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Game-Based Learning to Promote Complex Problem-Solving Capabilities

By

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Declaration

I hereby declare that, the contents and organization of this dissertation constitute my own original work and does not compromise in any way the rights of third parties, including those relating to the security of personal data.

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We Live to Play.

We Play to Live.

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Abstract

To successfully manage real-world complex problems that threaten our wellbeing, it is necessary to learn complex problem-solving (CPS) capabilities. Engagement in CPS processes can be promoted only in specific learning environments that simulate the uncertainty, unpredictability and uncontrollability of dynamic complex systems. Games can function as CPS learning environments because of their potential to (a) simulate authentic CPS dynamics in realistic complex situations, (b) promote cognitive, behavioural and affective holistic engagement of learners in game-based learning (GBL) processes, and (c) contribute to the acquisition, development, and improvement of CPS knowledge, skills, and attitudes. However, researchers and practitioners lack the appropriate tools to analyse and design gameplay features that may promote CPS processes in GBL environments.

Therefore, the aim of this thesis is to develop a set of complementary research tools that can support game experts to identify specific gameplay features of CPS scenarios that can be configured to promote intrinsically motivating GBL processes and cognitive CPS capabilities. Consequently, four research objectives were formulated, each guided by three research questions, that involve the development of instruments supported by conceptual models.

First, an analysis instrument was developed to support the identification of (a) simulated gameplay aspects of real-world CPS scenarios, and (b) key properties and functionalities of gameplay information flows that support player engagement with those gameplay aspects (i.e., the CPS-IF instrument, underpinned by the CPS-IF conceptual model). Then, an instrument was elaborated for identifying gameplay features that can make CPS processes in GBL environments intrinsically motivating to players (i.e., the CPS-GBL instrument, underpinned by the CPS-GBL conceptual model). Next, an analysis instrument was developed suitable to identify specific gameplay features that may promote required cognitive CPS conditions (i.e., the

GEFF-CPSC instrument, underpinned by the GEFF-CPSC conceptual model). Finally, guidelines were operationalised for configuring gameplay features to promote player engagement and cognitive CPS capabilities (the ability to engage in the uncertainty management process) (i.e., the CPS-GFC guidelines, based on the results of a systematic review).

The rigorous instrument development processes, the supporting conceptual models, the comprehensive systematic review method, and the results of the exploratory evaluation of the instruments, suggest that the produced instruments and models can be useful tools for game researchers and practitioners who are interested in (a) analysing or designing gameplay features that may promote CPS processes, (b) creating new research tools that are suitable to measure the effectiveness of games to foster CPS capabilities, and (c) generating new theories about how games can function as CPS learning environments.

Based on these contributions to research and practice and based on the key limitations of the thesis (i.e., (a) the exploratory nature of the validation tests and reliability assessments, involving low number of reviewers and games, and (b) the untested assumptions of the conceptual models for the effectiveness of games to promote CPS capabilities) the following directions for future work are suggested. Future research should involve more participants and diverse games for testing the instruments, and should integrate the instruments in a complementary way to explore the assumed potential of games to effectively promote CPS.

In conclusion, the thesis contributes to the research and practice of game design and analysis by providing research tools suitable for the identification of gameplay features that may promote player engagement in intrinsically motivating CPS and GBL processes. This study is one step on the path towards effectively analysing and designing games that may promote CPS capabilities through GBL.

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Acronyms

AI Artificial Intelligence.

CHC Cattel-Horn-Carroll.

CPS-GAME Complex Problem-Solving in Games.

CPS-GBL Complex Problem-Solving and Game-Based Learning processes.

CPS-GFC Complex Problem-Solving capabilities supported by Gameplay Features Configurations.

CPS-IF Complex Problem-Solving Information Flows.

CPSC cognitive Complex Problem-Solving Conditions.

CPS Complex Problem-Solving.

CWA Cognitive Work Analysis.

GBL Game-Based Learning.

GEFF-CPSC Gameplay Elements, Features, and Functions promoting Complex Problem-Solving Conditions.

GEF Gameplay Element Functions.

GFF Gameplay Feature Functions.

GF Gameplay Features.

ICC Intraclass Correlation Coefficient.

IT instrument Items.

PRISMA Preferred Reporting Items for Systematic reviews and Meta-Analyses.

RQ Research Question.

SDGs Sustainable Development Goals.

UMC Uncertainty Management Configuration.

UMF Uncertainty Management Function.

WST Work System Theory.

Chapter 1

Introduction

In our world we are surrounded by dynamic **complex systems** that are continuously evolving as a result of the interactions of a multitude of environmental, social and economic factors [7–9]. The societal transformations caused by this interplay have accelerated exponentially with recent industrial and technological progresses, leading to overwhelming threats to the health, happiness and prosperity of people worldwide [10–12]. These dynamic phenomena in the real world are difficult to understand and manage because they involve a large number of elements and interactions [13, 14]. Moreover, they are shrouded by uncertainty [13, 15] and generate emergent systemic effects that cannot be fully known nor predicted [13, 15], making the changing systemic dynamics uncontrollable [13, 15]. These interconnected, uncertain, unpredictable and uncontrollable phenomena are known as **complex problems** [6, 15, 16].

Similar to simple problems, complex problems involve a discrepancy between an undesirable initial state and a new goal state, where the problem solver either does not know how to transform the initial state into the goal state or is prevented from doing so by barriers and relevant environmental conditions [15, 17, 18]. Unlike simple problems, however, complex problems are characterised by an initial state of uncertainty, ill-defined goal state, dynamically changing barriers and environmental conditions, and unclear transformation approaches that may lead to desirable states but also generate unpredictable emergent effects [6, 12, 15, 18, 19]. Examples of real-world complex problems include the detrimental effects of climate change, the unstable economic impact of global population ageing, food and water insecurity, unaffordable housing and healthcare, energy crises and conflicting international policies [20, 21].

Population ageing can illustrate the typical characteristics of complex problems presented earlier. First, population ageing consists of a simultaneous increase in life expectancy and a decrease in the birth rate, leading to a progressive shrinkage of the working-age population, which consequent difficulties in raising the resources needed to support children and the elderly (*multiple elements and interactions*) [22, 23]. Second, the factors that currently define the levels of well-being of older people and the stability of healthcare systems and job markets are unclear (*initial state of uncertainty*) [22, 23]. Third, improving the ever-changing balance of priorities between evolving human needs, healthcare outcomes and employment security is an ambiguous goal (*ill-defined goal state*) [22, 23]. Fourth, although medical and technological progress improves the quality of health services and workplace practices, it also reduces the access to these systems due to increased demand from patients and workers (*dynamically changing barriers and environmental conditions*) [22, 23]. Finally, some governments are trying to raise the retirement age (*unclear transformation approaches*), leading to nation-wide protests (e.g. France, 2023 [24]), which can have disrupting effects on future elections (*emergent effects*) [22, 23].

For over half a century, the challenges posed by an increasingly complex world have motivated the international community to focus on the study of complex problems and the practical ways of managing them. As early as 1948, Weaver [25] suggested that the problems of organised complexity would define the future and that multidisciplinary research was needed to understand how to address these problems. Later in 1970, the Club of Rome, a global organisation concerned with worldwide challenges, proposed 49 continuous critical problems that humanity faces (e.g. war, wealth inequality, inadequate medical care, environmental pollution, misinformation, etc.) [26]. Similarly, in 2015, the United Nations General Assembly adopted 17 Sustainable Development Goals (SDGs) for the year 2030 aimed at tackling poverty, hunger, unemployment, disease, climate change, illiteracy, unaffordable energy and so on [27]. In addition, in 2017, the Millennium Project, formerly part of the World Federation of United Nations Associations, identified 15 major Global Challenges that threaten sustainable development, democratisation, equality, health, peace, and education [28].

In general, the international community strongly advocates for us as individuals and as a society to learn how to cope with complex problems [9, 26, 29], i.e. to learn **complex problem-solving (CPS)** skills and attitudes and to prioritise and promote them in modern education [29, 30]. CPS is the ability to achieve desirable state transformations in dynamically changing and uncertain environments while pursuing ill-defined goals [15, 31]. The development of CPS skills and attitudes requires specific learning environments that are suitable for simulating scenarios that mimic complex real-world problems and that motivate and support learners' proactive and holistic engagement (i.e., heads, hands, hearts) in such scenarios [15, 31–34].

With these requirements in mind, **games** can function as **CPS learning environments** because of their potential to simulate authentic CPS dynamics in realistic and complex situations [3, 35, 36]. In addition, games can promote holistic engagement by leveraging cohesive narratives and meaningful challenges to incentivise learners' willingness to tackle game-based problem scenarios, and consequently stimulate their cognitive, behavioural, and affective involvement in **game-based learning (GBL)** processes [9, 37, 38]. Finally, games can contribute to the acquisition, development, and improvement of CPS knowledge, skills, and attitudes by making these elements specifically relevant to achieve the challenges that players decide to embrace [9, 39, 40].

Considering these characteristics, games have been recognised as powerful learning environments suitable for eliciting and supporting CPS processes, however, their potential is yet to be fully realised [3]. In particular, game researchers and practitioners need enhanced tools to investigate which and how specific gameplay features may promote the development of CPS capabilities in games [36, 41], and may intrinsically motivate players to engage simultaneously in CPS and GBL processes [33, 42]. Motivated by this research problem, the aim of this study is to develop a set of complementary tools that will enable game researchers and practitioners to analyse existing games and design new games that can foster CPS skills and attitudes.

In the context of this study, games are conceptualised as **goal-directed work systems** [2], consisting of gameplay features (i.e. game elements, their properties and interactions) that can be configured to function in multiple ways (e.g., modifying the attributes and behaviour of game tools and game characters) to influence players' pursuit of assigned goals while making decisions based on a continuous assessment of the game state [3, 38]. Game state assessments are informed by gameplay information flows, i.e., clusters of information about the game state that are dynamically presented by the game in explicit (non-diegetic) or implicit (diegetic) form in response to the player's actions or triggered by events not controlled by the player [3, 38].

Based on this conceptualisation, we argue that to foster CPS, games should (a) simulate contexts, environments, and complex dynamics that define real-world CPS scenarios [6, 12, 35, 36]; (b) provide information flows with appropriate properties (e.g., diegetic or non-diegetic information presentation, domain relevance of the information content, timeliness and frequency of information presentation, etc.) and functionalities (e.g., support for learning, stimulation of actions, etc.) to help players dealing with the indeterminacy, unpredictability and uncertainty that characterise real-world CPS scenarios [3, 12]; and (c) present mechanisms suitable to intrinsically motivate players to engage in CPS processes in GBL environments [9, 33, 37, 38]. Consequently, the following four main research objectives are formulated to achieve the research goal:

1. develop an instrument for the identification of simulated gameplay aspects of real-world CPS scenarios, and key properties and functionalities of gameplay information flows that promote player engagement with those gameplay aspects;

2. develop an instrument to support the identification of gameplay features that can make CPS processes intrinsically motivating to players in GBL environments;

3. develop an instrument for identifying specific gameplay features that may foster necessary cognitive CPS conditions;

4. develop a set of guidelines for configuring gameplay features in ways that may simultaneously promote engagement in gameplay processes, and elicit and support cognitive CPS capabilities.

The main contributions of this study are the following:

- a set of tools developed for the analysis and design of games that may promote CPS skills and attitudes;

- a conceptual framework consisting of models that underpin each tool and can be used to develop new instruments and inform new theories;
- guidelines for gameplay features that may promote both player engagement and cognitive CPS capabilities, suitable for game analysis and design, and formulated through a systematic review of available methodological frameworks.

This chapter provides an introduction to the thesis by first introducing the context of the study, followed by the research problem, the research aim, the objectives and leading research questions, and the significance and limitations of the study.

1.1 Context of the study

1.1.1 Complex problem-solving

Traditional problem-solving can be defined as discovering a linear sequence of steps to transform an initial state of affairs into a goal state [43]. Instead, the characteristics of complex problems make CPS an iterative process that requires problem solvers to continuously interact with a dynamically changing environment and to explore, transform, evaluate, and predict its state [31]. Furthermore, while transforming the environment, problem solvers interpret dynamic changes and emergent effects, and subsequently reflect, criticise and modify their own behaviours [44, 45]. Finally, as they self-regulate their cognition, problem solvers generate and adapt partial solutions to high stakes challenges [15]. Considering (a) the relationships between these aspects of complex problems and these high demands on problem solvers [15], and (b) the recent emphasis of taking CPS back into real world contexts [15], the new definition proposed by Dörner and Funke [15] conceptualises CPS as follows:

1. CPS is a set of self-regulated processes and contextualised activities to achieve ill-defined goals;
2. CPS is situated in dynamically changing environments;
3. CPS is characterised by approaches and solutions that are incomplete;
4. CPS requires adaptivity, creativity, frequent collaboration, and a wide range of strategies for uncertainty management;

5. CPS involves the problem solver's cognition, affection, and motivation through highly challenging situations.

Based on this definition, CPS demands from problem solvers the skills and attitudes to (a) continuously observe and interpret complex problem scenarios, (b) iteratively define and adapt action plans, and (c) respond to relevant environmental changes based on incomplete and uncertain information [6, 15, 19, 42]. Even though it has been recommended that developing such CPS capabilities should be a priority of modern education [29, 30], formal learning environments have found it difficult to promote them effectively [15, 30, 44], thus the need for new innovative CPS learning environments has emerged [12, 46].

1.1.2 CPS learning environments

Constructivist learning may be particularly beneficial for the development of CPS skills and attitudes because it allows learners to experience the world and build knowledge by managing complex problems [44, 47, 48]. According to the constructivist paradigm, learners actively learn by (a) engaging in a contextualised process of constructing new knowledge, (b) using and reflecting on their real-world experiences, (c) formulating and testing hypotheses by interacting with the learning environment, and (d) evaluating the results of these interactions [49–51]. To foster this process, a constructivist learning environment should provide learners with: (a) a problem scenario based on real-world contexts; (b) appropriate information resources that support the problem-solving process; (c) sufficient tools that facilitate the transformation of the environment; (d) cognitive tools that assist with the exploration of the environment; and (e) conversational tools that promote collaborative social experiences [44, 48, 49]. Based on these characteristics, CPS learning environments should be constructivist, reflecting real-world contexts, and supporting problem solvers with a variety of tools and resources for exploration, transformation, and collaboration [44, 48, 51].

In addition to these recommendations, not only Sterman [32] (who models the learning process in complex systems) but also Dörner and Wearing [6] (who propose a theory of CPS) specifically suggest **virtual worlds** as suitable CPS learning environments. Virtual worlds are formal models or microworlds in which decision makers can play with features in the environment, learn from failure in the safety of the experimental space, and improve their decision-making skills through high-quality information flows [32, 37, 52]. Therefore, a learning environment that mimics complex problem systems, embeds complex dynamics, includes key aspects of virtual worlds, and promotes constructivist learning can be successful in developing CPS skills and attitudes [6, 32, 37, 44, 47, 48].

1.1.3 Games as CPS learning environments

Games based on simulation gameplay mechanics can act as microworlds and meet the urgent need for innovative CPS learning environments that are appropriately designed [3, 37]. Indeed, games have the potential to: (a) mimic real-world complex problem scenarios [12, 35]; (b) simulate contextualised and functional CPS dynamics in an experimental setting [3, 36]; (c) intrinsically motivate players to engage cognitively, affectively, and behaviourally in meaningful GBL environments [3, 9, 12, 37]; and (d) promote specific gameplay interactions for players to learn new CPS skills and attitudes [9, 39, 40]. Therefore, games can be effective constructivist learning environments for the development of CPS capabilities which has been difficult to achieve in ordinary educational contexts [3, 39, 53].

