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Video Games and the Development of Computational Thinking

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For many, video games represent a popular form of entertainment. However, numerous research studies confirm that playing video games is a complex process with a significant educational component in addition to entertainment. Several researchers, including Papert and other authorities, have argued that we can learn a great deal about the learning process through video games, either by playing them ourselves or by observing others play and discussing the processes and thinking strategies involved. The present paper aims to explore the potential of commercial off-the-shelf video games, particularly with regard to developing computational thinking. Five games representing different genres were analysed using standard content analysis. The analysis was based partly on the researchers' own gameplay, but primarily on observing and interviewing other participants during their gameplay. Four experienced video game players, all adults aged between 26 and 32, were invited to join the study as part of a purposefully formed sample. They were observed while playing and engaged in conversations about their practices and thought processes. The goal was to identify cognitive processes perceived as intrinsically related to computational thinking. The findings support claims made by Papert and Gee, demonstrating that video games can significantly enhance our understanding of computational thinking itself. Based on the analysis, it was concluded that video games offer rich opportunities for the development of certain components of computational thinking, particularly algorithmic thinking, decomposition and evaluation, as well as generalisation and abstraction. The findings are primarily relevant to adult learners, but ideas for school-age students are also discussed. While considering these ideas, we noted another phenomenon that intriguingly aligns with our other area of

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research, that is, the development of structural thinking within school informatics.[3]

Keywords: content analysis, development of computational thinking, informatics education, qualitative research, video games

3 In some countries, informatics is referred to as computer science or computing; however, in Slovakia, it is called informatics and is a mandatory school subject from Year 3 to Year 11, which includes all learners aged between 8 and 17.

Videoigre in razvoj računalniškega mišljenja

Mária Čujdíková in Ivan Kalaš

Za veliko posameznikov so videoigre priljubljena oblika zabave, številne raziskave pa potrjujejo, da je igranje videoiger zapleten proces, ki poleg zabave vključuje tudi pomemben izobraževalni vidik. Številni raziskovalci, med njimi Papert in drugi strokovnjaki, trdijo, da se lahko prek videoiger veliko naučimo o procesu učenja, in sicer tako, da jih igramo sami ali z opazovanjem drugih pri igranju ter razpravo o procesih in miselnih strategijah, ki so vključeni v igranje. Namen tega članka je raziskati potencial komercialnih videoiger, ki so prostodostopne na trgu, zlasti v povezavi z razvojem računalniškega mišljenja. Analizirali smo pet iger različnih žanrov z uporabo standardne vsebinske analize. Ta je deloma temeljila na lastnem igranju raziskovalcev, predvsem pa na opazovanju in intervjuvanju drugih udeležencev med njihovim igranjem. Štirje izkušeni igralci videoiger, vsi odrasli, stari od 26 do 32 let, so bili povabljeni k sodelovanju v študiji kot namenski vzorec. Opazovali smo jih med igranjem ter se z njimi pogovarjali o njihovih praksah in miselnih procesih. Cilj je bil identificirati kognitivne procese, ki so videti neločljivo povezani z računalniškim mišljenjem. Ugotovitve podpirajo trditve Paperta in Geeja, saj kažejo, da lahko videoigre pomembno prispevajo k razumevanju računalniškega mišljenja. Na podlagi analize smo ugotovili, da videoigre ponujajo bogate možnosti za razvoj nekaterih komponent računalniškega mišljenja, zlasti algoritmičnega mišljenja, razčlenjevanja in vrednotenja ter posploševanja in abstrakcije. Ugotovitve so relevantne predvsem za odrasle učence, vendar v raziskavi obravnavamo tudi ideje za učence, ki še hodijo v šolo. Pri obravnavanju teh idej smo opazili še en pojav, ki se zanimivo ujema z našim drugim področjem raziskovanja, tj. razvojem strukturne miselnosti v okviru šolske informatike.[4]

Ključne besede: vsebinska analiza, razvoj računalniškega mišljenja, izobraževanje na področju informatike, kvalitativna raziskava, videoigre

4 V nekaterih državah se za označevanje šolskega predmeta informatika uporablja izraz računalništvo ali računalniška znanost, na Slovaškem pa ga imenujemo informatika in je obvezen predmet od 3. razreda osnovne šole do 3. letnika srednje šole, kar torej vključuje vse učence, stare od približno 8 do 17 let.

Introduction

Video games are intrinsic to today's digital age and serve as a popular form of entertainment for many individuals. However, a growing body of research confirms that playing video games is not merely a form of entertainment but a complex process with strong educational implications. Video games facilitate the development of various cognitive skills, such as attention (Bediou et al., 2023; González-Pérez et al., 2025; Nguyen & Bavelier, 2023; Oei & Patterson, 2013; Ruiz-Marquez et al., 2019; Sattar et al., 2021), visual working memory (Blacker et al., 2014; Martinez et al., 2022; Sattar et al., 2021), decision-making (Reynaldo et al., 2021) and problem solving (Bediou et al., 2023; Gyaurov et al., 2022; Reynaldo et al., 2021). Players often engage in challenging scenarios that require complex thinking and promote continuous active and critical learning.

