Artificial Intelligence, Games, and Education

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Chapter 2

The Use of Video Games in Scientific Education

2.1 Introduction

This chapter explores aspects of the relationship between video games and scientific education. It is composed of two sections [33, 34]; in the first, we introduce the topic through a literature review. The review is focused on the experimental uses of video games in higher scientific education. Its goal is to highlight the variety and development of the field while also shedding light on criticalities that arise from the diversity of applications. The second article studies the relationship between video game design patterns and computational thinking skills. It examines inherent affordances between the two with practical examples. We position our work within the framework of computational thinking as defined by Wing [40] and further refined by Brennan et al. [41]. Specifically, we investigate whether game design patterns facilitate computational thinking practices, extending previous research in game-based learning with focus on engagement and motivation (e.g., [42] or [43]) as well as in constructivist learning theory [44], which suggests that learners construct knowledge through active engagement with their environment. In fact, games provide a structured yet flexible space where players experiment, make mistakes, and iterate on their learning strategies, a process closely related to the theory of constructionism [45]. We argue that video games create an environment that facilitates the activation of mental patterns as computational thinking through active experimentation. We conclude each section with a short summary of its relation to the overall chapter and the research questions.

2.2 How to Evaluate Games in Education: A Literature Review

The digitalisation of education is a common trend in many different contexts. Just to cite a few examples, the number of courses available online is countless, most books also make a digital version available, and a massive amount of lectures are streamed and available online every day. Digitalisation opens the way to new methods to convey information and its applications in education, creating spaces for new teaching tools and techniques. A very promising one is extracting elements from video games and their application to enhance education (*gamification*). Moreover, video games can also be used in their entirety to convey scholastic knowledge (*game-based learning*).

The current section collects and analyses studies involving controlled experiments on gamified and game-based learning. The focus of this review is experimental studies of gamified or game-based learning techniques applied to scientific secondary or higher education. When gamification is applied in this context, experimentation often translates as the application of playful elements in education. On the other hand, game-based learning usually involves the design of video games, fully focusing on conveying educational content. The goals of these experimental tools can vary from enacting behavioural changes [46, 47] to improving knowledge acquisition. In their literature review, Hainey et al. [48] analyse more than 100 studies in the field and report knowledge acquisition as the predominant learning outcome of 64 studies out of 105.

Regardless of the field of application, the cognitive effects of games or game elements vary as well. The most commonly reported effect is an increase in students' motivation and engagement, in line with the historical trend to utilise games in education as a medium to make experiences more pleasurable [9, 49]. On the other hand, the link between game elements and actual education effectiveness is not as clear. Even though many studies report a positive relation between the two [50] and are backed by empirical game research [51], many experiments in the field of games present opposite results [52] with the respective theoretical research to support them [53].

Such diversity of studies (and results) in the field justifies the relatively high number of meta-studies. These tend to focus on specific aspects of the gamified/game-based learning experiments, but also include more general information about the contexts of application (where possible). For example, the above-mentioned review by Hainey [48] focuses on documenting the diversity in the field. This is reported in terms of learning outcomes, topic of application, and quality of the study. The review selects empirical studies from 2000 to 2013 that apply game-based learning in primary education curricular subjects. Laine and Lindberg [54] focus on game motivators and how different studies in education used them and reported different effects. While the selection criteria are less strict compared to Hainey et al., the study also includes more recent papers (from 2000 to 2019). Finally, Hamari et al. [55] perform a broader review, focusing on how the studies were carried on. Through this perspective, they draw several conclusions about the quality of the experiments. In particular, they define multiple issues arising from the lack of clarity in the reporting style of many studies. They also report a sharp increase in studies involving gamification, which more than quadrupled in one year (2011-2012).

Problem Definition and Research Questions

The lack of clarity in the reporting style of many experiments makes comparative approaches challenging. In particular, the impact of different contexts of application related to the implemented game components is considered. The relevance of the context can become especially evident in controlled experiments. In these, the effect of experimental conditions (i.e. the game elements applied to education) can usually be better analysed with a clear understanding of the control conditions (i.e. the standard education method for that specific context). However, this is often challenging or impossible due to a lack of clarity in the description of the control conditions [55]. In practice, the lack of this type of contextual information makes it difficult to answer important questions to evaluate the experimental approach; how is the subject taught in the control group? What type of material is used? How are the experimental and control groups evaluated?

The present review arises from the need to study this lack of clarity and to define what elements of control groups (or, more generally, the no-game approach) are most frequently disregarded. Therefore, our first research question *Q1* is "(In controlled studies involving the use of game elements in education published between 2013 and 2020,) how is the information about the control group reported?" with a specific focus on the quality (and clarity) of this information regarding teaching method, teaching material/media, and experimental evaluation method.