Gameplay can be conceptualised as a problem-solving activity within a contextualised work system of goal-directed tasks, action-mediated by objects, tools and social entities, and generating real-world complex dynamics [2, 3, 38]. To achieve desirable goal states (e.g., building a house), players perform gameplay tasks (e.g., gathering building materials from a forest) by transforming target objects in the game environment (e.g., cutting down trees in a forest) through mediated interactions with enabling entities (e.g., an axe for cutting down trees) and hindering entities (e.g., hostile animals that protect the forest) [3, 38]. These gameplay tasks are always embedded in a fictional spatio-temporal and socio-cultural context that defines the meaning and functioning of features, events, and information flows involved in gameplay activities [3, 38]. Such game contexts vary in complexity, however, in the case of simulation games, they can replicate real-world complex dynamics [3, 38]. Essential for the development of cognitive CPS capabilities are the factors that *gameplay learning* processes (a) can transfer knowledge, attitudes, and skills from in-game to real-world scenarios, depending on the contextualisations of the game [9, 39, 54–57], and (b) are completely intrinsically motivated by the game goals, contextualisations, and mechanics [53, 58–61].

In light of this background, game researchers and practitioners have the opportunity to exploit the CPS possibilities offered by games by either analysing the extent to which existing games can trigger and support engagement in CPS processes, or by designing new games that can promote CPS skills and attitudes.

1.2 Problem statement

Even though this study argues that games can be effective constructivist learning environments for developing and improving CPS skills and attitudes [3, 9, 37, 39, 40, 48, 53], it also identifies four main challenges that first need to be addressed before game researchers and practitioners are able to analyse, design, and use games to promote CPS processes.

First, to engage players in CPS processes, simulated gameplay aspects of CPS scenarios and clear and effective information flows are required [3, 12]. The appropriate properties and functionalities of such information flows, that define these gameplay aspects and influence the performance of problem-solvers under uncertain circumstances, have not been identified yet.

Second, compared to other types of microworlds and simulations, games have the advantage of engaging players in GBL or in activities that are intrinsically motivating [3, 12]. However, there is a trade-off between creating meaningful learning experiences and intrinsically-motivating complex environments [36, 62]. New ways to effectively balance these two aspects of game design are needed.

Third, the development of CPS skills and attitudes, depends on the understanding of how specific gameplay features promote required cognitive CPS conditions [3, 6, 36]. This mapping between gameplay and CPS has yet to be systematically carried out or tested.

Finally, while there are many methodological frameworks for the analysis and design of entertaining gameplay features that may trigger and sustain player engagement (e.g., [63–65]), few of them address the learning effects of such features (e.g., [3, 66]), and none of them focus specifically on CPS.

Based on these arguments, the problem statement of this study can be summarised as follows. Existing research tools are inadequate to (a) identify simulated gameplay aspects of CPS scenarios, and the properties and functionalities of gameplay information flows that present those aspects to players, (b) identify mechanisms that make CPS processes intrinsically motivating to players in GBL environments, (c) identify gameplay features that may promote required cognitive CPS conditions, and (d) identify gameplay features that may promote both player engagement and cognitive CPS capabilities.

1.3 Research aim, objectives, and questions

The aim of this study is to develop a set of complementary tools that will enable game researchers and practitioners to analyse existing games and design new games that can foster CPS skills and attitudes. These tools will support game experts to identify how simulated gameplay aspects and specific gameplay features interrelate with cognitive CPS conditions and capabilities to provide information to players and to intrinsically motivate them to engage in CPS processes within GBL environments.

A theoretical framework for complex problem-solving processes within game-based learning environments (CPS-GBL theoretical framework) is developed to underpin the set of complementary tools. The CPS-GBL theoretical framework integrates components of:

- the framework of activity theory-based gameplay system [3],
- CPS theory [6, 15, 31],
- constructivist learning [44, 50],
- the game-based learning human factors framework [9],
- the self-determination theory [65],
- the Work System Theory [2],
- the Cattel-Horn-Carroll theory of cognitive capabilities [67].

The justification for selecting these theories and the development of the CPS-GBL theoretical framework based on the selected theories is presented in Chapter 2.

To achieve the research aim, the thesis has four main objectives and related activities. The first objective of the study is to develop an analysis instrument to support the identification of (a) simulated gameplay aspects of real-world CPS scenarios, and (b) key properties and functionalities of gameplay information flows that promote player engagement with those gameplay aspects. This analysis tool is developed based on the method by Moore and Benbasat [68]. The pursuit of this research objective is guided by the following set of research questions:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*
- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*
- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

The second objective of the thesis is to develop an instrument for identifying gameplay features that can make CPS processes intrinsically motivating to players in GBL environments. The instrument is developed based on an established method [68] and evaluated through a case study of participants playing a game. The research objective addresses the following research questions:

- *RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*
- *RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*
- *RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*

The third objective of the study is to develop an analysis instrument for the identification of specific gameplay features that may foster necessary cognitive CPS conditions. This analysis instrument is developed by following well-recognised multi-stage approaches of instrument development and validation [68–70]. The research objective attempts to answer the following set of research questions:

- *RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*
- *RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*
- *RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*

The fourth objective of the thesis is to develop a set of guidelines for configuring gameplay features in ways that may simultaneously promote engagement in gameplay processes, and elicit and support cognitive CPS capabilities. CPS capabilities can be viewed more specifically as the ability to engage in the multi-phase uncertainty management process [2, 15, 19]. This objective involves performing a systematic review [71] of available methodological frameworks for the analysis and design of entertainment games and identifying gameplay features that if configured to function in specific ways may promote player engagement and may support and/or demand uncertainty management. The systematic review analyses gameplay features based on the Work System Theory (WST) [2], the Cattel-Horn-Carroll (CHC) theory of cognitive capabilities [67], and the Cognitive Work Analysis framework (CWA) [72] through an inductive qualitative content analysis approach [73], and by adopting template analysis techniques [74, 75]. The research objective addresses the following research questions:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*
- *RQ4.2: How should gameplay features be configured to promote player engagement?*
- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

1.4 Significance of the study

This study will contribute to the research and practice of game design and analysis by providing appropriate theory-based tools for the identification and evaluation of simulated gameplay aspects, gameplay features and information flows that are intrinsically motivating for players to engage in CPS processes within GBL environments. This will help address the shortage of research tools that can support game experts in understanding and developing games that may promote CPS skills and attitudes. The following are the five main contributions of the thesis.

The first main contribution of the thesis is the developed tool for analysing simulated gameplay aspects of real-world CPS scenarios and the properties and functionalities of gameplay information flows that promote player engagement with those gameplay aspects. The **CPS-IF instrument** (i.e., instrument for Complex Problem-Solving Information Flows) satisfies the requirement for identifying the appropriate properties and functionalities of gameplay information flows that define complex gameplay aspects and influence the performance of problem-solvers under uncertain circumstances. The development process of the CPS-IF instrument is presented in Chapter 4.

The second main contribution of the study is the developed and evaluated analysis instrument for the identification of gameplay features that make CPS processes intrinsically motivating to players in GBL environments. The **CPS-GBL instrument** (i.e., instrument for Complex Problem-Solving and Game-Based Learning processes) meets the need to identify gameplay features that can balance meaningful learning experiences and intrinsically-motivating complex environments. The development and exploratory evaluation of the CPS-GBL instrument are detailed in Chapter 5.

The third main contribution of the study is the developed and preliminary validated analysis instrument of game elements, gameplay features and their functions suitable to promote cognitive CPS conditions. The **GEFF-CPSC instrument** (i.e., instrument for Gameplay Elements, Features, and Functions promoting Complex Problem-Solving Conditions) addresses the need to identify the functional relationships between specific gameplay features and the necessary cognitive conditions for fostering CPS processes. The development and preliminary validation of the GEFF-CPSC instrument are reported in Chapter 6.

The fourth main contribution of the thesis is the set of guidelines for configuring gameplay features in ways that may promote engagement in gameplay processes, and elicit and support cognitive CPS capabilities. The **CPS-GFC guidelines** (i.e., guidelines for Complex Problem-Solving capabilities supported by Gameplay Features Configurations) are formulated through the first review in the field of games studies that systematically analyses existing methodological frameworks of entertainment games for specific gameplay features that may promote engagement in the gameplay process and the ability to engage in the uncertainty management process (i.e., cognitive CPS capabilities). The systematic review fulfils the need to explore the potential of available and conceptualised gameplay features to promote both player engagement and uncertainty management. The complete systematic review process and the resulting CPS-GFC guidelines are presented in Chapter 7.

The fifth main contribution of the study is a developed conceptual **CPS-GAME framework** (i.e., Complex Problem-Solving in Games) consisting of three conceptual models (i.e., **CPS-IF model**, **CPS-GBL model**, and **GEFF-CPSC model**). These models are based on the CPS-GBL theoretical framework, and serve to inform the development of categories and items within each of their respective instruments. The CPS-IF model, CPS-GBL model and GEFF-CPSC model represent the structural components and functional relationships within a complex gameplay system that can intrinsically motivate players through engagement in the goal-directed and action-mediated gameplay process to learn CPS skills and attitudes. The rigorous development process and the sound theoretical background, enable the conceptual CPS-GAME framework to support game researchers and practitioners in designing new instruments and formulating new theories. The CPS-IF model, CPS-GBL model and GEFF-CPSC model are elaborated right before each of the instruments they underpin, respectively, in Chapter 4, Chapter 5, and Chapter 6.

1.5 Limitations of the study

The scope of the study is limited to digital games because these types of games, in particular can simulate CPS scenarios, dynamic relationships between aspects of complex GBL environments, and provide high-quality information flows, all of which are necessary to promote CPS skills and attitudes [3, 9, 12, 36, 37, 39, 40].

An important methodological limitation of the study is the exploratory evaluation and preliminary validation of the instruments. A low number of analysts and participants and the particular characteristics of selected games for testing may lead to inconclusive results in relation to some aspects of the instruments. However, the homogeneity of testers allows for the contextualisation of results towards the efficient modification of the conceptual CPS-GAME framework and its instruments [76]. In addition, there are further steps in the development process towards the complete validation of instruments that can be part of future research [68–70, 77, 78].

Another limitation of the study is the interpretative nature of the qualitative scales and items of the instruments and the qualitative content analysis of the systematic review that introduces an element of subjectivity in the instrument development process and the systematic review process. To mitigate reliability risks, rigorous instrument development methods [68–70] and data extraction and synthesis processes [73–75, 79–81] are adopted.

Finally, for pragmatic reasons, the developed instruments isolate and focus on certain aspects and relationships of the gameplay system. However, a complex gameplay system has multiple interacting elements and features that dynamically influence each other resulting in the fostering of CPS capabilities. Therefore, it could prove difficult to observe and interpret the full potential of such a system and its individual game elements and gameplay features without using the developed tools in a complementary manner. Since this type of complementary application of the instruments is outside the scope of this study, the expected effects (i.e., assumptions based on the conceptual models) of identified gameplay features remain untested through an analysis of existing games or the design of new games. Such analysis and design experiments for validating the effectiveness of gameplay features based on the complementary use of the developed instruments are suggested as future research in Chapter 8.

1.6 Thesis structure

The structure of this thesis and the organisation of its workflow are illustrated in Fig 1.1 and described as follows.

Chapter 1 introduced the context of the study and the research problem. The research aim, objectives and questions were identified. The resulting contributions were presented and the limitations of the study were discussed.

Chapter 2 reviews the literature from the research fields of games, CPS, motivation, learning and cognition to identify appropriate theories that can be integrated in new and complementary ways (i.e., the CPS-GBL theoretical framework) to serve as a theoretical foundation for the proposed tools.

Chapter 3 reports the research design of the thesis and outlines its workflow of developing conceptual models, instruments and guidelines, by addressing each objective and research question.

Chapter 4 addresses the first main research objective and answers the first set of research questions (i.e., *RQ1.1*, *RQ1.2* and *RQ1.3*) by presenting the methods, results and discussion related to the development of the CPS-IF instrument and the elaboration of the CPS-IF model.

Chapter 5 addresses the second main research objective and answers the second set of research questions (i.e., *RQ2.1*, *RQ2.2* and *RQ2.3*) by detailing the methods, results and discussion involved with the development and exploratory evaluation of the CPS-GBL instrument and the creation of the CPS-GBL model.

Chapter 6 addresses the third main research objective and answers the third set of research questions (i.e., *RQ3.1*, *RQ3.2* and *RQ3.3*) by reporting the methods, results and discussion about the development and preliminary validation of the GEFF-CPSC instrument and the formation of the GEFF-CPSC model.

Chapter 7 addresses the fourth main research objective and answers the fourth set of research questions (i.e., *RQ4.1*, *RQ4.2* and *RQ4.3*) by describing the methods, results and discussion of the systematic review of methodological frameworks for the analysis and design of entertainment games that leads to the CPS-GFC guidelines.

Chapter 8 discusses the results of the previous chapters in relation to the research objectives and questions. It reports the contributions of the thesis (i.e., four research tools and the conceptual CPS-GAME framework), considers the limitations of the study and proposes directions for future work.

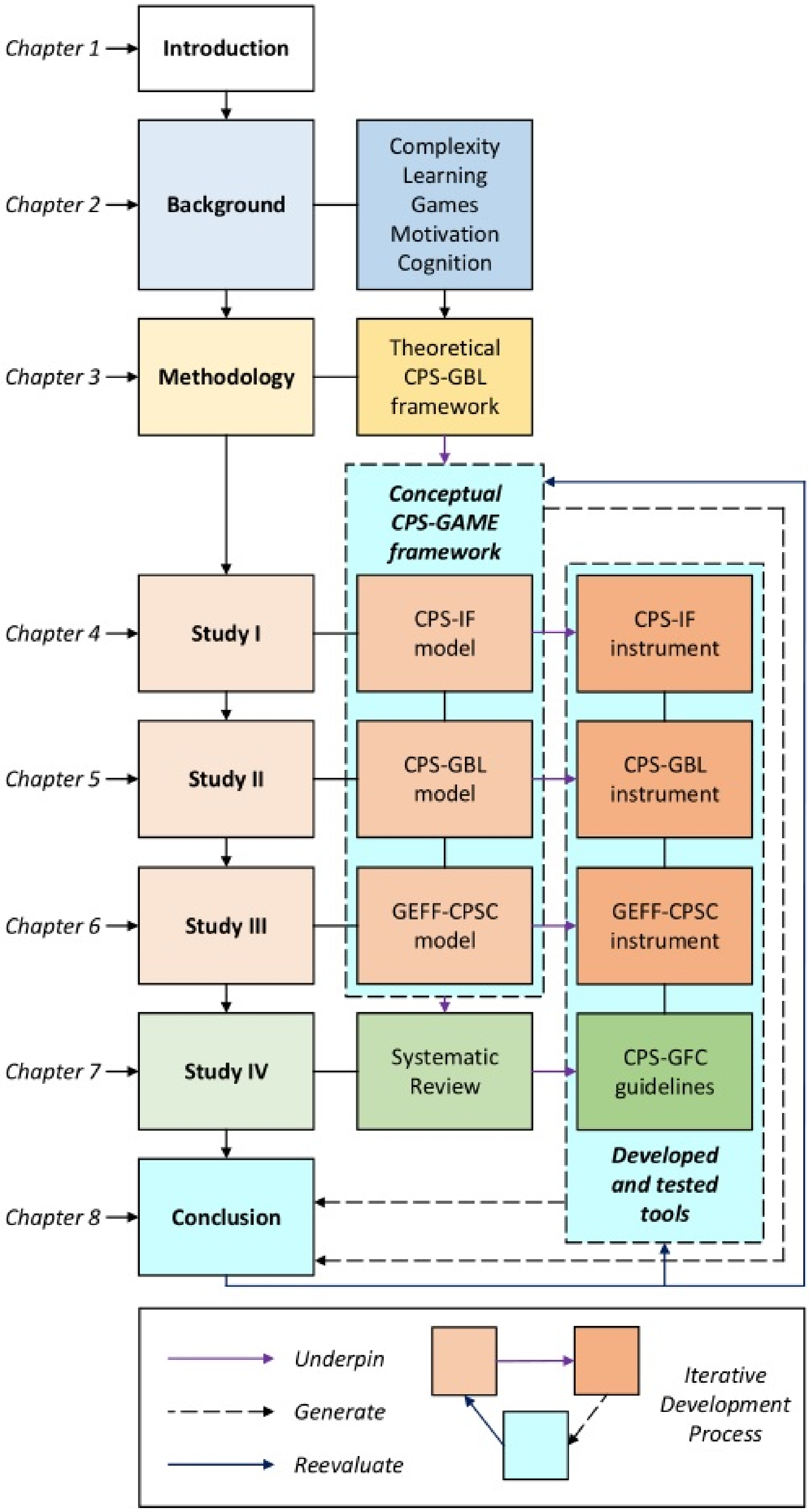

Fig. 1.1 Thesis structure organisation

Chapter 2

Background

2.1 Introduction

The research problem that motivates this study is the lack of suitable tools for the investigation of gameplay features that may promote intrinsically motivating CPS and GBL processes [33, 36, 41, 42]. To address this research problem, the formulated aim of this study is to develop a set of complementary tools that can support researchers and practitioners to identify specific gameplay features in games that may promote CPS capabilities.