In his influential book *What Video Games Have to Teach Us About Learning and Literacy*, Gee (2003) pointed out that the principles of learning are effectively mastered in video games, and we can learn a great deal about learning from them. He argues that the principles of learning inherent in well-designed games closely align with the most effective theories of learning. Similarly, Papert (1998) discussed how video games foster thinking in children. He suggested that by observing children playing computer games and discussing their actions, we can gain valuable insights into their cognitive processes. In another work (Papert, 1995), he stated that computer games encourage children to tackle difficult problems that they might not otherwise encounter.

In our project, we aim to explore what commercial off-the-shelf (COTS) video games can teach us about informatics education. More specifically, we seek to explore the thought processes involved in playing these games from a computational thinking (CT) perspective. But what is CT? Wing (2006) describes it as a way of thinking employed by computer scientists. She argues that this way of thinking is essential for everyone, not just computer scientists, and highlights its relevance across various disciplines and everyday activities. In her words: "Computational thinking involves solving problems, designing systems, and understanding human behaviour, by drawing on the concepts fundamental to computer science" (p. 33). In the same publication, she elaborates that CT is "a way that humans, not computers, think. Computational thinking is a way humans solve problems; it is not trying to get humans to think like computers. Computers are dull and boring; humans are clever and imaginative. We humans make computers exciting" (p. 35).

As early as 1980, Papert wrote about the exciting new avenues of thinking and *thinking about thinking* opened up by computers in his seminal work

Mindstorms: Children, Computers, and Powerful Ideas. It is here that he first introduced the term CT, viewing it as a way of thinking closely linked to self-creation and experimentation within software environments. Later, during his lecture at the ICMI [5] Study Conference in Hanoi, he stated that the true power of CT lies in "the making and understanding of computational objects" (Papert, 2006, p. 8). According to him, these objects facilitate a deeper understanding, as we can engage with them similarly to our interactions with people. They possess properties and behaviours that we can comprehend, and through programming, we can participate in their co-creation by adding new behaviours or altering their properties.

Lodi and Martini (2021) note that Wing's perception of CT differs from that of Papert. They argue that Wing adopts a more technical approach to CT, viewing it as a tool for understanding the algorithmic structure of the world. In contrast, Papert emphasises its affective dimension, which is linked to the creation and exploration of one's own artefacts. According to Lodi and Martini, these two perspectives complement each other, together forming a comprehensive picture of what CT truly encompasses. Several authors also seek to understand not only what CT is but also its core components. Cansu and Cansu (2019) analysed how CT is perceived by different authors in scholarly publications and identified the following core components:

- *Abstraction* – the ability to step back from certain details to clarify and simplify the problem;
- *Decomposition* – breaking a problem down into smaller, clearer subproblems;
- *Algorithmic thinking* – working with uniquely executable schemes for solving related problems and reasoning about their properties;
- *Automation* – creating and employing schemes for the automated processing of repetitive situations;
- *Generalisation* – identifying patterns, similarities and connections and applying them in different contexts, as is also characteristic of an inquiry-based learning approach (Golob & Ungar, 2023).

Selby and Woollard (2013) added *evaluation* as another component of CT, understood as the ability to assess situations, solutions and processes in terms of their effectiveness and resource utilisation, as well as the ability to recognise and evaluate outcomes. Although Cansu and Cansu (2019) did not include *evaluation* as a component of CT, they did mention *reflection* as one of the practices used in this context. The *reflection* component involves identifying

5 International Commission on Mathematical Instruction.

criteria and making accurate evaluations in relation to these criteria in order to effectively solve a problem.

In agreement with the referenced authors, we acknowledge that attempts to define a comprehensive concept of CT by identifying a suitable set of components are inherently approximate.[6] For the purposes of the present research project, however, we find this approach to be beneficial. We pose the following research question: *What opportunities for CT development do video games provide?* A qualitative design is employed to seek an answer, as we aim to understand the phenomenon under investigation rather than test predefined hypotheses (Creswell & Creswell, 2022). Several adult gamers were observed playing video games and then engaged in detailed discussions about their thought processes while playing and the problems they solved. In coding the collected data and conducting subsequent analysis, we employ the components presented by Cansu and Cansu (2019), extending them to include six preselected themes. We believe that our findings will enrich our understanding of cognitive processes in informatics and highlight the importance of playing video games in the context of CT development. The study focused on adult players, so the results primarily reflect the experiences of this age group. We hope that the results will be useful for future research projects, but above all that they will contribute to the evidence-based development of educational content for school informatics in an appropriate format. A similar call comes from Glasnović Gracin and Krišto (2022), albeit for different opportunities afforded by digital technologies. In our case, such contributions should be viewed as inspirations that require careful adaptation for younger learners, rather than direct evidence of how school-age students engage with COTS video games.

Method

The research question was addressed using content analysis of selected video games. According to Krippendorff (2004), this research strategy involves examining the content of a selected product to answer specific research questions. Historically, content analysis was primarily used to analyse documents, especially texts from print media. Today, however, it is also applied to the analysis of non-textual materials, such as paintings, films and artworks. Schmierbach (2009) and Malliet (2007) assert that it is a suitable tool for examining video games. Nevertheless, as these authors emphasise, it is crucial to respect the specificity of the medium under investigation. Unlike written texts or films, the course of a video game often depends on the particular player and their actions.