Another element that can potentially influence the clarity of reported information is the inherent differences between the fields in which gamification and game-based learning are applied [48]. This leads us to our second research question (Q2): "How does the subject of application influence information clarity?".

The present review aims to build on existing knowledge and aid experimental research by improving replicability, enhancing comparability between studies, and highlighting the use of games and game elements in different fields.

2.2.1 Research Space Definition

In this section, we explore relevant characteristics of the field further as we motivate the initial selection criteria and analysis tools. As mentioned above, our research question is derived and influenced by two main characteristics of the field: diversity in the type of studies and diversity in the context of its application.

Characteristic 1: Type of studies

Many empirical studies that utilise games involve the use of an experimental and a control group. Although information about control (or no-game) conditions can be helpful to evaluate findings, many studies in the field omit it to different degrees. This is a known issue that can hinder analytical approaches focused on the influence of experimental conditions [56]. Other studies do not use control groups and only rely on qualitative analyses of information gathered over the entire population. Categorising these studies is even more complex, and comparison with different studies is challenging. Based on this initial distinction, we create the following initial criterion to select papers relevant to our research question:

- Presence of a control group: defining starting conditions as the standard academic path, we add this criterion in order to ensure the relevance of pre-intervention context descriptions (also when provided by the same course results in previous years).

We also determine common elements that are necessary to replicate a controlled experiment involving the use of gamification and game-based in education:

- Elements of starting conditions: we categorise each paper by reporting how much information we can find about starting conditions, usually represented by the control group. In this regard, we define three elements as relevant: type of teaching material (the tools used to transmit course content), teaching method (how the course is taught), and evaluation method (how the effectiveness of experimental and control methods is evaluated).

Characteristic 2: Context of application

Games have been studied and used in education throughout different academic curricula, from scientific to humanistic subjects, in academic and technical education. In the study of languages, for example, game elements have been used and appreciated in both academic and "more commercial" settings [57, 58]. Also, the field of mathematics experimented with adding game components to different grades of education [59]. Moreover, games are used and studied for both practical (training) and theoretical knowledge acquisition. Finally, another big part of the studies involves the use of game elements in behavioural change projects aimed at educational environments, for example, to promote safer sexual practices [60]. Such diversity, which naturally arises from the shared interest of many disciplines in the use of educational games, makes comparisons between studies very challenging. Therefore, we narrow our search by using strict criteria to select studies to include in this review:

- Scientific subjects: we focus on studies about how games influence the absorption of scientific notions. Since we focus on how different fields produce different studies, we include both natural and social sciences in order to preserve some variation.

- Knowledge acquisition: we include studies that aim at the acquisition of theoretical or practical knowledge. The rationale behind this is to include studies in the field of medicine and nursing, which often mix the two. On the other hand, we exclude studies whose goal is to develop behavioural change.

- Secondary or higher education: the studies we select involve students currently enrolled in secondary education. This includes high school and university-level courses. It excludes doctoral and specialisation studies in which participants are often professionals.

2.2.2 Method

Inclusion criteria

We summarise and motivate further criteria used to filter the studies, including those identified in the previous chapters:

- Date: 2013-2020. We have chosen to focus on where Hainey et al. [48] left off. As mentioned in Hamari et al. [55], the number of game-based experiments in education is increasing sharply every year. Focusing on recent years allows us to also investigate recent developments in the field.
- Database: Leiden University Library [61].
- Type: video games and hybrid games. We added this criterion in light of the fact that the majority of the studies collected involve digital components. In this way, we want to eliminate the few outliers which could prove difficult to compare.
- Includes: game elements and games. The experiments involve the use of game elements or full games. This excludes pure simulations in which game systems, or more generally, "pleasurable" components, are not implemented.
- Search terms: ("serious game" OR "game-based" OR "gamification" OR "game elements") AND ("experiment" OR "evaluation" OR "impacts" OR "outcomes" OR "effects" OR "education" OR "learning")
- Language: English

Selection

After using the filters available on the database website ("Date" and "Language") to limit the date and the language of the studies, we proceed to read the abstract of each of the first 100 papers (sorted by Relevance and using a combination of the "Search Terms"). We then determine whether it respects the rest of the aforementioned selection criteria (double-checking the year of publication). In case it does not respect one or more of them, the study is excluded from the present review. At the end of this selection process, we collect 89 studies. We then proceed to read the full paper and make a final selection. The final number of included studies is 43.

Categorisation

With the goal of documenting diversity and clarity of starting conditions in mind, we summarise the categories through which the studies are classified:

- Field of application: medical sciences (medicine and nursing), natural sciences (biology, mathematics, physics, computer science, etc.), economics (economics, business, management), and social sciences (sociology, psychology, anthropology).