For this purpose core elements and dynamics in games that can function as CPS learning environments should be conceptualised based on sound theories and frameworks that integrate in a complementary way key characteristics of gameplay, learning and CPS. Therefore, a literature review of seminal works in the fields of game studies, learning and complexity science is performed and the selection of relevant theories, concepts and frameworks is justified in Section 2.2. Then, in Section 2.3 the integration of those selected theories, concepts and frameworks is presented in the form of the CPS-GBL theoretical framework (i.e. theoretical framework for complex problem-solving processes within game-based learning environments), which underpins the research activity of this study.

2.2 Relevant theories and concepts

2.2.1 Gameplay

Guided by the framework of activity theory-based gameplay system [3], gameplay can be conceptualised as a contextualised problem-solving activity consisting of a system of hierarchical and iterative goal-oriented tasks, mediated by objects and social entities, and driven by meaning-making. Meaning-making is an essential component of the gameplay activity. As players interact with the gameplay environment, they make sense of it, and interpret involved elements and dynamics to understand what needs to be done, how and why [38]. Through meaning-making players construct knowledge which they use to self-define goals, plan their actions, and evaluate the consequences of performed actions [3]. Meaning-making engages players holistically in gameplay situations that they face by integrating their affection, cognition and behaviour [3, 16].

Gameplay information flows are the key input for the meaning-making process that drives and motivates the gameplay activity [38]. Information flows are necessary for players to understand their role and what can happen in the game, how and why [38]. Effective gameplay information flows should: (a) support players in identifying, accepting and evaluating a gameplay task, (b) provide players with opportunities to plan ways to achieve a gameplay task, (c) help players to evaluate contextual conditions that may affect gameplay task performance, (d) enable players to understand aspects of the local and global game context, (e) support players in establishing connections between elements and events of the game space, and (f) be perceived by players as often as possible in response to the interactions between the player and the game space [3].

In addition to the provided conceptualisations of gameplay and information flows, other key frameworks and theories for the desirable conceptualisation of games as CPS learning environments are:

- **The GBL human factors framework (HF-GBL framework)** [9]: the HF-GBL framework is suitable to support the analysis of CPS-GBL features since it models the gameplay activity as a meaning-making process intrinsically driven by learning and promoting awareness, comprehension, caring and sense of agency regarding the gameplay environment [9].

- **Self-determination theory (SDT)** [65]: SDT is a well-supported theoretical framework and has been used for the evaluation of GBL environments which can motivate players and improve their CPS performance [33, 82]. SDT is focused on defining and measuring intrinsic motivation, operationalised as autonomy (i.e. sense of volition and personal agency), competence (i.e. need for challenge and sense of efficacy), relatedness (i.e. social connectedness) and presence (i.e. sense of being within the game world) in games [65].
- **Work System Theory (WST)** [2]: WST models goal-directed activities as task processes, defined by key environmental conditions and performed by actors who use tools and knowledge to achieve their goals [2].

Finally, crucial for the development of cognitive CPS capabilities are the following factors: (a) *gameplay learning* processes may enable the transferability of knowledge, skills and attitudes from game environments to real-world environments [9, 39, 54–57], and (b) *gameplay learning* processes are entirely intrinsically motivated by the goals, context and mechanics of the game [53, 58–61].

2.2.2 Constructivist learning

Constructivist learning may be especially valuable to foster GBL and CPS processes, because it provides the learner with an environment that can and should be transformed (similar to games and CPS situations) [44, 47]. Constructivist learners engage in the management of complex problems driven by meaning-making by interacting with the environment, transforming it to bring about a desirable goal state, interpreting it and using the acquired knowledge to progress the activity [44, 47, 50, 51].

To promote this constructivist learning process involving meaning-making, learning environments should provide learners with: (a) opportunities for exploration and transformation of the learning environment, (b) problem spaces based on real-world contexts, (c) information sources that support the problem solving process, (d) tools to enable the interactions with the environment, (e) cognitive tools to support exploration and reflection, and (f) collaboration tools for promoting social experiences [44, 49]. Based on this, it can be argued that contextualised CPS processes can be promoted in learning environments with these presented characteristics.

2.2.3 CPS

Based on a review of CPS literature, Quesada and Gomez [83] compare the four CPS traditions (i.e, Naturalistic decision-making, Dynamic decision-making, Implicit learning in system control, European CPS) and conclude that the European CPS tradition offers the most complex tasks and the more definitive CPS features. From the European CPS tradition, Dörner and Wearing propose the theory of intention regulation for CPS [6].

The theory of intention regulation explains how and why different patterns of human behaviour can lead to successful management of complex problems and it presents CPS as a process of intention regulation that relies on four cognitive CPS conditions (Figure 2.1): (a) acceptance of self-incompetence, (b) prioritisation of important problems, (c) routinisation of actions, and (d) recollection of correct mental representations [6].

Table 2.1 Cognitive CPS conditions, adapted from [6]

Cognitive CPS conditions	Importance of cognitive CPS conditions
Acceptance of self-incompetence	To act effectively in complex environments, it is important to accept and adapt to signals of self-incompetence, instead of ignoring those feelings.
Prioritisation of important problems	To prevent unfavorable future complex problem scenarios, it is important to anticipate and address larger problems, instead of only solving immediate ones.
Routinisation of actions	To engage in CPS activity and manage multiple pieces of information, it is important to master and perform repeated actions without thinking.
Recollection of correct mental representations	To deal with complex events, it is important to develop and recall clear and correct mental images of the characteristics of complex problem objectives.

The theory of intention regulation is goal-oriented and it integrates cognitive functions, motivational processes and emotional impacts [6]. This makes the theory highly compatible with the goal-directed gameplay processes described previously.

In addition, CPS should be considered as a contextualised process [15]. Real-world CPS scenarios require the problem solvers (a) to construct knowledge by interacting with the real-world problem space, (b) to transform the environment, (c) to interpret circumstance, (d) to consequently modify their own behaviours, and (e) to produce and adapt incomplete solutions [15, 44, 45]. Based on these relationships between elements of CPS, its can be conceptualised as: (a) a set of self-regulated processes and activities to achieve ill-defined goals, (b) existing in dynamic environments, (c) requiring creativity and wide range of strategies, (d) characterised by incomplete solutions, (e) involving the problem solver's cognition, affection and motivation through high stake-challenges, and (f) requiring collaboration with others.

Environment suitable to foster CPS learning should provide: (a) complex and challenging problem situations, and (b) multiple interacting variables that define explorable environments. To communicate these scenarios and variables, information flows are key and should be readily available for problem solvers to perceive the state of the environment and evaluate the effectiveness of their plans [31, 84, 85]. Therefore, the properties and functionalities of information flows are a significant influence of the CPS performance of problem solvers [85].

Finally, to specify CPS capabilities that can be investigated and measured, the Cattel-Horn-Carroll theory of cognitive capabilities (CHC theory) [67] can be used to define these CPS capabilities as the ability to engage in the necessary phases of the uncertainty management process (i.e., (a) perception, (b) hypotheses formulation, (c) hypothesis choice, and (d) hypothesis testing). This engagement should be demanded or supported for the development of cognitive CPS capabilities based on the configuration of features of the CPS environment.

2.3 CPS-GBL theoretical framework

It can be argued from the previous section that games can be effective learning environments to develop CPS capabilities. They can function as constructivist learning environments which are complex in nature [37] and are effective in promoting CPS, because of (a) their ability to simulate complex real-world situations and contextualise the gameplay activity [3, 16], (b) the iterative problem-solving nature of the gameplay activity [3], and (c) the role that meaning-making has in it (i.e., ability to engage players cognitively, affectively and behaviourally in gameplay scenarios [38]).

There are multiple possible conceptualisations such as this one, based on different approaches and theoretical frameworks that may tackle the requirements for integrating complementary theories related to gameplay, learning and CPS. Based on the selected theories and provided justifications for their selection in Section 2.2, the CPS-GBL theoretical framework is formulated (Figure 2.1, Figure 2.2, Figure 2.3

and Figure 2.4). The purpose of the framework is to support the creation of conceptual models that will underpin the development processes of instruments which are the main research objectives of this study in order to address the aim of the thesis.

Figure 2.1, Figure 2.2, Figure 2.3 and Figure 2.4 serve to illustrate the following mapping of concepts from previously selected theories: (a) the characteristics of players, learners, problem-solvers, (b) the characteristics of game, learning and complex environments, (c) the characteristics of gameplay, learning, complex tasks, and (d) the gameplay activity, learning activity and CPS process.

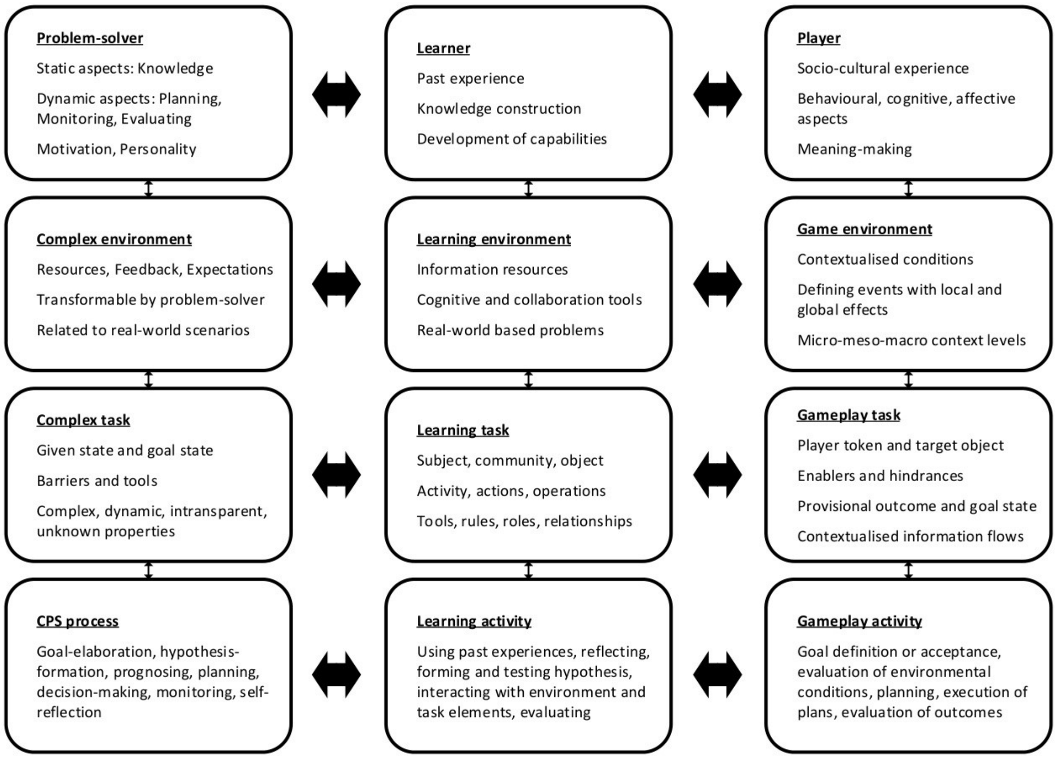

Fig. 2.1 The CPS-GBL theoretical framework 1

The potential application of the CPS-GBL theoretical framework (Figure 2.1, Figure 2.2, Figure 2.3 and Figure 2.4) for the development of conceptual models is by using different characteristics from the integrated components of the framework of activity theory-based gameplay system [3], CPS theory [6, 15, 31], constructivist learning [44, 50], the HF-GBL framework [9], the SDT [65], the WST [2], the CHC theory [67].

The CPS-GBL theoretical framework (Figure 2.1, Figure 2.2, Figure 2.3 and Figure 2.4) integrates the following aspects of each theory and framework:

- From the framework of activity theory-based gameplay system [3] - activity as a meaning-making process, gameplay interaction network, hierarchical game context, gameplay schemas, information flows;
- From CPS theory [6, 15, 31] - CPS elements (given state, goal state, barriers, etc.) and cognitive CPS conditions ((a) acceptance of self-incompetence, (b) prioritisation of important problems, (c) routinisation of actions, and (d) recollection of correct mental representations);
- From constructivist learning [44, 50] - contextualised process of constructing new knowledge, reflecting on real-world experience, formulating and testing hypotheses, evaluating results of interaction;
- From the HF-GBL framework [9] - impacts on the player's awareness, comprehension, caring and sense of agency;
- From the SDT [65] - intrinsic motivation, operationalised as autonomy, competence, relatedness and presence;
- From the WST [2] - work system elements (i.e., participants, customers, processes and activities, strategies, products and services, technologies, infrastructure, information, environment);
- From the CHC theory [67] - cognitive CPS capabilities (i.e., ability to engage in the phases ((a) perception, (b) hypotheses formulation, (c) hypothesis choice, and (d) hypothesis testing) of uncertainty management).

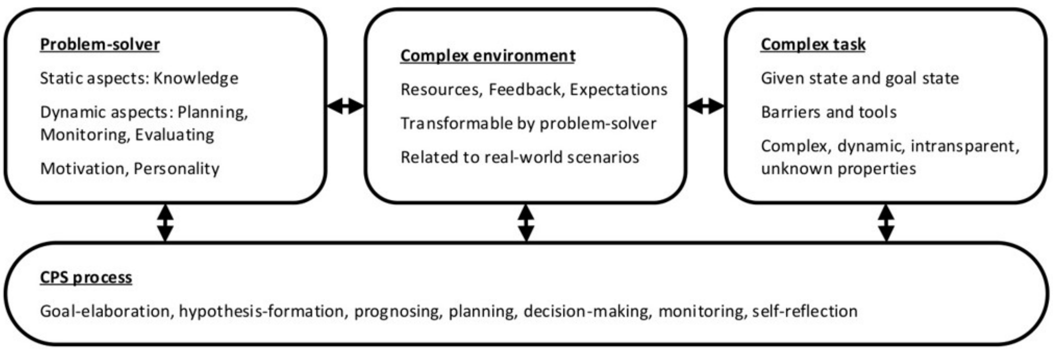

Fig. 2.2 The CPS-GBL theoretical framework 2

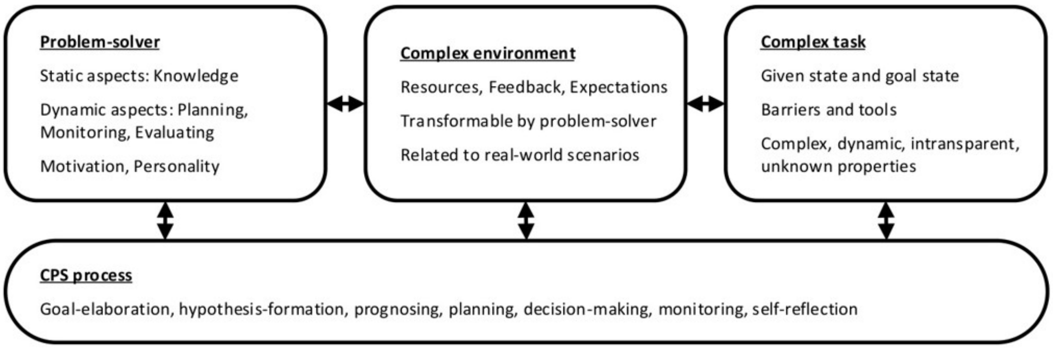

Fig. 2.3 The CPS-GBL theoretical framework 3

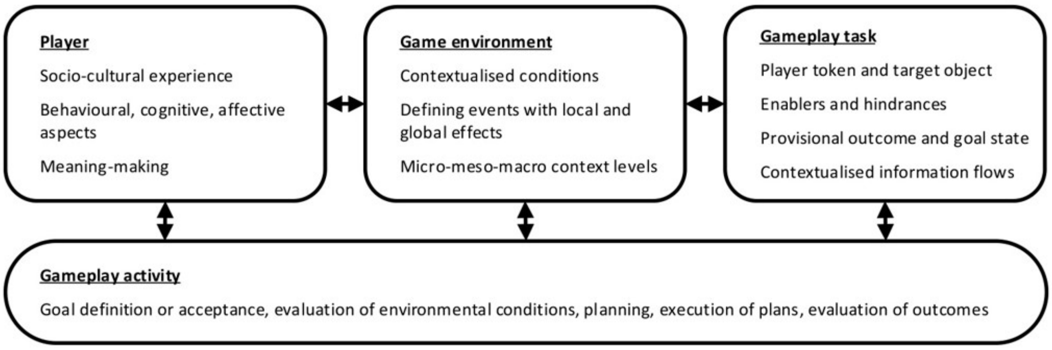

Fig. 2.4 The CPS-GBL theoretical framework 4

2.4 Summary

A literature review of seminal works in the fields of game studies, learning and complexity science was performed based on (a) the stated research problem that there is a lack of suitable tools for the investigation of gameplay features which may promote intrinsically motivating CPS and GBL processes [33, 36, 41, 42], and (b) the aim of the study to develop a set of complementary tools that can support researchers and practitioners to identify specific gameplay features in games that may promote CPS capabilities.