6 We will revisit this topic in the conclusions of the Discussion section.

Consequently, the player who engages with the video game is also a co-creator of the content being analysed.

Sample

This section highlights why we considered the sample in our study to be a two-dimensional structure. In one dimension, we focused on the individual video games included in the sample; in the other dimension, we considered the specific players, that is, the participants we observed while playing the games. We deliberately selected four young individuals (Creswell & Creswell, 2022) who were active video game players with extensive experience across various genres. They were prepared to be observed and interviewed about their practices and thought processes during gameplay. At the time of the research, they had recently played one or more games from our selection. It was also important that they not only agreed to participate in the research but also collaborated with us in the initial data analysis and formulation of our observations. The participants are characterised as follows:

- Martin, 32, is a graphic designer with a passion for video games that dates back to his childhood. He possesses extensive experience across various genres. His favourite games include KOTOR,[7] Beyond Good and Evil, the Dark Souls series, the Gothic series, Gris, Disco Elysium, Life is Strange, Deus Ex and Hades.
- Viktor, 26, is a PhD student in the Applied Informatics programme at our university, focusing on automated traffic tracking and object detection in both 2D and 3D environments. His relationship with gaming has been largely positive, and he has played games of various genres. Nowadays, he still enjoys gaming but plays less frequently, preferring more challenging games that he can invest hundreds of hours into improving. Some of his favourite games are Europa Universalis IV, Crusader Kings II, Victoria II, Baldur's Gate II: Shadows of Amn, Empire: Total War, Gothic and Team Fortress 2.
- Tomas, 32, graduated as an English language teacher and currently works as a bookseller. He has had extensive gaming experience since childhood. His favourite games include League of Legends, World of Warcraft, Fallout and Diablo.
- Adam, 27, is a PhD student focusing on future teachers' attitudes towards mathematics. He, too, has many years of experience playing video games. His favourite video games include Machinarium, Hollow Knight, Supraland, Hidden Folks and The Whispered World.

7 Star Wars: Knights of the Old Republic, commonly abbreviated as KOTOR.

A purposeful selection was employed in choosing the games. The goal was to select games from different genres to ensure that interesting opportunities for CT development were not overlooked. Two main considerations guided the selection. First, we focused on titles with higher cognitive complexity, which we expected would elicit a variety of problem-solving approaches and thought processes. Second, we focused on games that we intuitively recognised as containing a rich set of CT-related procedures. Additionally, we considered the recommendations of the participants and the games they had recently played, which allowed us to observe them in action. Five titles were selected that differ in genre and *game mechanics*.[8] Table 1 provides basic information about these titles. Our sample consisted exclusively of COTS video games intended for the general gaming audience.

Table 1

Basic information on the selected games, source https://howlongtobeat.com. The game ID in the first column is used only internally for the purposes of this paper.

Game ID	Video game	Production	Released in	Game genre	Playing time
❶	Hollow Knight	Team Cherry	2017	Metroidvania	26 to 57 hrs
❷	A Plague Tale: Innocence	Asobo Studio	2019	Action stealth adventure	9 to 24 hrs
❸	Hades	Supergiant Games	2020	Rogue-like game	21 to 95.5 hrs
❹	KOTOR	BioWare	2003	Turn-based role-playing game	29 to 48 hrs
❺	Divinity: Original Sin 2	Larian Studios	2017	Tactical role-playing game	56 to 148 hrs

The selected games can be briefly characterised as follows:

- Hollow Knight ❶ is a *Metroidvania* game, meaning that the player gradually explores a complex interconnected world. Initially, the player has very limited skills at their disposal, and many areas remain inaccessible. However, as the player gains new abilities, they can venture into previously unreachable areas. The game is notable for its atmospheric graphics, sombre music and non-linear exploration (allowing different parts of the world to be explored in various orders). The player assumes the role of a lone warrior exploring the mysterious underground realm of Hallownest, which is inhabited by an insect nation. During the quest, the player uncovers its enigmatic history, meets strange inhabitants and

8 Game mechanics are the basic rules and schemes that determine how the game works and what the player can do. These are repeatable actions or interactions, such as moving, collecting items, solving puzzles, battling or trading.

faces dangerous enemies. In battles, they must upgrade their sword and magical skills while timing their healing correctly.

- A Plague Tale: Innocence ❷ is an *action stealth adventure game* that combines story elements, combat and tactical evasion of enemies. Set in fourteenth-century France during the Hundred Years' War and the plague epidemic, the story follows young Amicia and her little brother Hugo as they strive to escape the cruelty of the Inquisition and survive in a dark world beset by war, disease and swarms of deadly rats. Although the game provides an authentic atmosphere of the time and portrays some historical aspects accurately, it also intersperses realistic elements with fictional and supernatural components. To progress, players must solve puzzles, fight enemies and use *stealth mechanics* that facilitate discreet movements, while avoiding direct conflict and using tactical elements such as hiding in the environment or silently eliminating foes. In this game, the correct use of light and fire is crucial for repelling rats and creating safe passages.
- Hades ❸ is set in the realm of Greek mythology, where the player assumes the role of Zagreus, the son of Hades, who is attempting to escape from his father's underworld. The game belongs to the *rogue-like genre*, characterised by a randomly generated environment that makes each subsequent run unique. The player progresses linearly from one room to another (meaning there is no possibility to go back or skip a room). Each room is inhabited by enemies and contains rewards or special challenges. To survive in combat, Zagreus must continuously attack, dodge and effectively combine attacks with his powers. Upon death, he must restart from the beginning, losing all temporary upgrades but retaining some permanent items that can enhance his abilities in the opening room, known as the House of Hades. This system allows the player to progressively improve and acquire new weapons, upgrades and story interactions with characters from Greek mythology. Each successful run reveals more about Zagreus's lineage.