- Type of education: theoretical, practical (training), or a mixture of both
- Clarity in the context of application: type of teaching material, teaching method, or evaluation method. For each:
  - Unclear - the experiment would not be replicable with the information presented
  - Clear - the experiment would be replicable with the information presented
- Grade of education: high school level or university level
- Results: The effect of the experimental condition on motivation and performance:
  - Negative (overall worse results in game condition)
  - Mixed/No-change (negative and positive results or no change in game condition)
  - Positive (overall better results in game condition)

2.2.3 Results

In this section, we report the quantitative results derived from the analysis of the included studies through the aforementioned categories.

2.2.4 The Dataset

We collected 43 controlled studies[1]. The studies are, in general, quite recent; almost half (N=20) were equally published in 2017 and 2019. Also, a good number (N=9) were published in 2020. The average year is 2018.

Classification by Field of Application

Medicine is the topic with the highest number of studies (N=8), followed by math (N=6) and computer science (N=6). All the other topics score equal to or smaller than 4. The number of studies which investigate the effect of game-based education,

[1] [62, 63, 64, 65, 66, 67, 68, 69, 70, 71, 72, 73, 74, 75, 76, 77, 78, 79, 80, 81, 82, 83, 84, 85, 86, 87, 88, 89, 90, 91, 92, 93, 94, 95, 96, 97, 98, 99, 100, 101, 102, 103, 104]

also (at least in part) on training, is 10, of which 8 are contextualised in courses involving a life science (medicine, nursing, or physiotherapy)(see Figure 2.1).

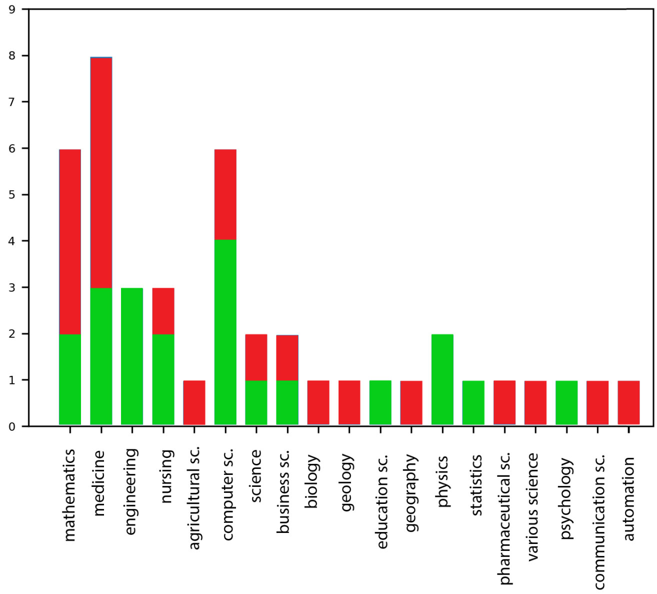

Figure 2.1: Number of studies per subject divided by success rate (”positive” in green, ”mixed” and ”negative” in red)

We cluster the fields reported in the studies into four categories: hard sciences, life sciences, social sciences, and engineering. For each category, we then calculate the success rate. The two categories with the highest success rate are hard sciences (N=10/18) and engineering (N=3/4), with computer science being the subject with the highest success rate (N=4/6). It is important to note that there is some possible overlap between these two categories (for example, subjects studied in computer science could also be studied in computer engineering). Life sciences present the lowest success rate (N=5/14). Almost the majority of the studies reported ”positive” results (N=21/43) while 12 studies reported ”mixed” results.

Classification by Clarity Scores

We analyse the frequency of the scores for the details of the educational context. For 22 studies, the details reporting the type of teaching material used in the control groups are deemed unclear (see Figure 2.2). In the case of the teaching method, the results show that in 30 studies, this information is evaluated as unclear(see Figure 2.2). On the other hand, testing methods are often more clearly reported, with only 12 studies marked as unclear (see Figure 2.2). In general, only a few studies lack detail in all three categories (N=6). Some are unclear in one or two categories (for both cases N=15) while a few others are clear in all three (N=7).

