed and which was successful. The result of the feedback form was then fed into a Python script. This is code for performing a one-sided binomial test. Binomial tests are very straight-forward. There are only three steps to the process.

We want to test a Null Hypothesis: we are testing if our experiment failed or succeeded. It seems like a ruthless scale, although it helps in the long run to create a successful project.

Table 3: Binomial test results and explanation

Question	P-value	Explanation
1	0.0000	Strong evidence that the proportion of positive responses is greater than 0.5.
2	0.0000	Strong evidence that the proportion of positive responses is greater than 0.5.
3	0.0000	Strong evidence that the proportion of positive responses is greater than 0.5.
4	0.0073	Evidence that the proportion of positive responses is greater than 0.5.
5	0.0000	Strong evidence that the proportion of positive responses is greater than 0.5.
6	0.9999	Strong evidence against the proportion being greater than 0.5, aligning with the negative framing of this question.
7	0.0001	Strong evidence that the proportion of positive responses is greater than 0.5.
8	0.0000	Strong evidence that the proportion of positive responses is greater than 0.5.

To understand the answers we got, the table explains the P-value and what it means. If you look at the *Table 3 Binomial test results and explanation*, each statement concludes a positive connotation. Looking through the answers, the only prominent answer that stands out is Question 6 with a P-value of 0.999.

This answer could not be further away than the 50 percent we are looking for. All the evidence that we see from it suggests that is the most negative answer. Now, let’s look at the *Table 2* and read out question number 6.

The negatively written question ''The game did not keep my interest while playing the game'' also concludes a positive answer. This is very important because after looking at *Table 3*, each question falls into the positive category, confirming that each statement has been approved. The Binomial test results also confirm the research questions.

If we were to make this into a two-sided binomial test for this question only, we would get a p-value of 0.00091. Meaning the value is too low for the distribution (4 positive vs. 21 negative) of answers was a coincidence. Combining the negative responses with the negative question posed, we get a strong positive sentiment.

6. Discussion

Looking at the responses, we can confirm that video games do enhance learnability. Once a balance has been found between teaching them while making it fun, there is not a single lesson or topic that cannot be taught. Seeing how these children have reacted throughout the game play and their enthusiasm after finishing the demo, is enough motivation and proof that we need to continue researching how to make games more education oriented.

This approach can let players have a hands-on chance to take educational content and learn through experimentation. Games that are educational only get boring quickly, since the children are constantly being fed new information without the fun aspect. Most of the school subjects like math, history, language classes have turned into game development, this also means that different learning subjects can become more appealing and approachable.

Table 4: Research Question Result

Number	Research Question	Conclusion
RQ1	Are learners more motivated when learning with a game	Yes
RQ2	Is the self-perceived competence higher with learning with a game	Yes
RQ3	Does gamification have a higher learning outcome than traditional teaching	Yes

These are the questions that got successfully answered in the research paper. There is concrete data for each answer that proves that gamification does work.

As can be seen in *Table 4 Research question result*, RQ1 answers the question whether their motivation is boosted from video games instead of learning the traditional way. Understanding the feedback from this data can be beneficial to the educators who can then design motivational educational tools.

RQ2 focuses on the competence or rather the confident of students while playing and finishing a game. The research wants to know if they believe in their abilities when learning through a game. This is crucial for a student's success since it will influence their willingness to try harder challenger therefore learn more complex material.

RQ3 seeks to determine if game elements that are introduced to a student would lead to a higher learning outcome rather than traditional teaching. Through digitization we can measure their learning outcomes, knowledge retention, problem-solving skills and their critical skills. This lets the researchers measure the effectiveness which can later be used to build even education tools with an improved overall learning experience.

Looking into the possibilities of educational video games we can tell that it can be adaptive. Applying variants of educational themes to the design of the game, developers can cater to many a wide range of edutainment. A term that has been created in 1954 is now making a comeback, edutainment. Educational entertainment, meaning that learning and play can co-exist.

In conclusion, video games have grown from mere entertainment to being powerful tools in education. This revolutionary method can be used to teach children programming from an early age. The study explored a new research area where video games are used for instructional purposes. Video games provide constant feedback and use a reward system that encourages children to continue learning. The merge of video games and learning new skills is a fast-approaching method that can be used more frequently in the future.

The main objective of the research was to demonstrate that video games can be used to learn programming, encouraging positive results from the design concept and creating an immersive environment that can teach debugging, problem-solving, and logical thinking. The feedback from the children showed that they were highly motivated, encouraged, and ready for new, harder levels.