Two *role-playing games* (RPGs) were also included in the sample. In these games, players assume the role of fictional characters with specific characteristics and abilities. Throughout the gameplay, players continuously develop their characters by acquiring new skills and abilities, improving chosen attributes and obtaining better equipment, weapons and armour. RPGs also emphasise storytelling, with the plot's development depending on the players' decisions.

- Star Wars: Knights of the Old Republic (KOTOR) ❹ is a *turn-based*

RPG set in the fictional Star Wars universe, thousands of years before the events of the film saga. The player can control up to three characters as they explore different planets. The game employs a turn-based combat system, where the player selects attacks or other character actions to be performed in each turn, followed by a sequential execution of these choices. The success of each action depends on the character's attributes and rolls of the virtual dice. Outside of combat, the player shapes their character's fate through various choices, leaning towards either the light or dark side of the Force.

- Divinity: Original Sin 2 ❺ is a *tactical RPG* set in a fantasy world. At the beginning, the player creates a character according to their preferences. As the game progresses, the player meets other characters who can become members of the team. The player can gradually improve all of the characters and undertake individual quests with up to four of them. This game also utilises a turn-based combat system, where the order of turns for both player-controlled characters and enemies is predetermined. Each character has *action points* to use during their turn for actions such as moving, attacking, casting spells or interacting with the environment. Each combat scenario requires careful tactics, necessitating strategic planning for every move and action. Additionally, the player's decisions outside of combat impact the development of the story. However, unlike in Game ❹, there is not just a simple choice between good and evil. The player's decisions have an impact on who their hero befriends, who survives and who gains or loses power. The game also has a number of different possible endings depending on the choices made during gameplay.

The participants had varying levels of experience with these games. Martin had played all of them, Adam had played Games ❶ and ❸, while Viktor and Tomas had both played Games ❹ and ❺.

Data gathering instruments

The data were collected using multiple methods. First, we played all of the selected games ourselves and recorded situations that offered opportunities for CT development. However, the primary source of data was the observation of the participants while they played, along with interviews conducted during and after gameplay, including reflections on the thought processes employed. The interviews were semi-structured, allowing several stimulating topics to arise during discussions. We worked more closely with Martin, as we had many opportunities to observe him playing all the selected games, and he was willing to elaborate on his thinking repeatedly and in detail afterwards.

Research design

Since the research focused on the development of CT in video gameplay, the content analysis of the collected data concentrated on identifying themes typically associated with the core components of CT, namely abstraction, decomposition, algorithmic thinking, automation, generalisation and evaluation. We employed a deductive approach to analysis with preselected themes (Braun & Clarke, 2021). In the first cycle, the observed gameplay situations, together with the players' solutions, were coded against the six CT components. We then conducted supplementary interpretative interviews with the participants, during which we presented our preliminary interpretations and invited them to critically evaluate them. Insights from these interviews were integrated by refining the codes, adjusting their boundaries and expanding the analytic perspective. The participants also highlighted additional aspects and described further in-game situations related to the CT components. These were documented and incorporated into the subsequent round of analysis.

We believe that the diverse experience levels of our team – one author being an experienced video game player and the other a novice – constituted an advantage. This dynamic aided our choice of games and participants, as well as the data collection and analysis processes. In this context, the second author's role was to oversee the interpretation and presentation of the results, ensuring that the findings are accessible to readers who may be unfamiliar with the world of video games.

Throughout the research, we adhered to the ethical principles recommended for qualitative educational research (Creswell & Creswell, 2022). All of the participants were informed in advance about the purpose and nature of the research, and all of them agreed to participate, with the freedom to withdraw at any time. In accordance with ethical principles, we also ensured that the video games analysed were correctly licensed.

Special attention was devoted to validation, which was secured through several measures. Data triangulation was employed by collecting data through multiple methods, as outlined in the Data gathering instruments sub-section of this chapter. We also consistently utilised member checking during our analysis and interpretation of findings, repeatedly consulting the participants on our intermediate findings and refining them based on their feedback. Furthermore, the fact that one author is an experienced gamer while the other is not, as described at the beginning of this sub-section, provided an opportunity for internal validation (Oluwatayo, 2012). Having an author without gaming experience ensured that the interpretation of the findings would be comprehensible to readers unfamiliar with the gaming world.

Results

This section presents the results of the content analysis, focusing on the opportunities that video games offer for CT development. Although the themes and components of CT are addressed separately, they are often intertwined and cannot be consistently separated during gameplay. Moreover, they are not presented in the order typically found in the literature but rather according to the significance assigned to them by the results of the analysis.