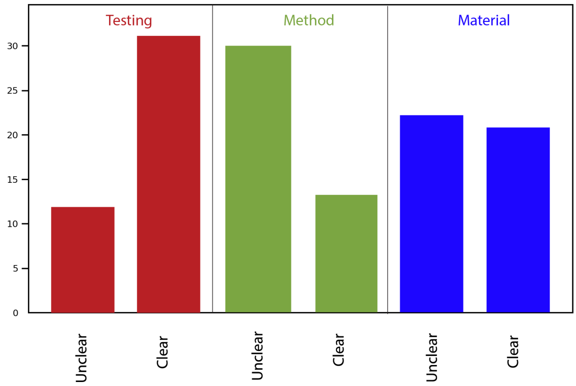

Figure 2.2: Number of studies per clarity score related to, from left to right: testing method, teaching method, and teaching material

Classification by Success Score

Almost half of the studies (N=21) report positive results across both performance and student attitudes (when this was relevant, see "5.1 Limitations"). 12 studies report mixed results, noticing only partial improvement in either performance or student attitudes. The rest (N=10) report worse results in the conditions involving games(see Figure 2.3).

Pearson correlation

We calculate the correlation coefficient between the success rate (mapping the scale 'negative' - 'mixed' - 'positive' over a scale from 0 to 2) and the average of the context clarity values (considering 'clear' labels as 1 and 'unclear' as 0) for each reviewed article. The result shows no meaningful correlation between the two (r=0.073). The correlation coefficient for the individual clarity of educational context values and the success scores also does not report a meaningful correlation (teaching material r=-0.078, teaching method r=0.229, testing method r=0.004). We additionally calculate the correlation coefficient between the values for the clarity of the educational context. Also in this case, the results are all well within the interval of -0.6 and 0.6; therefore, no

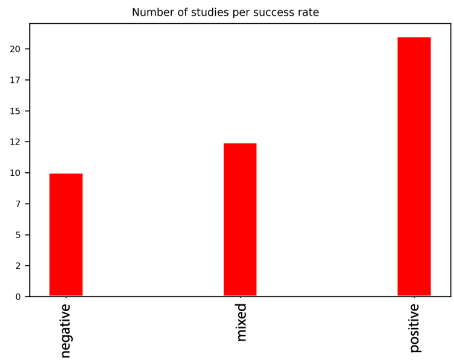

Figure 2.3: Number of studies per success score

meaningful correlation can be reported (material-teaching method r=0.369, material-testing r=0.089, testing-teaching method r=-0.042).

Clustering the Lack of Detailing

Within the studies we found lacking in terms of detailing scores, we delineate different groups based on how the lacking aspect is treated. This creates two categories valid for both the scores related to the clarity in reporting teaching material and method. One category includes studies that simply did not mention these two components [62, 64]. The other category does mention these elements of the control conditions but resolves them in generic terms (e.g., defining them as "standard", "classical" or "traditional") [67, 105].

The same categories cannot be applied to the scores of the evaluation method detailing. The main reason is that these studies are more consistent. Even when being "unclear", the evaluation is mentioned in the paper as an essential part of the experimental design. However, these cases refer to their results (e.g., the presence of an "improvement") without explaining in detail the type of tests and analyses that led to those conclusions.

2.2.5 Discussion

Q1: "How is the information about the control group reported?"

The present review focuses on how information in controlled studies involving games in education is presented. Our analysis shows that the most frequently unclear element of the educational context is the teaching method. In this regard, many studies fail to mention the way the teaching material is presented. It is important to notice that, when it comes to this teaching material, the actual information provided is more complete than the information regarding the teaching method; many studies report at least the type of material used (specific books, PowerPoint slides, and online courses are the most common).

Following also the qualitative parts of our analysis, we cluster those studies which are unclear according to these first two scoring systems and postulate reasons for the lack of detailing. Some of these studies rely on the idea that the respective educational practices (teaching method and material in this case) are supposedly standardised in certain contexts. However, this type of standardisation often does not account for teaching methods and/or the variation of these courses throughout the years in terms of content and material used. Other studies, in particular regarding the educational method, might simply overlook the importance of these elements and do not touch the subject.

The description of the testing method is usually clearer and in line with expectations. Few studies score 0, usually focusing on additional qualitative evaluations after the actual performance tests. Overall, it is rarer to encounter studies reporting no information at all in this regard, probably due to the intrinsic and fundamental nature of evaluation methods in experimental designs.

Q2: ”How does the subject of application influence the results?”

Looking at the success rate, results show that many studies (N = 21) reported benefits from using games for parts of their educational components. However, looking at the success score for each topic, games or game elements do not seem to be equally effective in every subject; for example, only three studies in the field of medicine report ”positive” results (N = 3/8). This could indicate that game elements are more effective in some fields compared to others. Topics that often heavily involve the study of technology (engineering and computer science) score above average (respectively, N = 3/3 for engineering and N = 4/6 for computer science). This could indicate that students who are usually more involved, or at least interested, in technology are more susceptible to the effects of games or more motivated by such tools. However, other subjects that make heavy use of computational tools, such as mathematics, show a low success rate (N=2/6).