The key takeaway of the thesis is that video games can be a powerful tool for education. By integrating lessons with a combination of storytelling, interactivity, immediate feedback, and reward systems, we create an environment that is safe, fun, and informative.

With children growing up in a world increasingly dominated by technology, it's more important than ever to teach them the correct way to use it. Incorporating programming into their daily routine through video games ensures the effectiveness of education at a high standard. Children will be excited by learning new concepts, sharing them with their friends, and developing new logic and problem-solving skills. This gives them passive life skills, where they learn how to communicate with others in group projects or debugging without complete frustration that will help in their future educational career.

The study proved that digital evolution in the educational system is not just about traditional teaching methods but also leveraging new tools to engage students. Video games have the power to become a learning tool that combines entertainment and learning to create the ideal environment for teaching programming. Video games can evolve from the purpose of pure entertainment into an educational platform. The first research question, are learners more motivated when learning with a game, has been proven right through the figures that I have showed positive data.

The second research question, Is the self-perceived competence higher with learning with a game, has also been proven from the data that shows that students would play the game again if there are new levels coming. The third research question does gamification have a higher learning outcome than traditional teaching has yet to be determined. There are two data figures one which has a high acceptance that they would rather learn from a game rather than a textbook.

Through the stages of effective learning—which include fail-safe environments, motivation, learner automation, and so on (Cambridge English 2023) children can feel safe to fail until they succeed. From these stages, we can see results because they cover the most important topics for teaching such as fail-safe environment where children can experiment fearlessly, knowing that failure is a stepping stone to success. Video games provide a safe space where trial and error lead to mastery.

Motivation through immediate feedback where gamified learning offers instant feedback. Whether it's solving puzzles, debugging code, or completing quests, players receive real-time responses that keep them motivated. Engagement through narrative in which video games immerse players in captivating stories. As they progress through game worlds, children forget they're learning—they're simply part of an exciting adventure.

The digitized era, where technology permeates every aspect of our lives, sees video games stand out as powerful educational tools. The American Psychological Association (APA) conducted a comprehensive review of research on video game effects, concluding in a paper that highlighted the positive impact of video games on learning, health, and social skills (Kirriemuir, J. 2002). Video games can be turned into a friendly tool that will continue to nourish and raise children with higher level knowledge in programming, collaboration, and problem-solving skills.

Codonia provides an immersive and interactive platform for children to learn programming. By integrating learning into the game play, it makes the process of learning programming concepts engaging and enjoyable for children.

Ethics declaration: I did not need ethical clearance for the research referred to in this paper.

AI declaration: No AI was used in the writing of this paper.

References

BI WORLDWIDE (2024) 'What is Gamification.' Available at: https://www.biworldwide.com/gamification/what-is-gamification.

Cambridge English (2023) 'How do video games provide effective learning?' Available at: https://www.cambridgeenglish.org/blog/how-do-video-games-provide-effective-learning/ (Accessed: 26 April 2024).

Harvard Graduate School of Education (2021) 'Can video games help kids learn?' Available at: https://www.gse.harvard.edu.

Kapp, K.M. (2012) 'The Gamification of Learning and Instruction.' Pfeiffer.

Rutledge, C., Walsh, A., Johnson, D., & Sideris, D. (2018) 'Gamification and Self-Determination Theory.' Available at: https://selfdeterminationtheory.org/wp-content/uploads/2020/10/2018_RutledgeWalshEtAl_Gamification.pdf.

Imran, H. (2022) 'An empirical investigation of different levels of gamification in an introductory programming course.'

Dicheva, D. & Hodge, A. (2018) 'Active Learning through Game Play in a Data Structures Course.' SIGCSE '18 Proceedings. Available at: ResearchGate.

Katan, S. & Anstead, E. (2020) 'Sleuth: A gamified programming environment.' IEEE EDUCON Conference Proceedings. Available at: https://ieeexplore.ieee.org/document/9125098.

Kirriemuir, J. (2002) 'Video gaming, education and digital learning technologies.' D-Lib Magazine. Available at: https://www.researchgate.net/publication/220273571.

Stewart, W.H. & Baek, K. (2023) 'Analyzing computational thinking studies in Scratch programming.' International Journal of Computer Science Education in Schools. Available at: https://ijcses.org/index.php/ijcses/article/view/156/114.