Algorithmic thinking

Algorithmic thinking is essential for success in most video games. Players frequently encounter a variety of challenging situations that require them to plan steps to overcome obstacles successfully. Importantly, there is often no single correct sequence of steps to resolve a given situation; instead, multiple approaches can lead to a successful outcome.

A recurring sub-theme is the behaviour of enemies. In each of the analysed games, players must understand the algorithms governing enemy actions: what they do, when they do it, how they move, how and when they attack, and their strengths and weaknesses. With this understanding, players can devise strategies for combat or avoidance.

While we identified opportunities for the development of algorithmic thinking in all of the games in our sample, the nature of these opportunities varies, influencing how players reason and act. In Games ❶, ❷ and ❸, where all actions, including combat, occur in real time, players must analyse and adapt quickly to dynamic situations. In these games, players must act in tandem with the enemy's actions based on their understanding of the enemy's operational algorithm. During combat, they need to determine when to dodge, how and when to attack, and where to aim their strikes. Timing for healing is also critical; otherwise, players may lose more health than they recover or be defeated outright. However, combat is not always the best approach. Some enemies may be too strong, or players may not be adequately prepared. In such cases, the best defence is to flee: players must discern the rules for hiding from specific enemy types and strategize how to escape successfully. Of the games analysed, this strategy is particularly useful in Game ❷, where the protagonists (young siblings) are physically significantly weaker than the enemies they face.

In contrast, turn-based games, such as ❹ and ❺, require advanced planning. In Game ❹, players can pause the battle and select the sequence of actions their character will perform. This mechanic allows players to effectively programme their character's future behaviour. Players must carefully consider which actions to choose and in what order; an incorrect sequence can lead to defeat. For instance, if a player attacks first and then activates defence, they may lose too much health. Alternatively, if they exhaust limited resources too early, they may find themselves unprepared when those resources are most needed.

Unlike Game ❹, in Game ❺, players do not input the entire sequence of actions upfront; instead, they choose actions sequentially during their turn, with immediate execution. However, it remains essential to plan the sequence in advance to ensure actions build on one another effectively. When planning, players must consider that some spells and skills require recovery periods during which they cannot be reused. If players use a spell or skill at the wrong moment, they risk being unprepared when it could be most beneficial. If they allocate all action points to an attack, they may miss the opportunity to reposition themselves advantageously. By observing the effects of each specified action immediately, players can further adjust their strategy based on the current situation. This approach is analogous to direct control in programming tasks.

Another opportunity for developing algorithmic thinking identified in the analysis is the game environment itself. Like enemies, the environment operates according to specific rules that players must uncover through analysis and experimentation. To progress, players must understand how these rules affect their movement, interactions and problem-solving opportunities. For example, in Game ❶, players discover that certain areas are only accessible after acquiring new skills, prompting them to plan their routes strategically and utilise their available skills effectively. In Game ❷, players may learn that shadows provide safe hiding spots from enemies or that rats avoid illuminated areas. Understanding these principles is crucial for survival and progress in the game. Game ❺ further complicates the rules governing the environment and the players' options for interaction. Here, players can combine magical abilities with various environmental elements to achieve specific effects. For instance, they can trigger explosions of toxic gases with fire spells or ignite oil puddles to obstruct enemies' paths. Ice spells can freeze bodies of water, creating slippery surfaces, while electric spells can conduct electrical discharges through water and stun characters within range. This interplay of game mechanics necessitates a systematic analysis of conditions, the ability to anticipate the consequences of actions, and effective adaptation of solutions to new circumstances.

In addition to the environment, friendly characters – known as *non-playing characters* (NPCs) – play a significant role in gameplay. These characters operate under specific rules, which players must understand and leverage to their advantage. Appropriate interactions with NPCs can yield novel items, experience points or valuable information to aid progress. Players must comprehend what NPCs offer, the conditions they impose, and the expected benefits of meeting those conditions. Rewards from NPCs are primarily earned by completing various tasks or engaging in suitable interactions during conversations. Notable NPCs include merchants who offer various goods. For each purchase, players must carefully consider which items are most worthwhile. Moreover, in Games ❺ and ❹, the prices of goods are not fixed; they depend on the player character's abilities, reputation and relationship with the merchant. Thus, players must make meaningful decisions to secure the most favourable terms.

In summary, the analysis indicates that algorithmic thinking in video games develops through the recognition of algorithms (governing the basis of enemies, friendly characters and environmental elements) and the planning of a sequence of steps to successfully resolve in-game situations and progress through the game.

Decomposition

Another component of CT that was observed developing during video gameplay is decomposition. Many problem situations require sequential resolution. In some games, the subproblems and their order are predetermined, particularly in Game ❷. In contrast, other games allow players to choose from multiple alternative problems at any given time. Thus, players apply decomposition to break down the given situation or problem into subproblems independently. This aspect was identified in the analysed games, especially in Games ❶ and ❺. Game ❶ offers considerable freedom in progression, allowing players to decide which tasks to complete first, second and so on. The only limitation is that some areas of the map are initially inaccessible. However, after acquiring new skills, players can return to face new challenges that may now be more manageable. These new challenges can again be completed in any order the player chooses. Additionally, not all of the challenges must be solved; however, completing optional challenges often provides advantages that facilitate progress. Similarly, in Game ❺, the player breaks down the completion of each task according to their priorities. It is then up to the player to determine the order in which to tackle them. When breaking the game down into individual tasks, the player must also consider their interconnectedness.