Finally, it is important to observe that the lack of correlation between the scores (in particular detailing scores and success scores) can in part attest to the research's quality since the final results of the experiment do not seem to influence reporting decisions.

Limitations

Our inclusion criteria are effective in defining the area of interest of our research. However, they also present some intrinsic limitations:

- Limited field: we focus our research on subjects related to natural, social, and technical sciences. On one hand, this is functional to collect studies that follow a common scientific experimental method. On the other hand, it excludes a relevant amount of studies, in particular in the fields of language acquisition and history education.

- Limited types of courses: our current collection contains studies that involve both practical and theoretical knowledge acquisition. However, our previously mentioned field selection (sciences) automatically excludes studies in purely professional training settings. This often (but not always) affects experimental applications to training courses in vocational schools.

- Subjective clarity scoring system: the scoring system we use is strongly related to our personal interpretation of the various texts. This refers to the natural distance between the intention of the author and the interpretation of the reader.

- Relative success scoring system: the success scoring system (negative-mixed-positive results) is highly dependent on the scope of the individual study. Some focus and report exclusively on performance improvement, while others might include students' engagement and motivation. However, it is a valid parameter to determine how the results are analysed in each study and what perspective each paper takes on game-based education effectiveness.

2.2.6 Conclusions

The study successfully highlights the lack of clarity in describing the educational context as a common issue in the field of game-based education studies. This has an impact on the difficulty of interpreting exactly what educational elements the gamified/game-based experience goes to replace. Subsequently, this can strongly hinder comparative analyses. Moreover, it is very challenging to perform any in-depth categorisation according to the educational context within studies with incomplete information. Future studies indicated below need to either adapt to this issue to minimise its impact. The study also hints at a relationship between the success of gamified/game-based education and students' intrinsic motivation. Although this link is usually accepted, it is often disregarded in terms of its intrinsic value for learning. We argue that, in part, this is related to the tendency to belittle the importance of play as an activity that fosters fun, limited to the definition of 'autotelic' as an activity that has a purpose in itself. If we accept the effect of video games on motivation in educational contexts, we then understand how the purpose of play as a pleasurable activity goes, in certain cases, beyond play itself.

Future Work

Basing ourselves also on the aforementioned limitations, there are several directions to extend this work:

- One can use the same method and apply it to studies in the field of humanities. This is a better option than incorporating these studies directly into the current selection, since the two groups present very different teaching goals and methods. Moreover, the way study results are reported may also vary.

- It is also relevant to apply the same method to studies in vocational education. Notice that the three clarity scores (material, teaching, and testing) might need to be adjusted to include categories more closely linked to practical education.

- As shown in Figure 2.2, the studies are very diverse, also when it comes to the completeness of information reported. Comparative studies based on this collection should take this diversity into account, developing a methodology that can either adapt to it or compare studies from a different perspective, which minimises the impact of starting conditions.

2.2.7 Section Summary

The study above relates to two of the research questions of our thesis, in particular RQ1; and RQ2;. First, it highlights the effectiveness of games in education when it comes to motivation. It also indicates a positive impact on performance, though further research is needed. Secondly, the section investigates how experimental research in the field is carried out. It reports critical points in terms of clarity and, therefore, comparability. In general, we identify the need for tools for further analysis of the effect of video games in education. In the next section, we are introducing a potential solution to this problem. We highlight a correspondence between computational thinking skills and game design patterns. In doing so, we show how this tool can be effective in framing individual game elements and analysing them in terms of how they influence play.

2.3 Computational Thinking Through Design Patterns in Video Games

Learning how to program involves more than absorbing the syntax and semantics of a specific programming language; it also requires sensibility in combining and implementing these terms in an efficient and functional way. Programming makes use of procedural thinking, planning, data analysis, data re-elaboration and established practices such as testing and debugging [106]. All these components and skills find definition under the concept of "computational thinking". Training computational thinking skills and being able to use them proficiently is a common objective for programming education, and it is often one of the most challenging components for learners.

An important part of the research in the field is focused on finding new media and techniques to facilitate the development of these skills. Promising research has been conducted using computer games to train computational thinking components [107].

Video games present advantageous characteristics for this scope: they can support problem-based learning, require information retrieval to succeed, provide immediate feedback allowing testing, can easily embed assessments and often create a social environment or community [108]. They also motivate users with challenges and entertaining components [109]. Prior research at the intersection of video games and computational skills has often been carried out in two main directions: one tends to embed and test these components in environments that were created specifically for that purpose, such as is generally the case in educational games [110]. The other seeks to analyse the effect of general gaming experiences (i.e., not purpose-built for personal improvement) on a set of computational thinking skills [106].