Based on this literature review relevant theories, concepts and frameworks were identified that were integrated in a complementary way in the CPS-GBL theoretical framework (Figure 2.1). The CPS-GBL theoretical framework serves to underpin the creation of conceptual models that support the development of instruments representing the research objectives of the study. The research design and the methods used for this development process are described and justified in the following Chapter 3.

Chapter 3

Methodology

The stated aim of this study is to develop a set of complementary tools that will enable game researchers and practitioners to analyse existing games and design new games that can foster CPS skills and attitudes. To achieve this aim, appropriate methodological decisions underpin this study and are highlighted and justified through the presented research design and research strategies in this chapter.

3.1 Research design

The research design of this study has been constructed based on the 'research onion' by Saunders et al. [1], presented in Fig 3.1.

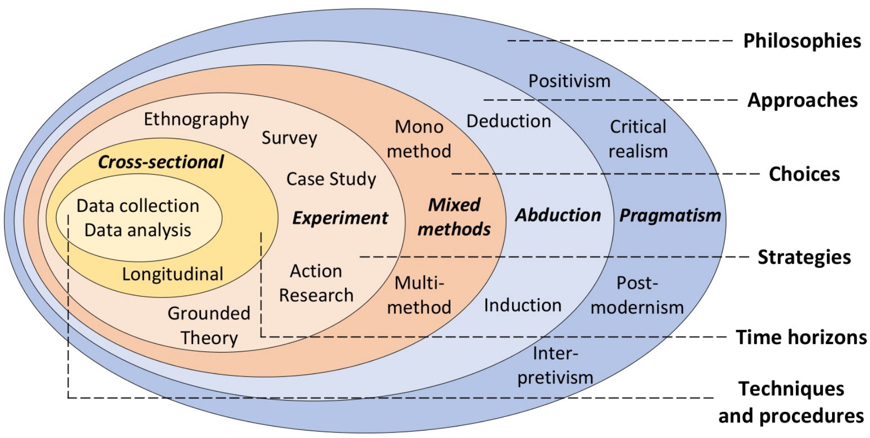

Fig. 3.1 Research design construction, adapted from Saunders et al., [1]

The 'research onion', which has been successfully adapted and used for robust methodological designs in different research fields [86–91], serves as a framework for selecting the most appropriate research methodology for the study and justifying its selection [1]. Each of the six layers of the 'research onion' (i.e., research philosophy, research approach, methodological choice, research strategies, time horizon, and research techniques and procedures (Fig 3.1)) represents an important research design choice that must be made and each layer needs to be peeled away so that a methodological rationale for the study can be provided [1]. Accordingly, the following describes the research design of this study based on each layer of the 'research onion' [1].

- *Research philosophy* - Saunders et al. [1] identify five major research philosophies (i.e, positivism, critical realism, interpretivism, postmodernism and pragmatism) that have different ontological, epistemological and axiological assumptions. The aim of the thesis is to develop appropriate research tools that can support game experts to adequately analyse and design games for learning CPS capabilities, therefore the study follows **pragmatism** (i.e., freely employing different strategies to achieve useful solutions for identified research problems, [1, 92, 93]).

- *Research approach* - Deduction, induction and abduction are the three main types of approaches [1]. An **abductive approach** (i.e., gathering data to develop a new theory or modify an old one, and then gathering data again to test the theory [1, 94]) is chosen for this study, not only because pragmatists gravitate to abduction more often [1], but also and primarily because the objectives of this thesis are to iteratively develop new instruments that are underpinned by a theoretical framework and conceptual models.

- *Methodological choice* - There are three types of choices, i.e., mono-method (quantitative and qualitative), multi-method (quantitative and qualitative), and mixed methods (simple and complex) [1, 95]. The methodological choice for this study is a sequential multi-phase **mixed methods** research, because the iterative nature of the development process of multiple analysis instruments involves integrating both quantitative and qualitative research.

- *Research strategies* - The research strategy is related to the research objectives and questions (e.g., grounded theory, action research, experiment, case study, survey, ethnography, etc., [1, 95]). This study adopts elements of **experimental** design as a research strategy [1, 95], because the objectives of the thesis require conceptually modeling a gameplay system, developing analysis instruments, selecting games as materials for testing, performing exploratory evaluations and preliminary validations with experts and participants, and systematically reviewing gameplay features of methodological frameworks. The research strategy and the way it relates to the research objectives and questions is described and outlined in detail in the following Section 3.2.

- *Time horizon* - The time horizon can be cross-sectional (i.e., studying a specific phenomena in a particular time frame) or longitudinal (i.e., studying change and development through time) [1]. This study is **cross-sectional** because it does not require investigation for a long period of time.

- *Research techniques and procedures* - The research techniques and procedures refer to different data collection and analysis processes [1]. This study uses:

  - literature review method and qualitative content analysis to identify, categorise and integrate theories and concepts for the development of a theoretical framework and conceptual models [96–98];
  - multi-stage approaches for instrument development, evaluation and validation [68–70];
  - theory-based inductive analysis [81], qualitative content analysis approach [73] and template analysis technique [74, 75] for developing guidelines through a systematic review method [71].

  The research techniques and procedures for the four individual studies, that each produce a research tool, are presented in detail in these studies' respective Methods sections of Chapter 4, Chapter 5, Chapter 6 and Chapter 7.

3.2 Research strategy and outline

As described in the previous section, the thesis adopts elements of experimental design as a research strategy [1, 95]. This choice of research strategy is related to the research problem that the thesis aims to address and the relevant objectives and questions that support achieving this research goal. Consequently, reintroducing the research problem, aim, objectives and questions can support the outlining of the research strategy in more detail.

The research problem that motivates this thesis is the lack of adequate tools that can support game experts in identifying gameplay features that may influence CPS processes and the development of CPS skills and attitudes. To address this research problem, the aim of the thesis is to develop a set of complementary tools for analysing and designing games that consist of specific game elements, gameplay features, information flows, and intrinsically motivating CPS processes within GBL environments. To achieve this aim, four studies were conducted, each developing a research tool that can support researchers and practitioners in analysing and designing games that promote CPS capabilities. The research methods for each study are outlined in the following subsections.

3.2.1 Study I

Study I (Chapter 4) addresses the stated research problem by developing an analysis instrument to support the identification of (a) simulated gameplay aspects of real-world CPS scenarios, and (b) key properties and functionalities of gameplay information flows that support player engagement with those gameplay aspects (the **CPS-IF instrument** (i.e., instrument for Complex Problem-Solving Information Flows)). This objective requires: (a) first, the modeling of a gameplay system consisting of CPS aspects of gameplay process, environment and tasks, and the properties and functionalities of information flows that may influence those CPS aspects (i.e., the CPS-IF model); (b) then, the creation of instrument items related to the modeled gameplay aspects, based on the method by Moore and Benbasat [68]; (c) next, the categorisation of those items into scales [68], leading to the development of the CPS-IF instrument which consisted of a questionnaire, because the synergistic combination of data types in a questionnaire can reveal otherwise hidden concept relationships to the instrument user through design thinking processes [99, 100]; and (d) finally, the testing of the CPS-IF instrument for reliability. The reliability testing involves modifying the CPS-IF instrument into an online questionnaire (*Google Forms*) and selecting the game *Stop Disasters* [101] as a case study for the testing of the CPS-IF instrument by game analysis experts. The objective of this study is guided by the following research questions:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*
- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*
- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

The research outline of this study, illustrated in Figure 3.2, involves (a) its research objective and questions, (b) the concepts of the CPS-IF model, (c) the scales and items of the CPS-IF instrument, and (d) aspects of the reliability testing process. The methods for the development of the CPS-IF model and CPS-IF instrument are further described in Section 4.2 of (Chapter 4).

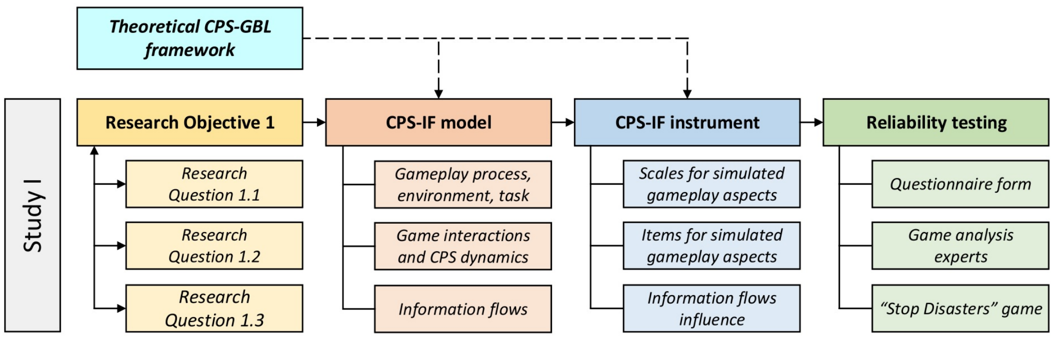

Fig. 3.2 Research outline of Study I

3.2.2 Study II

Study II (Chapter 5) tackles the established research problem by developing an instrument for the identification of gameplay features that can make CPS processes in GBL environments intrinsically motivating to players (the **CPS-GBL instrument** (i.e., instrument for Complex Problem-Solving and Game-Based Learning processes)). For this objective, the first step is using the CPS-GBL theoretical framework to create the conceptual CPS-GBL model that underpins the development of items and scales, based on an established method [68], of the CPS-GBL instrument, consisting of a questionnaire [99, 100]. Then the exploratory evaluation of the instrument requires (a) transforming the instrument into an online questionnaire (*Google Forms*), (b) selecting the game *Stop Disasters* [101] as a case study, (c) creating a protocol for the experiment, and (d) selecting game design students for the evaluation of the CPS-IF instrument. The objective of this study is driven by the following research questions:

- *RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*
- *RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*
- *RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*

The research outline of this study, represented in Figure 3.3, consists of (a) its research objective and questions, (b) the concepts of the CPS-GBL model, (c) the scales and items of the CPS-GBL instrument, and (d) aspects of the exploratory evaluation process. The detailed presentation of the methods for the development of the CPS-GBL model and the CPS-GBL instrument is reported in Section 5.2 of (Chapter 5).

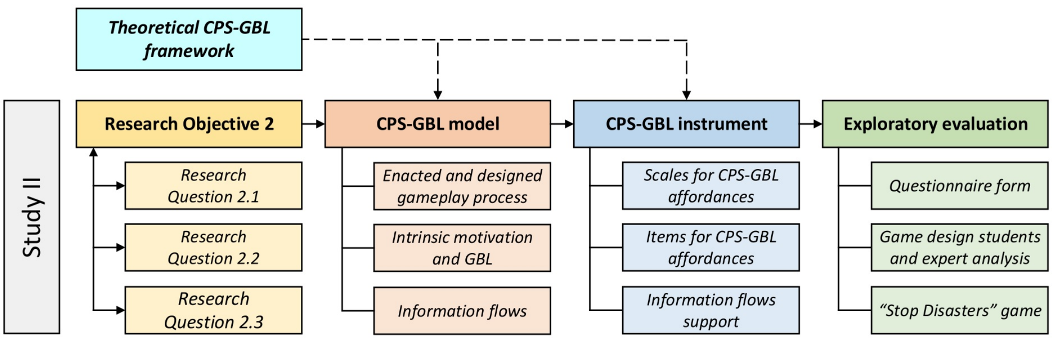

Fig. 3.3 Research outline of Study II

3.2.3 Study III

Study III (Chapter 6) addresses the described research problem by developing an analysis instrument suitable for identifying specific gameplay features that may promote required cognitive CPS conditions (the **GEFF-CPSC instrument** (i.e., instrument for Gameplay Elements, Features, and Functions promoting Complex Problem-Solving Conditions), consisting of a questionnaire [99, 100]). This objective involves the modeling of gameplay features that may promote cognitive CPS conditions and the game elements that may promote those features. Based on this model, items and scales for the GEFF-CPSC instrument are developed by following a multi-stage approach for instrument development and validation [68–70]. Finally, the instrument is assessed by reviewers and pre-tested by game analysts using the game *The Witness* [102] for the preliminary validation of the GEFF-CPSC instrument. The objective of this study is guided by the following research questions:

- *RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*
- *RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*
- *RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*

The research outline of this study, illustrated in Figure 3.4, involves (a) its research objective and questions, (b) the concepts of the GEFF-CPSC model, (c) the scales and items of the GEFF-CPSC instrument, and (d) aspects of the preliminary validation process. The full description of the methods for the development of the GEFF-CPSC model and instrument is presented in Section 6.2 of (Chapter 6).

3.2.4 Study IV

Study IV (Chapter 7) tackles the formulated research problem by developing the **CPS-GFC guidelines** (i.e., guidelines for Complex Problem-Solving capabilities supported by Gameplay Features Configurations) for configuring gameplay features

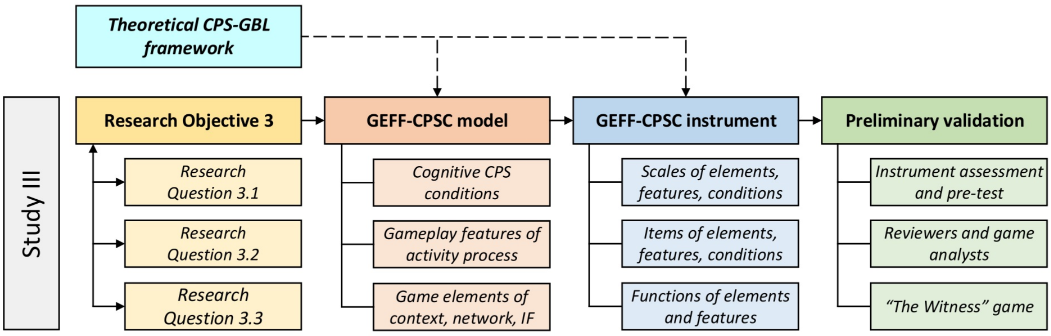

Fig. 3.4 Research outline of Study III

to promote player engagement and cognitive CPS capabilities (i.e., the ability to engage in the uncertainty management process). This objective involves systematically reviewing [71] existing methodological frameworks for the analysis and design of entertainment games. The goal of the review is to identify gameplay features that if suitably configured may promote player engagement and may support and/or demand uncertainty management, and can consequently be operationalised into the CPS-GFC guidelines, by using results and concepts from Study I, Study II and Study III. For this systematic review method, gameplay features are analysed based on the Work System Theory (WST) [2], the Cognitive Work Analysis framework (CWA) [72] and the Cattell-Horn-Carroll theory of cognitive capabilities (CHC theory) [67], by adopting an inductive qualitative content analysis approach [73] and template analysis techniques [74, 75]. The objective of this study is driven by the following research questions:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*
- *RQ4.2: How should gameplay features be configured to promote player engagement?*
- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

The research outline of this study, represented in Figure 3.5, consists of (a) its research objective and questions, (b) the categories and items of the coding schema, (c) variables of the CPS-GFC guidelines, and (d) aspects of the systematic review method. The complete details of the systematic review method and the development of the CPS-GFC guidelines are described in Section 7.2 of (Chapter 7).