A typical problem in video games that requires decomposition occurs when players face multiple enemies. In such cases, it is beneficial to find a way to divide them and engage either one at a time or in smaller groups (employing a *divide et impera* strategy). In the video games from the research sample, such situations were identified mainly in Games ❷, ❶ and ❺. For example, in Game ❷, upon discovering a group of enemies, players must first analyse their distribution, recognise their movement patterns and assess environmental elements that can assist in luring or safely eliminating some of them. In addition to determining how to eliminate individual enemies, players must carefully consider the order in which they are engaged to avoid being detected by multiple foes simultaneously. Similarly, in Game ❶, players need to assess their surroundings and strategize how to eliminate enemies gradually. Dividing enemies into smaller groups and confronting them gradually is also crucial in Game ❺. However, this game offers the advantage of a turn-based system, allowing players more time to analyse the involved enemies and devise a meaningful division. Furthermore, if the battle does not proceed according to plan, players can adjust their strategy based on the current situation and rethink their next division each time.

Based on these findings, we conclude that decomposition is a key element of problem-solving in video games, and its principles are analogous to those found in informatics and programming. In both contexts, players and programmers strive to understand the structure of the problem, decompose it into manageable segments, and systematically address each part to achieve an overall solution.

Evaluation

Playing video games necessitates constant evaluation of various aspects. Players continuously experiment with different strategies and assess their effectiveness. Whenever a strategy appears ineffective, players analyse the underlying reasons and contemplate alternative approaches to resolving the problem. Some situations require several iterations of such refinements, akin to the debugging process in programming.

Additionally, players often evaluate whether to engage in solving a particular problem at any given moment. For example, in Game ❶, they must consider whether they have sufficient health to tackle the problem at that time, whether they possess the necessary skills, and whether they are adequately equipped. Similarly, in Game ❺, players need to assess whether each character on their team is prepared to confront the situation.

Another crucial aspect of analysing and evaluating the gaming situation is optimising resource utilisation. This is particularly important in games where resources are limited, as in Games ❷ and ❶. Here, players must constantly evaluate which items or upgrades to utilise in a given situation. In Game ❷, they need to determine which item is most worthwhile to create with the available resources. This consideration is essential; if an item or raw material is used to create something unnecessary at a given time, it may be lacking later. In Game ❶, players must optimise their choice of upgrades to gain specific advantages. Only a limited number of such upgrades can be selected and activated simultaneously, making it beneficial for players to choose those that are most advantageous for the current situation.

In Games ❶ and ❺, as well as in other games where healing is possible, players constantly assess whether they have enough health or need to regenerate. In the latter case, the player considers when and where they can do so safely. Healing operates on a different principle in ❸ but remains important. After completing each room, players must decide which door is most advantageous to enter next to enhance their future chances. If they choose the door leading to a healing room, they forfeit the opportunity to enter the door that would have provided an upgrade.

In conclusion, we note that evaluation is an integral part of video gaming. Regardless of the game genre, players are continuously analysing the results of their actions, adapting their strategies based on the experiences gained and optimising their progress.

Generalisation

Generalisation is another important aspect of successful video gaming. Once a player learns a new procedure or discovers a specific connection in a game, they typically apply this knowledge in other situations. Thus, generalisation and the application of previous experiences occur continuously during gameplay.

One of the most common areas where players utilise generalisation is in combat with enemies. If a player understands the rules applicable to fighting a particular enemy, they will apply this knowledge when encountering the same or a similar type of enemy again. For example, if a player in ❶ encounters a flying enemy and recognises that it attacks from above, they will anticipate this behaviour when they face another type of flying enemy. Moreover, the more behaviour patterns a player recognises in common enemies, the more effective they will be when fighting *bosses*,[9] who often combine a greater number of behavioural elements from standard enemies.

Generalisation is also crucial for understanding the rules of the environment. Players gradually learn how the environment reacts to different actions and then apply these findings in new situations. For instance, in game ❷, if players understand that rats avoid light, they can use a lit torch to navigate past them. When they encounter another group of rats, they will search the vicinity for other available sources of light to ensure continued successful advancement.

Abstraction

When playing video games, players are constantly exposed to a complex environment filled with various characters – dangerous, harmless or beneficial – along with numerous visual and audio cues and other details. However, in addressing each situation, players must first identify the elements that will help solve the immediate problem while filtering out those that could unnecessarily delay or endanger them. For example, in ❶, players must observe the enemy's mode of attack, their own character's health, and the opportunities the surrounding space offers for successfully dodging the attack, retreating or counterattacking safely. If players focus on visual details in the background, they may miss important moments requiring immediate reaction. Similarly, in ❸, players need to concentrate on the enemies present during the fight, the traps set to injure them, and the items that can assist them in healing or attacking.

Abstraction also plays a significant role in conversations with NPCs. Players gather a wealth of information during these interactions, from which they must identify what is relevant for further progress in the game. For example, during conversations in Games ❹ and ❺, NPCs share their personal stories or details about the history and culture of their world. Players need to discern the main message conveyed by this information, recognising what they are specifically supposed to do, where they should do it, what rewards they can expect, and how it will affect the overall gameplay.