While the first approach tends to deliver results for the study of the actual medium, the second takes a too general point of view that often faces noisy results due to the extreme diversity of elements in the game world. In this paper, we argue that focusing on generalizable game features and design patterns that benefit the development of computational thinking skills offers a valuable middle ground between these two approaches. We present this approach by outlining examples of design patterns that are most promising in the context of supporting programming education. In the following sections, we present and describe the set of computational thinking skills we decided to use. We will then list and describe design patterns that we think can be positively connected to each of them, also providing practical examples of where they are applied. The diversity and specificity of the examples suggest that each skill is activated by different video game components. Recognising these, we can explore a new potential way to study the relation between gaming and computational thinking.

2.3.1 Related Work

Computational Thinking and Programming Education

The definition of computational thinking skills varies depending on the author, with different sets of overlapping components; often conceptually related to methods for data extraction and re-elaboration or logical and procedural reasoning. A commonly cited model comes from Kazimoglu et al. [111] and builds on the work of Wing 2006 [40], Wing 2008 [112], Ater-Kranov et al. [113] and Berland & Lee [114]. It lists five fundamental computational thinking skills. These are (1) conditional logic, (2) building algorithms, (3) debugging, (4) simulation and (5) distributed computation.

Conditional logic involves an understanding of true and false values and their use in control flow statements. This involves being able to evaluate the status of a system in a specific local statement and an understanding of how each operation manipulates it. **Building algorithms** is a form of step-by-step problem-solving that requires a more solution-driven view of the multiple conditional logic instances. It shares some overlap with the previous skill, but in this case, it is necessary to have an overview of all the single manipulations to understand how the system reaches a desired final status (i.e., the solution). **Debugging** describes the process of testing in order to spot and find solutions to problems in the code. **Simulation** refers to the creation of mental or physical models to define how to implement algorithms and which circumstances apply. Finally, **distributed computation** groups all the social aspects of programming, from project-oriented working to making use of and contributing to a community [111].

The main advantage of this set of computational thinking skills is its practicality; each skill is well-defined, easy to understand and covers a good part of the components that are necessary in the process of programming. It goes to depict a picture of computational thinking as a reasoning process that goes from the detail (conditional logic) to a larger view of the relations between them (building algorithms). It further includes practical elements that are necessary throughout the whole programming process, such as debugging and simulating interactions between the components to reach the desired final state. Finally, programming is often an activity that heavily relies on the community behind it, and distributed computation can be used to describe all the skills necessary to access, use and contribute to this community.

Design Patterns in Video Games

In order to identify useful video game components, we follow the definition of "game design patterns" as described by Björk and Holopainen [115]. Generally, design patterns are reusable structures for finding solutions to common problems in a domain (such as architecture [116] or computer science [117]). Depending on the field, this can range from the application of narrowly defined instructions to more general recommendations for specific circumstances. In the field of game research, Björk and Holopainen define game design patterns as *"semi-formal interdependent descriptions of commonly reoccurring parts of the design of a game that concerns gameplay"*.

Game design patterns fit the purpose of our approach for multiple reasons. First, their definition is derived from a common term in the field of computer science. When studying computational thinking, this is a beneficial connection, especially in terms of communication and the structure of the knowledge for both the fields of computer science and game research. Second, they help to deconstruct video games into elements that can be studied and used more flexibly than focusing on the entirety of a game.

2.3.2 Concepts of Computational Thinking in Video Games

While previous research has examined computational thinking in educational games, little work has explored how video games (inadvertently or not) teach these skills. In this section, we propose a new perspective that extends existing models by incorporating game design patterns as a means for the activation and, perhaps, training of computational problem-solving.

Conditional logic: Some could argue that most decisions, especially in video games, are binary, therefore based on conditional logic. Even though this could be the case, there are some particularly connected components in video games that are worth mentioning. In [115] we find the pattern of **"Incompatible goals"** which refers to those situations in which pursuing a certain objective automatically forbids trying to pursue others. Players need to be able to evaluate the conditional status of those game elements that are triggering this pattern in order to understand the logical development of the video game. Another pattern that requires the application of conditional logic is **"Varied gameplay"**. This pattern describes how certain choices and settings can provide the players with completely different game instances. Especially role-playing games (RPGs) serve as a fitting example, given that every decision players make opens up some paths while closing down others. A popular example can be found in the 'The Elder Scrolls' [118] series where different choices in the character creation and in the story itself lead to very different gameplay options and overall narrative experiences (see Figure 2.4). This is facilitated by a sequence of conditional choices that allow and disallow certain features within the game as players progress.