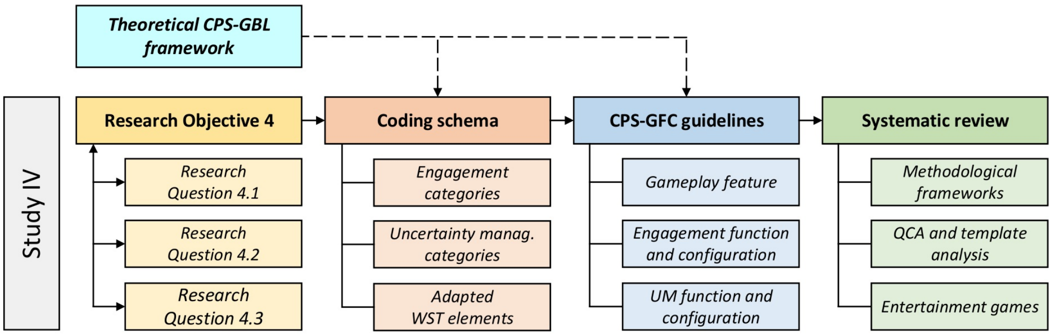

Fig. 3.5 Research outline of Study IV

As illustrated in Figure 3.2, Figure 3.3, Figure 3.4 and Figure 3.5, the conceptual models, the coding schema of the systematic review method, and the related instruments and guidelines from the four studies are all underpinned by the CPS-GBL theoretical framework (Section 2.3).

3.3 Summary

This chapter reported the research design of the thesis (Section 3.1) based on the 'research onion' by Saunders et al. [1]:

- *Research philosophy* - Pragmatism
- *Research approach* - Abduction
- *Methodological choice* - Mixed methods
- *Research strategy* - Experimental design
- *Time horizon* - Cross-sectional
- *Research techniques and procedures* - Development of conceptual models, development and validation of instruments, theory-based inductive analysis, qualitative content analysis, template analysis, and systematic review method.

In addition, the chapter outlined the specific methods, in relation to each of the four studies' research objectives and questions, used for the development of conceptual models, instruments and guidelines (Section 3.2) [68–71, 73–75]. The following Chapter 4 presents the methods, results and discussion of the first conducted study (i.e., the development of the CPS-IF instrument) towards achieving the aim of this thesis.

Chapter 4

Study I: CPS-IF instrument

4.1 Introduction

Chapter 4 presents adapted sections from a published paper in [103].

This chapter describes a study that attempts to address the specified research problem that available research tools are insufficient to identify the necessary gameplay aspects of CPS scenarios and the ways that those aspects can be communicated to players. Motivated by this problem, the research objective of this study is to develop an analysis instrument to support the identification of simulated gameplay aspects of real-world CPS scenarios and key properties and functionalities of gameplay information flows that promote player engagement with those gameplay aspects. This objective is driven by the following research questions:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*
- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*
- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

To satisfy these questions, first, the necessary simulated gameplay aspects of CPS scenarios (i.e., players, gameplay environment, gameplay process and gameplay tasks) [6, 15, 31, 44, 50] and the properties and functionalities of information flows that may influence those gameplay aspects (i.e., timeliness, frequency, relevance, etc.) [3] were modeled based on the CPS-GBL theoretical framework (i.e., theoretical framework for complex problem-solving processes within game-based learning environments) (Section 2.3) and methods for the development of conceptual models [96, 98], resulting in the CPS-IF model (i.e., model of information flows for complex problem-solving). Then, instrument items related to the simulated gameplay aspects were generated from the CPS-IF model, based on the method by Moore and Benbasat [68]. Next, these generated items were rephrased and categorised into scales [68], leading to the development of the CPS-IF instrument (i.e., instrument for information flows for complex problem-solving) which consisted of a questionnaire [99, 100]. Finally, the CPS-IF instrument was exploratorily tested for reliability [104] by modifying it into an online questionnaire (*Google Forms*) so that selected game experts can use it to analyse the game *Stop Disasters* [101]. The full development process of the CPS-IF instrument is reported in Section 4.2.

The contribution of this study is the CPS-IF instrument that can support researchers and practitioners to identify simulated gameplay aspects of real-world CPS scenarios and the properties and functionalities of gameplay information flows that promote player engagement with those gameplay aspects and influence the performance of problem-solvers under uncertain circumstances. In addition, the CPS-IF model that underpins the CPS-IF instrument can be used to create new research tools and formulate new theories.

This chapter reports the methods for the development of the CPS-IF instrument and the CPS-IF model in Section 4.2, the results of that development process and of the exploratory testing for reliability of the CPS-IF instrument in Section 4.3, and the implications of the findings in relation to the CPS-IF instrument, and the contributions and limitations of the study in Section 4.4.

4.2 Methods

4.2.1 Development of CPS-IF model

Developing a model of simulated gameplay aspects of CPS scenarios and the information flows that may influence those aspects is important so that the components of the model support the generation of relevant instrument items [96, 98]. We elaborated the CPS-IF conceptual model (Figure 4.1 and Figure 4.2) by integrating selected components from the CPS-GBL theoretical framework that are relevant for the purposes of this study (i.e., components of CPS theory [6, 15, 31], components of constructivist learning [44, 50] and components of activity theory-based gameplay processes [3]). Specifically, the CPS-IF model presents gameplay as a contextualised, meaning-making-driven activity process [3, 38] and combines these theoretical components into conceptual structural components (Figure 4.1) of a gameplay activity system in the following ways:

- The thoughts, feelings and behaviour of the problem solver [6, 15, 31], learner [44, 50] and player [3] are combined into "Player";
- The contextual aspects of complex environments [6, 15, 31], constructivist learning environments [44, 50] and gameplay environments [3] are combined into "Gameplay Environment";
- The elements of complex tasks [6, 15, 31], learning tasks [44, 50] and gameplay tasks [3] are combined into "Gameplay Task";
- The process phases of CPS [6, 15, 31], constructivist learning [44, 50] and gameplay activity [3] are combined into "Gameplay Process";

These structural components of the CPS-IF model (i.e., "Player", "Gameplay Environment", "Gameplay Task" and "Gameplay Process") are defined by gameplay elements (e.g., "Player" consists of the thoughts, feelings and behaviours of players engaged in a gameplay task) (Figure 4.1). Additionally, the model includes (a) the relationships and dynamics between its structural components and their elements (Figure 4.2), and (b) the properties and functionalities of information flows (i.e., timeliness, reiteration, response, relation, relevance and strength) that emerge from the interactions of players with a gameplay activity system (Figure 4.1).

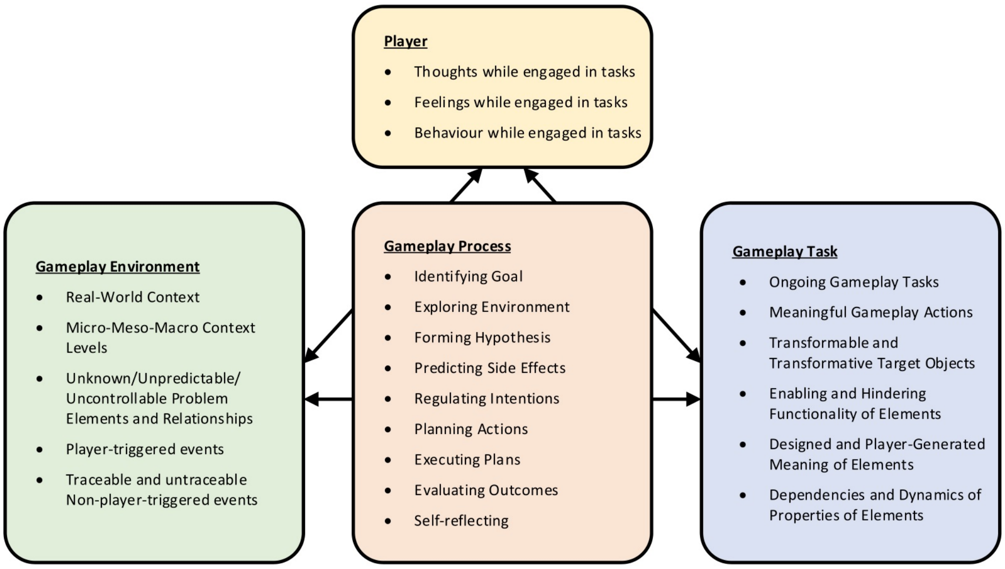

Fig. 4.1 CPS-IF model - structural components

The CPS-IF model (Figure 4.1 and Figure 4.2) conceptualises CPS aspects of a gameplay activity system as follows. The player's thoughts, feelings and behaviours influence their gameplay interactions and are in turn affected by those interactions. The gameplay environment is based on real-world contexts that provide complex problems defined by multiple unknown, unpredictable and uncontrollable elements and relationships. Environmental elements either (a) can be explicitly perceived by the player and can directly affect the ongoing gameplay task (i.e., elements in the micro-context), or (b) can be perceived by the player but can only indirectly affect the ongoing gameplay task (i.e., elements in the meso-context), or (c) cannot be directly perceived by the player but may indirectly affect the ongoing gameplay task (i.e., elements in the macro-context). Additionally, the gameplay environment includes player-triggered and non-player-triggered events. Some non-player-triggered events can be traced back to their source, while the effects of others cannot be traced back to their causes, creating uncertain circumstances.

The gameplay process, defined by the player interacting with the gameplay environment, consists of sub-phases (Figure 4.1 and Figure 4.2). These sub-phases require the player to iteratively identify a goal, explore the environment, form hypotheses, regulate their intentions accordingly, plan and execute actions, evaluate the outcomes of those actions, and self-reflect on their performance. The player performs gameplay actions with the intention to transform gameplay objects and

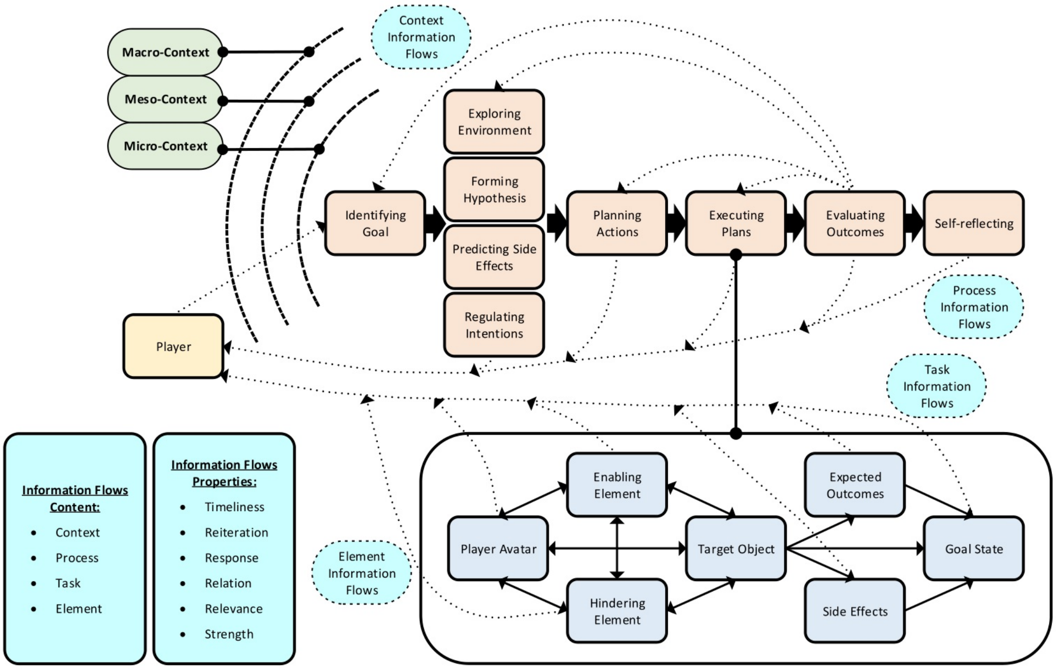

Fig. 4.2 CPS-IF model - relationships and dynamics between components

can be enabled or hindered by gameplay elements. These gameplay elements are designed with specific purposes but also offer the opportunity for players to generate new meanings based on the dependencies and dynamics of the properties of the gameplay elements.

The described relationships and dynamics between structural components of a gameplay activity system are communicated to the player through gameplay information flows that emerge from the game context, gameplay process, gameplay tasks and gameplay elements (i.e., content of information flows) (Figure 4.1 and Figure 4.2). In addition, information flows are characterised by the following properties and functionalities:

- *Timeliness* refers to the time between the player performing an action or a game event occurring and the presented information flows related to that action or event;
- *Reiteration* refers to the frequency and duration of the presented information flows;

- *Response* refers to the difference between presented information flows as a result of either performed player actions or non-player-triggered events;
- *Relation* refers to the level of clarity between the presented information flows and a performed player action or a non-player-triggered event;
- *Relevance* refers to the appropriateness of the information flows types as a response to a performed player action or a non-player-triggered event;
- *Strength* refers to the ability of information flows to direct player attention away from the ongoing task.

4.2.2 Development of CPS-IF instrument

The purpose of the CPS-IF instrument is to support the identification of simulated gameplay aspects of CPS scenarios and the properties and functionalities of information flows that may influence those gameplay aspects. The CPS-IF instrument was developed based on the components and dynamics of the CPS-IF model and by following the method by Moore and Benbasat [68], which consists of three stages: (a) generating instrument items, (b) categorising generated items into relevant instrument scales, and (c) testing the instrument.

First stage: CPS-IF instrument items

The goal of this stage of the CPS-IF instrument development process was to generate instrument items and to assess their clarity. First, two game analysis experts, who are familiar with the theories and concepts underpinning the CPS-IF model, created an initial set of instrument items. Each instrument item corresponded to an individual element of the components of the CPS-IF model (e.g., real-world context, identifying goal, meaningful gameplay actions, etc.). Then, the game experts conceptually pilot-tested these instrument items with different games and discovered that some items are unclear (e.g., micro-context, meso-context and macro-context). Consequently, ambiguous concepts were rephrased to provide self-explanatory definitions (e.g., the item "elements of the micro-context" was rephrased to "elements that the player perceives as directly influential on the ongoing task").

Next, in addition to these updated definitions, each instrument item was modified to include examples which can support the use of the instrument with a variety of games. For instance, (a) the instrument item "Aspects of player-triggered events" was exemplified with "signing trade agreements leads to geopolitical consequences; helping the people in town leads to unlocking new quests", and (b) the instrument item "Regulating intention" was clarified with "consider being friendly with characters and not provoking them; consider interacting with the puzzle for as long as possible to see changes in patterns".

Finally, the modification of instrument items was completed during the second stage of the development process, when items were organised in relevant categories and redundancies were removed (e.g. "Task Goal State" from the category "Gameplay Task" was removed because it was overlapping with "Identifying Goal" from the category "Gameplay Process").

Second stage: CPS-IF instrument scales

The objective of this stage of the CPS-IF instrument development process was to categorise the generated and iteratively modified items. First, instrument scales (i.e., "Game Context Structure", "Gameplay Process", "Gameplay tasks" and "Player Impacts") were developed based on the components of the CPS-IF model (i.e., respectively, "Gameplay Environment", "Gameplay Process", "Gameplay Task" and "Player"). Then, a fifth scale (i.e., "Information flows general properties") related to the proprieties and functionalities of gameplay information flows was created.