Abstraction is also important for overall progression within the game environment. Players must notice elements that they can potentially use later in appropriate ways. For example, in Game ❷, they may identify objects to hide behind, items and resources to collect or sources of light that may be needed. Other environmental details, such as building surfaces or the animations of non-interactive objects, are irrelevant to actual progression in the game, and

9 Bosses are powerful enemies that typically appear at key moments in the game. Enemies of this type usually present a greater number of attacking behavioural elements than common enemies.

players do not need to focus on them, provided they can accurately distinguish these elements.

Automation

Automation is less explicitly represented in the analysed games than the other CT components. It primarily manifests in the way players are repeatedly exposed to similar situations, allowing them to solve these challenges more efficiently. In such situations, players draw on previously detected behavioural patterns; the more frequently they encounter these patterns, the more automated and effective their solutions become. From a CT perspective, this process involves generalising and automatically applying strategies.

Automation is particularly noticeable in the repeated battles found in Games ❶ and ❸. After a certain period, players stop consciously analysing every move of the enemy, and their reactions to familiar attacks and behavioural patterns become automatic. Consequently, the ability to dodge, time an attack precisely or heal can become almost reflexive. In turn-based games such as ❹ and ❺, automation is associated with the repeated use of effective tactical sequences; for example, choosing the optimal order of attacks in ❹ or regularly employing specific combinations of spells and abilities in Game ❺. In Game ❷, automation manifests in the repeated use of verified strategies for hiding, luring enemies away and using light to scare off rats. These activities become almost routine as the game progresses.

At the same time, we found that automation is the component of CT that is most challenging to distinguish from the others, as it intersects with them in significant ways, especially decomposition, algorithmic thinking and generalisation, as presented in previous sections.

Discussion

In the present research project, we conclude that, consistent with the claims of Papert (1995, 1998), Gee (2003) and others, we have successfully enriched the understanding of how playing video games can contribute to the development of each component of CT as listed by Cansu and Cansu (2019), along with an expanded evaluation. All of the results presented in detail in the Results section are compactly summarised in Table 2. In formulating its content, we aimed to shift the focus away from the context of the games themselves and formulate the results from the perspective of school informatics and its programming. The research question posed at the beginning of the project is thus considered answered within the framework of the two-dimensional sample, which will be discussed in the Conclusions.

While we view the aforementioned context as primarily beneficial for the research component of our work, we also consider the presented analysis and its results to be significant for our ongoing development of educational content.[10] Given the scope and diversity of how video gaming supports CT development, the results motivate us to explore additional game elements to incorporate into our curriculum and how to do so. Naturally, there are connections between the worlds of video games and the Scratch programming environment. In Scratch, we are currently seeking a productive balance between two extreme approaches: the first is 'learn programming by creating your own game', while the second is the more academic and systematic 'develop programming skills by solving appropriately chosen problems' in designing the programming curriculum for Years 6–9.[11] Several observed results from the analysis presented above inspire new ideas for us to work with concepts such as scenes and their scenarios; behaviours and reactions; multiple characters along with their dynamic clones; interactions between characters and their responses to different situations; synchronisation and cooperation of characters and their clones through messaging; and the evolving behaviours of characters based on changing situations in their environment. It is essential that all inspiring themes from the world of video games undergo careful transformation into forms that respect the developmental appropriateness and cognitive demands of pupils in this age group and level of CT and digital literacy.

In the Results section, we presented the results demonstrating how inherent it is for games to gradually explore the behaviours of characters, their changing skills and constraints. In fact, we implement a similar approach in our development work, even for lower primary pupils, as seen in Kalas et al. (2022), Kalas and Horvathova (2022) or Cujdikova and Kalas (2025). For these age groups, we employed a design principle with three intersecting challenges: (a) exploring the behaviours, reactions and constraints of the character and the environment; (b) exploring tools to control the character and using them for direct manipulation; and (c) in the character's language, planning its future re-executable behaviours, as discussed by Blackwell (2002) and Kalas et al. (2018).

10 In our work, the components of research and development intertwine and complement each other productively, which is characteristic of a research strategy called design research or design-based research (see Plomp & Nieveen, 2013).

11 Pupils in Slovakia in Year 6 have already participated in developmentally appropriate programming from Years 3–5. For example, they have engaged with programming environments of Informatics with Emil (Kalas et al., 2018; Kalas et al., 2022; Kalas & Horvathova, 2022; Cujdikova & Kalas, 2025).

Table 2

Opportunities for CT development through playing video games (identified components of CT as introduced in the Introduction section)