Figure 2.4: Example of an interaction with mutually exclusive choices with an NPC in Skyrim

Building algorithms: Building algorithms entails following a step-by-step plan to solve a problem. It requires the ability to individually evaluate those steps (using conditional logic) and to analyse the results of their sequential combination. Many of the game patterns that stimulate this skill make use of different aspects of this skill, requiring players to plan, concatenate and modulate the manipulations necessary to reach the desired status. A fitting game design pattern is the **"producer-consumer"**

pattern, which guides the use and importance of resources. In some games, it even determines the speed of the gameplay [119, 120]. In complex systems, this pattern generates a network of interrelated producers and consumers. Often, to reach a specific objective, there are multiple steps of resource gathering, production and manipulation (which usually includes consumption) to be developed. Being able to foresee and plan over multiple cycles of discovering, extracting, transporting, storing and consuming resources requires similar mental mechanisms as building a computational algorithm. We can compare the producer-consumers to different functions returning elements as outputs and requiring outputs from other functions as input. The sequence of these elements and their inputs and outputs must be planned carefully in order to reach a certain goal. A very important concept of building an algorithm is taking a step-by-step approach [111], and similarly, we can see a step-by-step approach when building a producer-consumer network in many '4X' games (a sub-genre of strategy games that involves eXploration, eXpansion, eXploitation, and eXtermination). This game design pattern is noted to conflict with the pattern "predictable consequences" which makes sense from a computational thinking point of view as well: complex algorithms with multiple steps and data manipulations are often more difficult to manage and usually require careful debugging.

Practical examples for this pattern are numerous, and it is arguably an essential component to most strategy games. For instance, in 'Stellaris' [119], developed by Paradox Development Studio, certain jobs (tasks in the game) produce 'minerals' that are then consumed to produce 'consumer goods'. These can then be consumed again by other jobs to produce 'research'. Since the ratio of consumption to production is hardly 1:1, this system requires players to carefully plan the construction of jobs, usually in order not to end up with a negative balance in any of the above-mentioned resources. Another typical example is the complex and ramified network of resources of 'Thea 2: The Shattering' [121], developed by MuHa Games and Eerie Forest Studio. In this case, we have four different tiers of resources, with the last one being 'crafted', consuming resources of the previous tier and requiring the acquisition of specific technologies. In this case, we can see a sequence of steps necessary in order to acquire technologies, gather resources and craft them into a higher level one. Similarly, in 'Civilization V' [120], the player funnels resources into 'science' production, which in turn unlocks the exploitation of new resources.

Debugging: In order to analyse debugging, we need to unpack the several elements that compose this skill. Debugging is understood as a process of trial and error that is developed through testing. A corresponding game design pattern is "experi-

Figure 2.5: Screenshot of 'Doodle God' showing combinations of basic elements to create complex elements.

mentation". It usually indicates that a part of the game mechanics requires a process of trial and error to be evident, understood or mastered. In the most extreme cases, the whole gameplay revolves around experimentation in the form of 'puzzles' to be solved. Experimentation is often realised through trial and error as well, with testing being a necessary component of it. Similarly, debugging usually involves being able to critically think about the current configuration and can necessitate multiple trials to determine where the errors are, as well as how to fix them efficiently. It is important to point out that experimentation is a quite broad pattern and its usefulness to debugging skills generally holds only under specific applications. If we want to better specify the context, we need to limit it to the intersection with the game design pattern referred to as "Puzzle-solving". This refers to game features that need to be solved through inductive or deductive reasoning. If applied together with experimentation, we are arguably defining an even closer reasoning to debugging; a mental process that, through deductive or inductive trials and errors, attempts to spot and solve problems in the current solution. An interesting game example can be found in the mobile game 'Doodle God' [122] by JoyBits (see Figure 2.5). In the game, the player needs to combine basic elements (such as fire or water) to create new, more complex ones (for example, life or energy) that can be used to create even more complex elements. The whole game is based on a process of reasoning and, especially, trial and error. Players can think about potential element combinations and try them to see if they achieve new elements. The game also features helpful support for players that can partially (but rarely completely) provide hints to the creation of new components, highlighting one of the two elements that need to be combined.

Simulation: Similarly to 'conditional logic', simulation is a very broad category that refers to essential concepts of many video games built as representations of real or imaginary phenomena. It seems self-evident that video games include simulations of some sort. However, it can be beneficial to focus on patterns that allow or elicit simulation skills within games themselves rather than understanding games as a simulation of real-life processes. Here we encounter some overlap with "debugging" since the game design pattern "experimentation" can once again be useful in this context. Players can create a set of possible actions and evaluate them using simulation skills. Subsequently, these actions are validated by experimenting with them. In general, experimentation requires activating mental simulation mechanisms in order to narrow the set of possibilities to try. Other game patterns do not directly trigger simulations but might favour them. A typical example is the 'Save-load cycle' pattern, where players can save and reload games at specific points (or, in more flexible cases, from the main menu), allowing them to revert to a previous state and replay challenges or actions. This can elicit simulation skills similarly to experimentation; players can simulate and select certain solutions and then try them in multiple rounds, loading back the game at every iteration. In the 'Final Fantasy' game series (for instance 'Final Fantasy X' [123], see Figure 2.6), players can usually find saving spots right before the most challenging battles. In this way, the player can try certain settings and, in case of failure, analyse their own errors, improving on them after reloading the game from that last saving location.