In the following Figure 4.3, an example of the structure of the CPS-IF instrument is illustrated. The instrument category "Game Context Structure" attempts to identify to what degree information flows influence the instrument item "Aspects of non-player-triggered events which cannot be traced to a known source", which is supported by clarifying examples (i.e., "effects of an unknown disease outbreak; disasters caused by unknown geological phenomena; social effects of unknown political decisions; etc."). The item assesses the influence of information flows on a five-point Likert scale (1: “Strongly Disagree; 2: "Disagree"; 3: "Undecided"; 4: "Agree"; 5: “Strongly Agree”).

	Strongly Disagree	Disagree	Un-decided	Agree	Strongly Agree
	1	2	3	4	5
Scale: Game Context Structure *Information flows support the identification and comprehension of the following game context aspects:*					
Item : Aspects of non-player-triggered events which cannot be traced to a known source (for example: effects of an unknown disease outbreaks; disasters caused by unknown geological phenomena; social effects of unknown political decisions; etc.)					

Fig. 4.3 CPS-IF instrument - structure example

The complete CPS-IF instrument, formulated as a questionnaire [99, 100] and consisting of 34 items, five scales and a five-point Likert scale, is presented in Figure 4.6 and Figure 4.7 in Subsection 4.3.1.

Third stage: CPS-IF instrument testing

The goal of this stage was to assess the reliability of the CPS-IF instrument through exploratory testing. The instrument was modified into an online questionnaire (*Google Forms*) and was tested independently by three game analysis experts, who were all familiar with the gameplay theories and concepts that underpin the CPS-IF model and instrument. One of the testers was blind to the development process of the CPS-IF instrument.

The game *Stop Disasters* [101] was used for the exploratory testing (Figure 4.4).

Fig. 4.4 Stop Disasters - Wildfire scenario

Stop Disasters is an online sustainability-based game that simulates five natural disasters that challenge players to develop urbanised areas by mitigating risks for the population and by protecting the environment.

Stop Disasters [101] was selected because it simulates gameplay aspects of real-world CPS scenarios (i.e., mechanics for dealing with natural disasters, real-world-based contexts, and problems involving multiple variables and interdependencies) and provides players with different information flows that are worth exploring in relation to CPS processes.

The three game analysis experts were instructed to: (a) first, play the *Tsunami* scenario (Figure 4.5) in *Stop Disasters* on medium difficulty for at least ten minutes, and (b) then, assess the game using the online questionnaire (*Google Forms*) (i.e., the CPS-IF instrument). The results of this assessment are reported in Subsection 4.3.2

Fig. 4.5 Tsunami scenario in Stop Disasters

4.3 Results

4.3.1 The CPS-IF instrument

Figure 4.6 and Figure 4.7 present the CPS-IF instrument, as the result of the development process described previously in Section 4.2.

The instrument consists of five scales (i.e., "Game Context Structure", "Gameplay Process", "Gameplay tasks", "Information Flows general properties" and "Player

		Strongly Disagree	Disagree	Un-decided	Agree	Strongly Agree
		1	2	3	4	5
	Scale 1: Game Context Structure *Information flows support the identification and comprehension of the following game context aspects:*					
1	Elements based on real-world context (for example: weather patterns; political systems; city layouts; population behaviours; geographical features; historical events; etc.)					
2	Elements that the player perceives as directly influential on the ongoing task (for example: if the task is "upgrade the water tower", then properties and functions of the selected water tower are directly influential on the current task)					
3	Elements that the player perceives as not directly influential on the ongoing task, but could lead to modified plans and actions (for example: if the task is "upgrade the water tower", then properties and functions of other buildings and nearby environmental elements could lead to modification of the current task)					
4	Elements that the player can't directly perceive or control, but may indirectly influence the ongoing task (for example: if the task is "upgrade the water tower", then cutting down forest trees as a resource for the tower could later on have uncontrollable impacts on wildfires or the happiness of the town population)					
5	Unknown/unpredictable/uncontrollable problem elements and their relationships (for example: uncontrollable behaviour of characters during unpredictable environmental changes; unclear paths towards population's wellbeing; etc.)					
6	Aspects of player-triggered events (for example: signing trade agreements leads to geopolitical consequences; helping the people in town leads to unlocking new quests; etc.)					
7	Aspects of non-player-triggered events traceable to known source (for example: environmental effects of day and night cycle; seasonal changes; an earthquake; social effects of tax raises in a foreign country; etc.)					
8	Aspects of non-player-triggered events which cannot be traced to a known source (for example: effects of an unknown disease outbreaks; disasters caused by unknown geological phenomena; social effects of unknown political decisions; etc.)					
	Scale 2: Gameplay Process *Information flows support the following aspects of the gameplay process:*					
9	Identifying goal (for example: obtain information; solve puzzle; etc.)					
10	Exploring environment (for example: searching for characters to talk with; observing the patterns of a puzzle mechanism; etc.)					
11	Forming hypothesis (for example: "if I find the right characters and ask the right questions, then I'll gather the required information"; "if I monitor the puzzle mechanism, then I'll discover predictable patterns"; etc.)					
12	Predicting side effects (for example: characters could become hostile while asking for information; the puzzle could change its patterns when interacting with it; etc.)					
13	Regulating intentions (for example: consider being friendly with characters and not provoking them; consider interacting with the puzzle for as long as possible to see changes in patterns; etc.)					
14	Planning actions (for example: plan to talk with family members first, then with neighbours and finally with friends; plan to move puzzle items on the left platform first, then on the middle platform, and finally on the right platform; etc.)					
15	Executing plans (for example: walking to characters, starting dialogue, asking questions, taking notes; moving on platforms, picking up items, putting items in puzzle mechanism, jumping from obstacles; etc.)					
16	Evaluating outcomes (for example: the information gathered from family members sounds more realistic; moving items on the middle puzzle platform caused the least amount of changes to the mechanism; etc.)					
17	Critically evaluating activity plans and involved methods (for example: "the plan to talk with family members first was good, but I should have been more direct in the dialogue options to get more information"; "I was jumping from platform to platform too often and was not patient enough to find the complete puzzle pattern on time"; etc.)					

Fig. 4.6 CPS-IF instrument 1

		Strongly Disagree	Disagree	Un-decided	Agree	Strongly Agree
		1	2	3	4	5
	Scale 3: Gameplay tasks *Information flows support the identification and analysis of the following aspects of gameplay tasks:*					
18	Which gameplay tasks are ongoing, either set by the player or provided by the game (for example: complete the quest; collect all artefacts; finish the level; etc.)					
19	Gameplay actions as meaningful building blocks of tasks (for example: avoid enemy; build house; walk to town; etc.)					
20	Gameplay target objects as elements that should be transformed through whole tasks or isolated actions (for example: doors to open; enemies to defeat; etc.)					
21	Transformable and transformative gameplay elements (for example: elements of a puzzle are changed by interacting with them, and in turn they change the puzzle solving process which affects the player's understanding and approach; etc.)					
22	Enabling and hindering functionality of elements (for example: player's shield position enables blocking some enemy attacks; limited resources hinder player's ability to build many structures quickly; etc.)					
23	Designed and player-generated meaning of elements (for example: in city-building games, roads are designed to generate a functional transport system, but the player can also use them to draw on the map area, construct realistic city layouts, experiment with citizen's behaviour, etc.)					
24	Dependencies among properties of elements involved in game task (for example: player character power depends on their statistics, armor, weapons, abilities, etc.)					
25	Dynamics among properties of elements involved in game task (for example: player character power evolves over time in unpredictable short-term and long-term directions by increasing statistics, replacing armor, collecting new weapons, etc.)					
	Scale 4: Information Flows general properties *Complex-problem solving processes, learning, and/or gameplay activity were supported through the following properties of information flows:*					
26	Timeliness of information flows (for example: selecting a dialogue option leads to an instant reaction from the character or it leads to a delayed reply through a cutscene)					
27	Reiteration of Information flows (for example: the current quest objective is always shown to the side or it appears on the map once every minute)					
28	It is clear whether information flows are provided in response to player actions, or to non-player-triggered events (for example: trees grow in town because the player planted them, or they grow randomly independent of the player)					
29	Information flows can be clearly related to events/elements in the audio-visual representation of the game scenario (for example: selling a building shows the profits received at the building's location in the game, to the side in the budget user interface; a crackling log sound is emitted when there is a wild fire on the screen)					
30	The type of information flows - or their combination - are appropriate to convey the meaning of the information (for example: receiving written information about dialogue options; receiving pictorial information about location of enemy units; receiving auditory information about quests, etc.)					
31	Strength of information flows (for example: a strong emergency alert notification shifts the player's attention to a new important task)					
	Scale 5: Player Impacts *Information flows may impact on:*					
32	Player's thoughts while engaged in game tasks (for example: making plans for the current quest; evaluating previous mission results; improving understanding of enemy behaviour; etc.)					
33	Player's feelings while engaged in game tasks (for example: excited with a new environment to explore; frustrated with a puzzle; scared by a haunted house; happy with completing the level on time; etc.)					
34	Player's behaviour while engaged in game tasks (for example: moving and jumping quick; taking notes of character interactions; buildings placed in safe locations; etc.)					

Fig. 4.7 CPS-IF instrument 2

Impacts") and 34 items that are categorised into their appropriate scales. Scale 1 ("Game Context Structure") and its eight items represent simulated gameplay aspects of the game context (Figure 4.6). Scale 2 ("Gameplay Process") and its nine items describe simulated gameplay aspects of the gameplay process (Figure 4.6). Scale 3 ("Gameplay tasks") and its eight items refer to simulated gameplay aspects of the gameplay task (Figure 4.7). These three scales and 25 items answer the first research question of this study:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*

Scale 4 ("Information Flows general properties") and its six items represent the properties and functionalities of information flows that influence the simulated gameplay aspects (Figure 4.7). This scale, its six items and the way they relate to the previous three scales and 25 items answer the second research question of this study:

- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*

Scale 5 ("Player Impacts") and its three items describe the influence of information flows on the thoughts, feelings and behaviours of players who are engaged in gameplay tasks (Figure 4.7). This scale, its three items and their relationships with Scale 4 and its items answer the third research question of this study:

- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

4.3.2 Exploratory testing results

Data analysis aimed to calculate the inter-rater reliability between the testers by using intraclass correlation coefficients (ICC) [104]. Inter-rater reliability between the three testers was calculated as "good" (ICC = 0.69), based on the standard guidelines for evaluating instruments and for qualifying values provided by by Cicchetti [104].

Figure 4.8 and Figure 4.9 present the testers' scores for the 34 instrument items (IT1-IT34) and their mean.

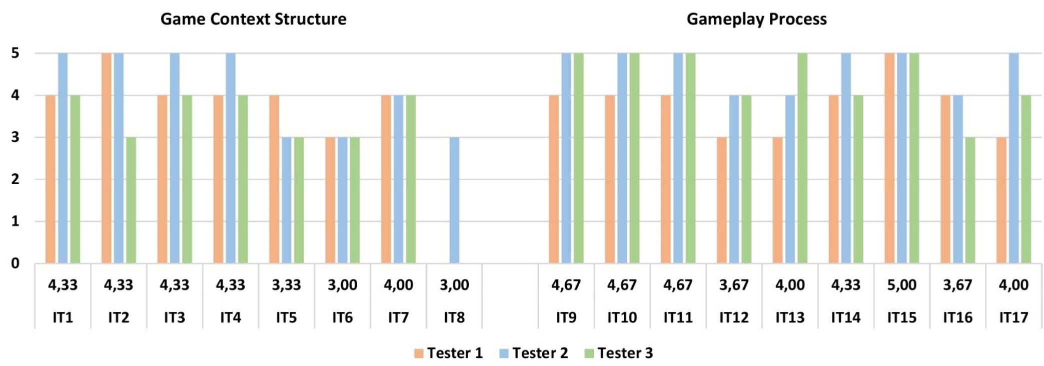

Fig. 4.8 Scores for items in "Game Context Structure" and "Gameplay Process"

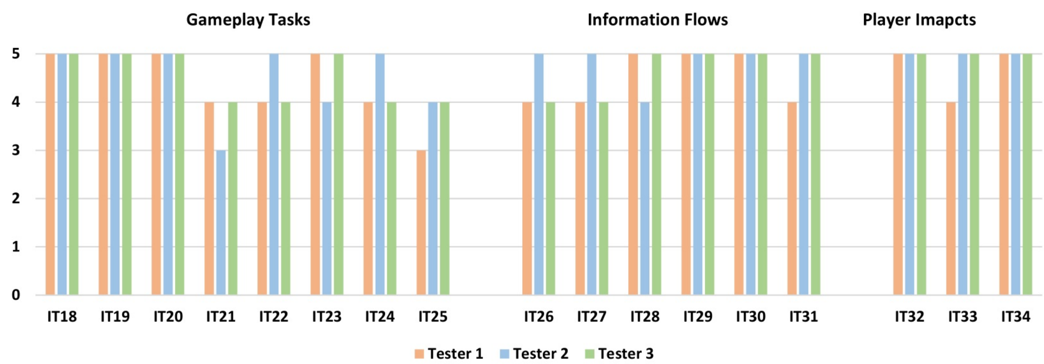

Fig. 4.9 Scores for items in "Gameplay tasks", "Information Flows" and "Player Impacts"

4.4 Discussion

The development of the CPS-IF instrument is a necessary contribution towards enabling researchers and practitioners to analyse and design games that can foster CPS skills and attitudes. Specifically, the CPS-IF instrument (Figure 4.6 and Figure 4.7) addresses the need for research tools that can support the identification of simulated gameplay aspects of real-world CPS scenarios and the properties and functionalities of gameplay information flows that may influence those aspects [41]. This is achieved by the CPS-IF instrument, because its five scales and 34 items represent (a) simulated gameplay aspects of the game context, gameplay process and gameplay tasks, (b) general properties of gameplay information flows, and (c) the ways that information flows affect those gameplay aspects and the player. In addition, the reliability of the CPS-IF instrument was tested by three game analysis experts who used the game *Stop Disasters* [101]. The results of this exploratory testing and the strengths and limitations of this study are discussed in the following subsections.

4.4.1 Implications of exploratory testing

The analysis results suggest that simulated gameplay aspects in the game *Stop Disasters* [101] may have been influenced by all six properties of information flows (IT26 - IT31 (Figure 4.7 and Figure 4.9)). This observation confirms the recognised importance of gameplay information flows to support player comprehension of gameplay elements and dynamics [3, 38]. Information flows strongly affected the following simulated gameplay aspects: (a) key elements of gameplay tasks (i.e., the ongoing task (IT18), meaningful actions (IT19) and target objects (IT20) (Figure 4.9)), and (b) essential sub-phases of the gameplay process (i.e., identifying goals (IT9), exploring environment (IT10), forming hypothesis (IT11), planning actions (IT14) and executing plans (IT15) (Figure 4.9)). In addition, gameplay information flows were highly impactful on the thoughts (IT32), feelings (IT33) and behaviour (IT34) of players (Figure 4.9).

Stop Disasters [101] provides players with most of the relevant gameplay information only at the end of a game scenario. This characteristic untimeliness of information flows (IT26) may have negatively influenced players' interpretations of: (a) elements of the game context (i.e., IT1 - IT8 (Figure 4.8)) (b) some sub-phases of the gameplay process (i.e., IT12, IT13, IT16 and IT17 (Figure 4.8)), and (c) elements of the ongoing gameplay task (IT21, IT22, IT24 and IT25 (Figure 4.9)). However, overall, the exploratory testing results suggest that all properties of gameplay information flows in *Stop Disasters* affected some of the key simulated gameplay aspects of the game.

4.4.2 Strengths and limitations

The strengths of the CPS-IF instrument elaboration process include: (a) following a rigorous instrument development method [68], (b) conceptualising the CPS-IF model (Figure 4.1 and Figure 4.2) to support the CPS-IF instrument (Figure 4.6 and Figure 4.7) [96, 98] by integrating components [3, 6, 15, 31, 44, 50] of the sound CPS-GBL theoretical framework (Section 2.3), (c) iteratively generating and modifying instrument items and scales related to conceptual components and elements of the CPS-IF model [68], and (d) assessing the CPS-IF instrument by performing an inter-rater reliability analysis which suggests that the instrument may be a robust and useful tool for its designed purpose.