Component of CT	Contribution to developing CT
Abstraction	• Constantly analysing the situation and environment to filter out irrelevant aspects. • Distinguishing the aspects that are relevant for addressing the current situation and registering aspects that may be relevant for future situations. • Extracting important information from conversations with different characters.
Decomposition	• Understanding the structure of the problem, state or situation, as well as the possibilities of breaking it down into smaller units. • Proceeding from the evaluation of a situation, state or behaviour to its decomposition into smaller components, e.g., subproblems or other elements (*divide et impera* strategy). • Considering whether the parts of the overall situation can be addressed in parallel or sequentially. • Choosing a strategically appropriate sequence for dealing with the individual elements, subproblems or sub-situations.
Algorithmic thinking	• Examining the state of the environment and the situation or the behaviour of a character, along with their reactions, skills, capacities and limitations. • When appropriate, responding with some action, in the sense of *direct control*.[12] • When appropriate, planning a sequence of steps leading to the resolution of a problem or situation, in the sense of *planning* or *programming*[13] a solution. • Selecting one of the appropriate alternative courses of action.
Generalisation	• Recognising certain patterns and rules in the functioning of the environment or in the behaviour of characters. • Generalising these patterns and rules, and applying them repeatedly in other similar situations, where similarity can mean various things.
Evaluation	• Continuously evaluating the current state, resources and capacity of all characters. • Analysing and evaluating different strategies and actions, iteratively refining them. • Optimising (usually limited) resources, considering how to acquire new skills and resources. • Considering various alternatives when choosing the next step.
Automation	• Learning how to deal more effectively with recurring situations. • Automating reactions to certain patterns of enemy behaviour. • Regularly using effective tactical sequences of actions.

Finally, we would like to highlight one more aspect that we consider important. As mentioned earlier, we also examine the results obtained in terms of our curriculum design for programming with Scratch. This leads us to contemplate the concept of CT itself. We align with Brennan and Resnick (2012), who argue that "programming with Scratch provides a context and set of opportunities for contributing to active discussions about computational thinking" (p. 2). This position is supported by reasons articulated by others, such

12 For this level of control, see Kalas et al. (2018).
13 As the highest level of control, see e.g. (Kalas et al., 2018).

as Voogt et al. (2015), Cansu and Cansu (2019) and Lodi and Martini (2021). Specifically, the characterisation of the concept of CT in the research literature, through the identification of its individual components, is neither definite nor definitive. In analysing the data collected from the present video game research, we adopted a deductive approach with preselected themes; namely, the aforementioned components of CT. However, we identified one skill that we perceive to be important and challenging for pupils in Scratch programming. This skill repeatedly emerged in our analysis but does not fit well within the existing system of CT components. It involves considering the *overall structure* of the game or project, its elements (i.e., computational objects, as described by Papert (2006)), the relationships and interactions between these elements, as well as the overall state of the environment and the momentary states of the individual elements.

We believe that the issues surrounding a better understanding of *structural thinking* in school informatics and its relation to CT are important and understudied in the literature. We consider this an intriguing challenge for further research activities.

Conclusions

The aim of the present research project was to explore what video games can teach us about developing CT. Above, we have outlined the results obtained and how we interpret them in the context of our research and development activities. The findings show that the selected video games provide rich opportunities for developing various components of CT. Specifically, we noted a strong presence of algorithmic thinking, as players are continually required to plan sequences of actions and respond flexibly to dynamic environments or turn-based challenges. We also found substantial instances of decomposition, as players naturally break down complex problems into manageable subproblems. Furthermore, through repeated exposure to similar challenges, players are prompted to generalise their experiences and gradually automate effective responses, applying learned strategies flexibly in new and varied situations. These results demonstrate how video games offer a cognitively rich environment that aligns well with the core constructs and practices of CT and provides authentic opportunities for players to experience and reflect on problem-solving processes. We also believe that the results offer a valuable contribution to the current discourse on what constitutes CT itself, particularly by illustrating how it can emerge and develop through rich, interactive and situated experiences such as video games.

The results may serve as a resource for informatics educators and curriculum developers aiming to support CT in engaging and meaningful ways. The detailed analyses of in-game cognitive processes provide a foundation for designing educational interventions that mirror game-based challenges. For example, programming activities in Scratch can be designed to replicate common game mechanics such as exploration, interaction with characters, dynamic responses or strategic decision-making. We believe that such an approach could make CT more accessible, relatable and motivating, particularly for pupils who already engage with video games in their leisure time.

In interpreting the results, we also observed a phenomenon that interestingly fits with our other area of research, namely *the development of structural thinking* within school informatics and programming. In video games, structural thinking involves recognising relationships between characters, actions and environmental states, and designing coordinated behaviours for these elements. However, such skills are crucial not only in the context under study, but also in school programming. We believe that this deserves further attention in evidence-based design of educational content, particularly in exploring how game-inspired reasoning processes can inform the programming curriculum and related pedagogy.

We acknowledge the various limitations of the research and the need for its continuation, particularly in investigating the opportunities that playing video games provides for the development of mathematical thinking. The main limitation of the research is the small number of players involved. Since different players engage with games in various ways, a broader participant base could yield different approaches and additional findings. Furthermore, the analysis did not cover all existing game genres. In follow-up research, it would be interesting to focus on analysing other games, such as real-time strategy, choice-based adventures, simulations, sandbox games and puzzle games. Since automation was represented less explicitly in the selected games compared to the other analysed CT components, it would certainly be interesting to examine games such as Factorio or Satisfactory, where automation plays a key role. It might also be worthwhile to explore other aspects of informatics education that develop in the context of playing video games, such as the aforementioned structural thinking.

Ethical statement

The research was conducted in accordance with ethical standards for pedagogical research, as confirmed by the Ethics Committee of the Faculty of Mathematics, Physics, and Informatics of Comenius University in Bratislava, Slovakia.

Disclosure statement

The authors declare no conflict of interest.

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