Distributed Computation: We can identify several game design patterns that show useful traits in aspects of distributed computation. One example is "communication channels" which are present in many games that allow players to communicate with each other. "Cooperation" is another design pattern that can be connected to the idea of working together for a goal. However, we argue that it is even more compelling to notice how programming and gaming often behave similarly in their relationship with the respective communities [124]. We would argue that distributed computation is a skill that is necessary not only in computational thinking but also in many multiplayer games, or perhaps even certain single-player games with multi-agent aspects. Indeed, both involve massive online communities interacting, debating and

Figure 2.6: Example of a saving point in Final Fantasy X

sharing information to complete tasks that would be hard or impossible to achieve alone. Moreover, even though both tend to also congregate on different platforms focusing on the context (e.g. GitHub for programmers and Steam for gamers), sometimes these communities even interact on the same online networks such as Twitch or Reddit. The similarities do not stop here; as already mentioned, both communities developed mainly online and became important resources for the fields (at least in many modern video games). In this sense, both communities based themselves on a "Remix culture" encouraging the sharing and re-elaboration of information, blurring the line between final consumer and contributor [125, 126]. The overall argument in this case is that learning to make use and contribute to a gaming community probably involves similar skills to be able to do the same in a programming community because of these underlying similarities. A great example of an online community not directly connected to a video game (not referring to online gaming necessarily) is the community that formed around the 'Elder Scrolls' series. Many online resources surrounding that series share information with both new and more seasoned players about how to develop their characters and how to customise their game experience. Another more general example is the massive amount of online videos of 'playthroughs' (often referred to as "Let's Play" content) in which players record their game sessions while commenting and explaining their actions to show other players how to achieve a certain goal in a video game. Curiously, we can find similar videos about programming, with (more or less) expert programmers coding and illustrating how to use certain languages, libraries or functions.

2.3.3 Discussion

When highlighting video games as educative media for computational thinking purposes, we often tend to neglect the great variety of genres, mechanics and, more in general, game experiences. However, as we argue in this thesis, the individual constituent game design patterns are perhaps a more fitting lens to assess the potential of a video game to improve computational thinking skills. Such individual elements can trigger very different thinking strategies and stimulate users in different ways. What we proposed is a different way of studying the connection between gaming and the development of programming skills, starting from the design elements that make up a video game rather than from the medium or specific game titles in general. This approach can also be instrumental to the creation of educational video games that make use of design concepts developed specifically for the medium rather than adapting them to the scope. In this paper, we presented examples of design patterns and games that could be investigated regarding their ability to improve computational thinking skills. Further research, both empirical and theoretical in nature, should focus on developing a design process to create or modify video games for that purpose. This would strengthen the case for the use of video games to improve computational thinking skills in general, and deepen our understanding of how to target such efforts towards individual skills.

2.3.4 Section Summary

In the work above, we describe the connections between game design patterns and computational thinking skills. In doing so, we answer one of our research questions RQ3;. We see how specific mental mechanisms that are activated by certain game elements present similarities with computational thinking skills. Moreover, we practically show how game design patterns are a recognised tool to analyse video games and can be applied to the field of games for education. On the other hand, it is important to note how individual games can be played in different ways, and the thinking mechanisms involved can present some degree of variation. This could potentially impact the correspondence between the individual design pattern and computational thinking skill. However, the methodology we present can still be a useful tool in comparative work among research in the field.

In this chapter, we have noticed how game-based learning is particularly susceptible to natural differences arising from the context of application; different subjects, students, or design choices yield very different results. However, recent advancements in AI-driven procedural content generation (PCG) and adaptive learning environments offer new opportunities to personalise programming education. Building on previous work on AI-assisted game design, it could be interesting to explore how generative AI can be used to create dynamic learning experiences that adapt to different skill levels and learning styles. Another interesting question is whether the increasing integration of generative AI tools in programming education (e.g., code completion with GPT-based models) interacts with traditional learning methods, for example, by investigating if generative AI enhances or diminishes the role of games in developing computational thinking and problem-solving skills. In the coming chapter, we will first discuss aspects of the relationship between AI and video games. We will also investigate to what extent this relationship can bridge the digital gap in the real world in *hybrid* games.