The following key limitations of this study are recognised and suitable future directions for addressing them are proposed:

- The reliability test of the CPS-IF instrument was merely exploratory. Additional assessments and testers are needed to achieve more conclusive results. For example the differences between novices and experts who analyse CPS processes in GBL environments could be investigated [41] to inform changes in both the CPS-IF model and the CPS-IF instrument. This is partially addressed in Chapter 5.
- The testing of the CPS-IF instrument was limited to only one game (i.e., *Stop Disasters* [101]) which is characterised by its own unique gameplay aspects. Further tests with similar games to *Stop Disasters* and with games representing other genres (e.g., adventure games, strategy games, etc.) would be an appropriate approach to enhance the analysis abilities of the instrument which could lead to additional iterations of the CPS-IF model.
- The ambiguity of instrument items from Scale 1 ("Game Context Structure") and Scale 5 ("Player Impacts") indicates the need to further iterate on their components and dynamics from the CPS-IF model (e.g., "player impacts" is modeled as "impacts of GBL" and "intrinsic motivation of GBL" in Chapter 5).
- Information flow analysis is necessary but it alone is not sufficient to infer player engagement in CPS processes. Specific gameplay features that may promote both engagement and learning in CPS scenarios need to be identified. This is addressed by the following Chapter 5.
- Because one individual tool (i.e., the CPS-IF instrument) cannot tackle the multi-dimensional nature of CPS on its own, the use of complementary CPS-

analysis tools is recommended [42]. This aligns with the aim of the thesis and the main objectives of Chapter 5, Chapter 6 and Chapter 7.

4.5 Summary

This chapter described a study designed to address the shortage of research tools that can support the identification of required gameplay aspects of CPS scenarios and the game information that conveys those aspects to players. To this end, the CPS-IF instrument (Figure 4.6 and Figure 4.7) was developed [68] based on the prospectively conceptualised CPS-IF model (Figure 4.1 and Figure 4.2) [96, 98] and the sound CPS-GBL theoretical framework (Section 2.3). This development process was driven by the following research questions:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*
- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*
- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

Each of these research questions was answered by the scales and items of the CPS-IF instrument:

- *RQ1.1* was answered by Scale 1 ("Game Context Structure"), Scale 2 ("Gameplay Process"), Scale 3 ("Gameplay tasks") and their 25 instrument items (Figure 4.6 and Figure 4.7);
- *RQ1.2* was answered by Scale 4 ("Information Flows general properties"), its six instrument items and their relationships with Scale 1, Scale 2, Scale 3 and their 25 items (Figure 4.7);
- *RQ1.3* was answered by Scale 5 ("Player Impacts"), its three instrument items and their relationships with Scale 4 and its six items (Figure 4.7).

The developed CPS-IF instrument (Figure 4.6 and Figure 4.7) can support game researchers and practitioners to identify simulated gameplay aspects of real-world CPS scenarios and properties and functionalities of gameplay information flows that communicate to players those gameplay aspects. In addition, the CPS-IF model (Figure 4.1 and Figure 4.2) may enable game experts to design new instruments and formulate new theories related to CPS processes in games. The CPS-IF model can be iterated on by using the results from the exploratory testing of the CPS-IF instrument.

Even though simulated gameplay aspects and relevant gameplay information flows are necessary conditions for creating, understanding and learning CPS processes, making these processes intrinsically motivating is also crucial. This can be done by iterating and building on the CPS-IF model and it is the goal of the study presented in the following Chapter 5.

Chapter 5

Study II: CPS-GBL instrument

5.1 Introduction

Chapter 5 includes modified sections from a published paper in [5].

This chapter presents a study that tackles the described research problem that existing research tools are inadequate to balance the mechanisms of meaningful learning experiences and intrinsically-motivating complex environments in games. To address this problem, the research objective of this study is to develop an instrument suitable to identify gameplay features that can make CPS processes intrinsically motivating to players in GBL environments. The pursuit of this research objective is guided by the following research questions:

- *RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*
- *RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*
- *RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*

To answer these questions, first the CPS-GBL theoretical framework (i.e., theoretical framework for complex problem-solving processes within game-based learning environments) (Section 2.3) was used to model impacts of GBL (i.e., awareness, comprehension, caring and sense of agency) [9] and basic needs underpinning intrinsic motivation (i.e., autonomy, competence, relatedness and presence) [65]. Then, these were integrated with conceptualisations of the gameplay system from the CPS-IF model (i.e., model of information flows for complex problem-solving) (Section 4.2) by using methods for the development of conceptual models [96, 98], resulting in the CPS-GBL conceptual model (i.e., model for complex problem-solving and game-based learning processes). Next, based on the components and elements of the CPS-GBL model, instrument items and scales were generated while following the method by Moore and Benbasat [68]. This lead to the development of the CPS-GBL instrument (i.e., instrument for complex problem-solving and game-based learning processes) which consisted of a questionnaire [99, 100]. Finally, the CPS-GBL instrument was evaluated by re-formulating it into an online questionnaire (ı*Google Forms*) and selecting game design students to use it to analyse the game *Stop Disasters* [101]. The complete development process of the CPS-GBL instrument is reported in Section 5.2.

The contribution of this study is the CPS-GBL instrument that researchers and practitioners can use to analyse and design games that offer a balance between meaningful learning experiences and intrinsically-motivating complex environments, by identifying specific gameplay features that may promote intrinsically motivating CPS and GBL processes to players. Additionally, the CPS-GBL model that underpins the CPS-GBL instrument can be suitable for designing new research tools and generating new theories.

This chapter describes the methods for the development of the CPS-GBL instrument and the CPS-GBL model in Section 5.2, the results of that development process and of the exploratory evaluation of the CPS-GBL instrument in Section 5.3, and the implications of the findings regarding the CPS-GBL instrument, and the contributions and limitations of the study in Section 5.4.

5.2 Methods

5.2.1 Development of CPS-GBL Model

The purpose of the CPS-GBL model is to support the development of the CPS-GBL instrument by conceptualising gameplay features that may function to promote intrinsically motivating CPS processes in GBL environments [96, 98]. Therefore, these gameplay features are defined as CPS-GBL affordances [105]. The CPS-GBL model, presented in Figure 5.1, was elaborated based on concepts from the CPS-IF model (Section 4.2) and relevant components of the CPS-GBL theoretical framework from Section 2.3 (i.e., self-determination theory (SDT) [65] and the game-based learning human factors framework (HF-GBL framework) [9]).

The main components of the gameplay activity system in the CPS-GBL conceptual model (Figure 5.1) are the "Player-Subject" and the "Game Space". The "Player-Subject" consists of two sub-components (i.e., "Internal Activity Context" and "Enacted Gameplay Process"), while the "Game Space" includes "External Activity Context" and "Designed Gameplay Process" (Figure 5.1).

The "Internal Activity Context" is specifically modeled based on the SDT [65] and the HF-GBL framework [9]. SDT is represented in Figure 5.1 by the four basic needs that underpin intrinsic motivation (i.e., autonomy, competence, relatedness and presence [65]). Awareness, comprehension, caring and sense of agency of the player are the impacts of GBL that are integrated from the HF-GBL framework [9].

The "Enacted Gameplay Process" is conceptualised, based on components of the CPS-IF model (Section 4.2), as a multi-loop gameplay process. When the player-subject interacts with the game space, they (a) identify game goals, (b) explore the game environment while generating hypotheses and predicting possible side effects of their planned actions, (c) adapt their game plans based on formulated hypotheses and predictions, (d) perform game actions, (e) evaluate the effects of their actions, and (f) identify new game goals based on transformations to the game space, thus continuing the gameplay process. According to the CPS-GBL theoretical framework (Section 2.3), in order for sub-phases of this enacted gameplay process to function as CPS-GBL affordances, the player should "Self-define Game Goals" (i.e., CPS-GBL affordance number "2" in Figure 5.1), should perform game actions "Mimicking real-world actions" (i.e., CPS-GBL affordance number "3" in Figure 5.1), and should

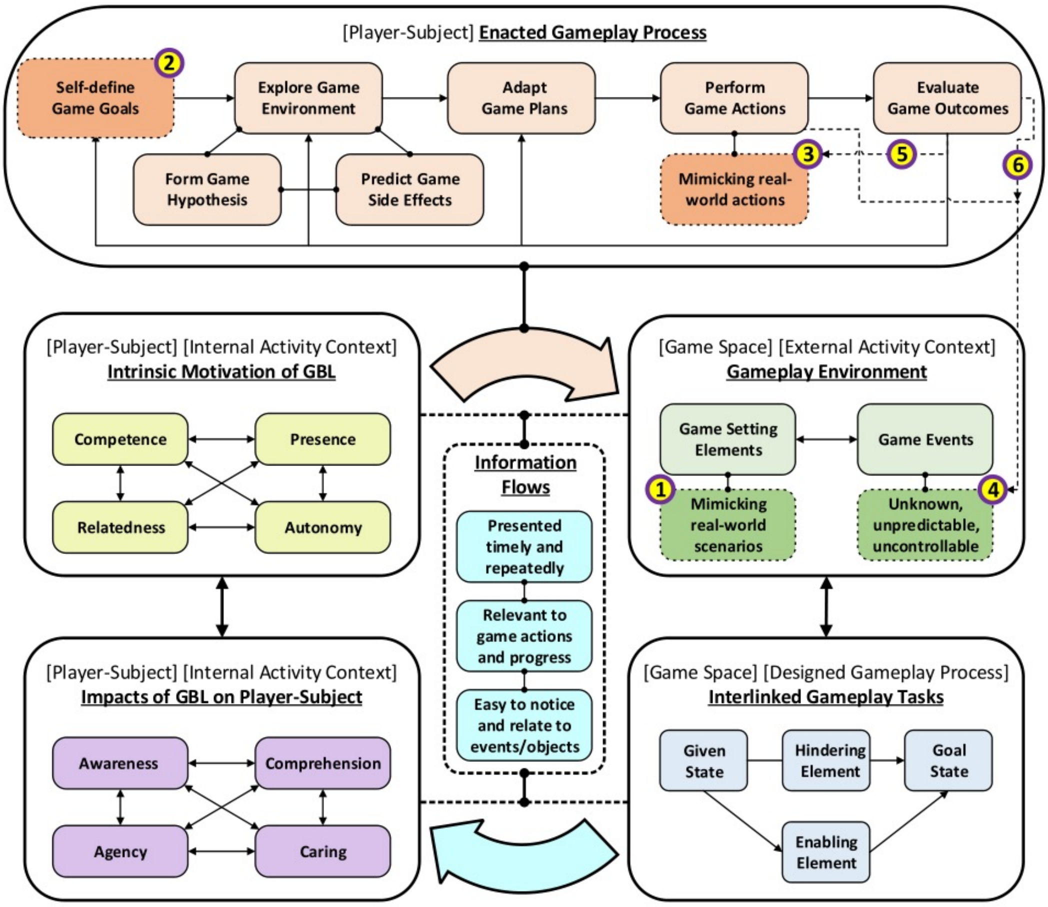

Fig. 5.1 CPS-GBL model

evaluate the effects of those types of performed actions (i.e., CPS-GBL affordance number "5" in Figure 5.1).

Both the "External Activity Context" and the "Designed Gameplay Process" are modeled by integrating components of the CPS-IF model (Section 4.2). The "External Activity Context" represents the gameplay environment, its game setting elements and game events (Figure 5.1). The "Designed Gameplay Process" is conceptualised as interlinked gameplay tasks that consist of a given game state that should be transformed by the player into a desirable goal state by overcoming hindering elements and using the support of enabling elements. Based on the CPS-GBL theoretical framework (Section 2.3), in order for some of these gameplay aspects to function as CPS-GBL affordances, the player should interact with game setting elements "Mimicking real-world scenarios" (i.e., CPS-GBL affordances number "1" in Figure 5.1), should deal with game events which are "Unknown, unpredictable, uncontrollable" (i.e., CPS-GBL affordance number "4" in Figure 5.1), and should evaluate the effects of those types of game events (i.e., CPS-GBL affordance number "6" in Figure 5.1).

In addition to the described structural components of the CPS-GBL model, in order to support the interactions between the player-subject and the game space, gameplay information flows should be: (a) presented timely and repeatedly, (b) relevant to player actions and progression in the game, (c) noticeable and linked to game objects and events (Figure 5.1).

Finally, the relationships between the presented elements of the gameplay activity system are modeled as follows: (a) first, the player interacts with the game space to satisfy their need for autonomy, competence, relatedness and presence which promotes intrinsic forms of motivation, (b) then, the player engages with game setting elements and game events by performing interlinked CPS-GBL tasks, and (c) finally, the player's awareness, comprehension, caring and sense of agency are impacted by completion of these CPS-GBL tasks which further motivates the player to enact the gameplay process (Figure 5.1).

5.2.2 Development of CPS-GBL instrument

The goal of the CPS-GBL instrument is to support the identification of CPS-GBL affordances (i.e., gameplay features that may function to promote intrinsically motivating CPS processes in GBL environments). The instrument was developed based on a three-stage method [68] (i.e., creating instrument items, categorising items into appropriate instrument scales, and evaluating the developed instrument) by adapting components of the CPS-GBL model (Figure 5.1) into a questionnaire form [99, 100].

First stage: CPS-GBL instrument items

The aim of this stage of the CPS-GBL instrument development process was to create instrument items identifying the importance of CPS-GBL affordances to promote (a) progression in a game, (b) impacts of GBL on the player, and (c) intrinsically motivating CPS processes. Following this objective, nine instrument items were iteratively generated from the relevant CPS-GBL components (i.e., progression, awareness, comprehension, caring, sense of agency, autonomy, competence, relatedness and presence) (Figure 5.2).

Additionally, five more items were formulated for the analysis of properties and functionalities of information flows that support CPS-GBL affordances (i.e., relevance for game actions, timeliness, repeated presentation, noticeable relation to objects and events, and relevance for game progression) (Figure 5.3).

Was important to progress in the game
Enhanced my awareness of [Complex Problem]
Helped me understand how [Complex Problem] works
Made me care more about [Complex Problem] in the real world
Made me think that I could do something about [Complex Problem] in the real world
Made me feel challenged
Helped me feel that I could change the game world in desirable ways
Made me feel that I could choose how to tackle the game tasks
Made me care more about what happened in the game world, and the characters in it

Fig. 5.2 CPS-GBL instrument items 1

Relevant to understand what could be done, how and/or why
Timely presented to the player
Presented repeatedly, as the game progressed
Easy to notice and relate to objects/events it refers to
Relevant to understand what could help or hinder progress in the game

Fig. 5.3 CPS-GBL instrument items 2

All CPS-GBL instrument items were defined on a five-point Likert scale (1: “Strongly Disagree; 2: "Disagree"; 3: "Undecided"; 4: "Agree"; 5: “Strongly Agree”). An sixth option was added if an instrument item was perceived as irrelevant (N/A: "Not Applicable").

Second stage: CPS-GBL instrument scales

The objective of this stage was to categorise the created instrument items into scales that represent each of the six CPS-GBL affordances:

- interacting with game setting elements mimicking real-world scenarios;
- self-defining goals;

- performing game actions mimicking real-world actions;
- tackling events that could not be fully known, controlled or predicted;
- evaluating and/or predicting consequences of game actions;
- evaluating and/or predicting consequences of events that could not be controlled.

A total of 13 instrument scales were created: (a) one scale (consisting of six items) that measures the overall gameplay experience (e.g., enjoyment with the game, satisfaction with provided game resources, etc.); (b) six scales (one for each affordance) that measure the importance of CPS-GBL affordances to promote progression in a game, impacts of GBL on the player, and intrinsically motivating CPS processes (Figure 5.2); and (c) six scales (one for each affordance) that identify the properties and functionalities of information flows that support CPS-GBL affordances (Figure 5.3).

Finally, all 13 instrument scales and 90 instrument items were rephrased into a questionnaire form [99, 100]. The complete CPS-GBL instrument is presented in Figure 5.6 and Figure 5.7 in Subsection 5.3.1.

Third stage: CPS-GBL instrument evaluation

The aim of this stage was to evaluate the CPS-GBL instrument through an exploratory case study involving the game *Stop Disasters* [101]. 29 university students studying game design in the United Kingdom were selected as participants. 21 of the participants had some familiarity ("f-participants") with the theories underpinning the CPS-GBL instrument (e.g., GBL, player motivation, elements of a gameplay activity system, etc.), while 8 of the participants were unfamiliar ("u-participants") with those theories. In addition to the 29 participants, one game analysis expert, who was part of the development process of the CPS-GBL instrument, independently tested the instrument with the game *Stop Disasters*. The intentional choice to investigate the differences between novices and experts who analyse CPS processes in GBL environments [41] is based on the discussion of the feedback and results from the development and testing of the CPS-IF instrument (Subsection 4.4.2).

Following the ethical guidelines of the university in which the study was conducted, a *Project Ethical Review Form* was completed and assessed by the project supervisor, who indicated that any associated ethical issues had been adequately addressed and that the study can proceed.

The CPS-GBL instrument (Figure 5.6 and Figure 5.7) was adapted into an online questionnaire (*Google Forms*) for this exploratory case study. Some of the modifications made to the instrument involve asking participants to identify themselves and replacing the term "[Game]" with "Stop Disasters" and the term "[Complex Problem]" with "wildfires".

Stop Disasters [101] is an online game which requires players to protect the population of an urban area from an imminent natural disaster (Figure 5.4).

Fig. 5.4 Stop Disasters - Flood scenario

The game was selected because the study in Chapter 4 suggests that *Stop Disasters* [101] simulates different gameplay aspects of CPS processes and GBL environments to varying degrees of success, which may produce interesting evaluation results related to the influence of the different CPS-GBL affordances in the game.

The exploratory evaluation of the CPS-GBL instrument involved three separate sessions in university classrooms. At the start of each session, a game researcher presented instructions for the evaluation procedure. The 29 participants were asked, first, to play the "Wildfire" scenario of the game *Stop Disasters* [101] (Figure 5.5) on medium difficulty without looking at the questionnaire, and then, to answer the questions while continuing to play if they chose to. The evaluation procedure in all three sessions was completed within thirty minutes. From the first two sessions, 21 out of 23 "f-participants" finished their questionnaires, while from the last session, 8 out of 10 "u-participants" completed their questionnaires. The results from the exploratory evaluation of the CPS-GBL instrument are reported in Subsection 5.3.2.

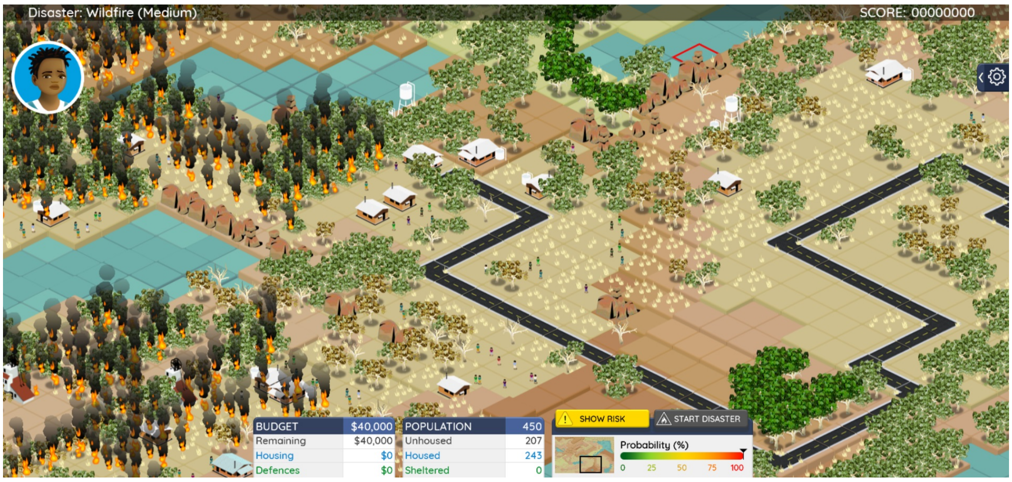

Fig. 5.5 Wildfire scenario in Stop Disasters

5.3 Results

5.3.1 The CPS-GBL instrument

Figure 5.6 and Figure 5.7 present the CPS-GBL instrument, which is produced as a result of the instrument development process that was described in the previous Section 5.2.

The CPS-GBL instrument consists of 13 scales (i.e., "Overall gameplay experience" and two scales for each of the six CPS-GBL affordances) and 90 items (six items are part of the scale "Overall gameplay experience" and 14 items are repeated six times for each CPS-GBL affordance). Scale 1.1, Scale 2.1, Scale 3.1, Scale 4.1, Scale 5.1 and Scale 6.1, which identify the importance of CPS-GBL affordances to promote progression in a game, impacts of GBL on the player, and intrinsically motivating CPS processes (Figure 5.6 and Figure 5.7) partially answer the first and second research questions of this study (on account of four of their items related to GBL impacts and four of their items related to intrinsic motivation):

Reflecting on your gameplay experience with [Game], please mark below what best represents your opinion regarding the following game aspects.

	Overall gameplay experience	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
	I enjoyed playing [Game]						
	[Game] was useful to learn about [Complex Problem]						
	[Game] was challenging						
	[Game] was easy to play						
	It was clear what I had to do in [Game]						
	[Game] provided sufficient resources to do what I had to						
	Scale 1.1: Interacting with game setting elements mimicking real-world scenarios:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
1	Was important to progress in the game						
2	Enhanced my awareness of [Complex Problem]						
3	Helped me understand how [Complex Problem] works						
4	Made me care more about [Complex Problem] in the real world						
5	Made me think that I could do something about [Complex Problem] in the real world						
6	Made me feel challenged						
7	Helped me feel that I could change the game world in desirable ways						
8	Made me feel that I could choose how to tackle the game tasks						
9	Made me care more about what happened in the game world, and the characters in it						
	Scale 1.2: The game supported interactions with game setting elements mimicking real-world scenarios by providing information:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
10	Relevant to understand what could be done, how and/or why						
11	Timely presented to the player						
12	Presented repeatedly, as the game progressed						
13	Easy to notice and relate to objects/events it refers to						
14	Relevant to understand what could help or hinder progress in the game						
	Scale 2.1: Self-defining which goals to pursue:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
15	Was important to progress in the game						
16	Enhanced my awareness of [Complex Problem]						
17	Helped me understand how [Complex Problem] works						
18	Made me care more about [Complex Problem] in the real world						
19	Made me think that I could do something about [Complex Problem] in the real world						
20	Made me feel challenged						
21	Helped me feel that I could change the game world in desirable ways						
22	Made me feel that I could choose how to tackle the game tasks						
23	Made me care more about what happened in the game world, and the characters in it						
	Scale 2.2: The game supported self-defining which goals to pursue by providing information:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
24	Relevant to understand what could be done, how and/or why						
25	Timely presented to the player						
26	Presented repeatedly, as the game progressed						
27	Easy to notice and relate to objects/events it refers to						
28	Relevant to understand what could help or hinder progress in the game						
	Scale 3.1: Performing game actions mimicking real-world actions:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
29	Was important to progress in the game						
30	Enhanced my awareness of [Complex Problem]						
31	Helped me understand how [Complex Problem] works						
32	Made me care more about [Complex Problem] in the real world						
33	Made me think that I could do something about [Complex Problem] in the real world						
34	Made me feel challenged						
35	Helped me feel that I could change the game world in desirable ways						
36	Made me feel that I could choose how to tackle the game tasks						
37	Made me care more about what happened in the game world, and the characters in it						
	Scale 3.2: The game supported performing game actions mimicking real-world actions by providing information:	Not Applicable N/A	Strongly Disagree 1	Disagree 2	Undecided 3	Agree 4	Strongly Agree 5
38	Relevant to understand what could be done, how and/or why						
39	Timely presented to the player						
40	Presented repeatedly, as the game progressed						
41	Easy to notice and relate to objects/events it refers to						
42	Relevant to understand what could help or hinder progress in the game						

Fig. 5.6 CPS-GBL instrument 1

Reflecting on your gameplay experience with [Game], please mark below what best represents your opinion regarding the following game aspects.							
	Scale 4.1: Tackling events that I could not fully know, control or predict:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
43	Was important to progress in the game						
44	Enhanced my awareness of [Complex Problem]						
45	Helped me understand how [Complex Problem] works						
46	Made me care more about [Complex Problem] in the real world						
47	Made me think that I could do something about [Complex Problem] in the real world						
48	Made me feel challenged						
49	Helped me feel that I could change the game world in desirable ways						
50	Made me feel that I could choose how to tackle the game tasks						
51	Made me care more about what happened in the game world, and the characters in it						
	Scale 4.2: The game supported tackling events that I could not fully know, control or predict by providing information:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
52	Relevant to understand what could be done, how and/or why						
53	Timely presented to the player						
54	Presented repeatedly, as the game progressed						
55	Easy to notice and relate to objects/events it refers to						
56	Relevant to understand what could help or hinder progress in the game						
	Scale 5.1: Evaluate and/or predict consequences of my game actions, and adapt my plans accordingly:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
57	Was important to progress in the game						
58	Enhanced my awareness of [Complex Problem]						
59	Helped me understand how [Complex Problem] works						
60	Made me care more about [Complex Problem] in the real world						
61	Made me think that I could do something about [Complex Problem] in the real world						
62	Made me feel challenged						
63	Helped me feel that I could change the game world in desirable ways						
64	Made me feel that I could choose how to tackle the game tasks						
65	Made me care more about what happened in the game world, and the characters in it						
	Scale 5.2: The game supported evaluating and/or predicting consequences of my game actions, and adapting my plans accordingly by providing information:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
66	Relevant to understand what could be done, how and/or why						
67	Timely presented to the player						
68	Presented repeatedly, as the game progressed						
69	Easy to notice and relate to objects/events it refers to						
70	Relevant to understand what could help or hinder progress in the game						
	Scale 6.1: Evaluate and/or predict consequences of events I could not control, and adapt my plans accordingly:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
71	Was important to progress in the game						
72	Enhanced my awareness of [Complex Problem]						
73	Helped me understand how [Complex Problem] works						
74	Made me care more about [Complex Problem] in the real world						
75	Made me think that I could do something about [Complex Problem] in the real world						
76	Made me feel challenged						
77	Helped me feel that I could change the game world in desirable ways						
78	Made me feel that I could choose how to tackle the game tasks						
79	Made me care more about what happened in the game world, and the characters in it						
	Scale 6.2: The game supported evaluating and/or predicting consequences of events I could not control, and adapting my plans accordingly by providing information:	Not Applicable	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
		N/A	1	2	3	4	5
80	Relevant to understand what could be done, how and/or why						
81	Timely presented to the player						
82	Presented repeatedly, as the game progressed						
83	Easy to notice and relate to objects/events it refers to						
84	Relevant to understand what could help or hinder progress in the game						

Fig. 5.7 CPS-GBL instrument 2

- *RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*
- *RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*

The questions of the effectiveness of the CPS-GBL affordances to promote GBL processes (*RQ2.1*) and intrinsic motivation (*RQ2.2*) are addressed in Subsection 5.3.2.

Scale 1.2, Scale 2.2, Scale 3.2, Scale 4.2, Scale 5.2 and Scale 6.2 identify the properties and functionalities of gameplay information flows that support CPS-GBL affordances (Figure 5.6 and Figure 5.7), thus answering the third research question of this study:

- *RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*

5.3.2 Exploratory evaluation results

Results of the exploratory evaluation of the CPS-GBL instrument are reported into two tables and three figures: (a) "Overall gameplay experience" scores (Table 5.1), (b) "Gameplay progress" scores (Table 5.2), (c) "Impacts of GBL" scores (Table 5.3), (d) "Intrinsic motivation of GBL" scores (Table 5.4), and (e) "Information Flows" scores (Table 5.5).

Table 5.1 presents the scores given by "f-participants" and "u-participants" to the game *Stop Disasters* [101] in relation to the overall gameplay experience. "F-participants" felt more overall satisfaction by playing the game (mean = 3.53, SD = 0.97) compared to "u-participants" (mean = 3.04, SD = 0.97). Both groups of participants gave their highest scores to the degree of challenge in *Stop Disasters* (mean = 3.81 and mean = 3.38). The biggest difference in mean scores between "f-participants" and "u-participants" was about the clarity of goals in the game (mean = 3.81 (second highest score for "f-participants") and mean = 1.75 (lowest score for "u-participants")) (Table 5.1).

Table 5.2 compares the expert analysis of the importance of each CPS-GBL affordance (F1 - F6) for gameplay progress to the perceived importance by "f-

Table 5.1 "Overall gameplay experience" scores

Overall gameplay experience	F-participants			U-participants		
	M	N	SD	M	N	SD
I enjoyed playing Stop Disasters	3.06	16	1.12	3.29	8	1.11
Stop Disasters was useful to learn about wildfires	3.75	16	0.93	3.38	8	0.74
Stop Disasters was challenging	3.81	16	0.98	3.38	8	1.06
Stop Disasters was easy to play	3.06	16	1.00	3.17	8	0.98
It was clear what I had to do in Stop Disasters	3.81	16	0.98	1.75	8	1.04
Stop Disasters provided sufficient resources to do what I had to	3.69	16	0.79	3.25	8	0.89
Total	3.53	16	0.97	3.04	8	0.97

participants" and "u-participants". Overall, the expert, the "f-participants" and the "u-participants" consider that the CPS-GBL affordances are important for progression in *Stop Disasters* (respectively, mean = 3.50, mean = 3.81, and mean = 3.73). Based on the scores of items F4, F5 and F6, both groups of participants felt that the game was more complex, compared to the expert. Differences between the perceptions of "f-participants" and "u-participants" are indicated by item F1 (respectively, mean = 3.71 and mean = 3.12) and item F4 (respectively, mean = 3.57 and mean = 4.00) (Table 5.2).

Table 5.2 "Gameplay progress" scores

Gameplay progress	Expert Analysis	F-participants			U-participants		
		M	N	SD	M	N	SD
F1: Interacting with game setting elements	5.00	3.71	21	1.01	3.12	8	0.83
F2: Self-defining goals	5.00	3.67	21	0.91	3.50	8	0.93
F3: Performing game actions	4.00	4.05	21	1.12	3.88	8	0.99
F4: Tackling complex events	2.00	3.57	21	1.12	4.00	8	0.76
F5: Evaluating consequences of game actions	3.00	3.95	21	1.12	4.00	8	0.82
F6: Evaluating consequences of complex events	2.00	3.90	21	1.07	3.86	8	0.38
Total	3.50	3.81	21	1.03	3.73	8	0.79

Table 5.3, completes the answers to "*RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*", by comparing the scores from the expert, the "f-participants" and the "u-participants" on the effectiveness of CPS-GBL affordances (F1 - F6) to impact the GBL process in *Stop Disasters* (i.e., awareness, comprehension, caring, and sense of agency).

Table 5.3 "Impacts of GBL" scores

Expert Analysis (N=1)	F1: Interacting with game setting elements	F2: Self-defining goals	F3: Performing game actions	F4: Tackling complex events	F5: Evaluating consequences of game actions	F6: Evaluating consequences of complex events	Total	
	M	M	M	M	M	M	M	SD
Awareness	5,00	5,00	4,00	2,00	3,00	3,00	3,67	1,21
Comprehension	5,00	5,00	4,00	2,00	3,00	3,00	3,67	1,21
Caring	2,00	3,00	2,00	1,00	2,00	2,00	2,00	0,63
Agency	2,00	3,00	3,00	1,00	2,00	2,00	2,17	0,75

F-participants (N=21)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Awareness	3,48	1,21	3,62	0,97	3,57	1,12	3,33	1,24	3,48	1,12	3,62	1,28	3,52	1,16
Comprehension	2,95	1,20	3,29	0,96	3,48	1,12	3,33	1,20	3,48	1,17	3,48	1,21	3,34	1,14
Caring	2,71	1,15	2,81	1,17	2,86	1,24	3,00	1,22	2,50	1,05	2,86	1,31	2,79	1,19
Agency	2,05	1,07	2,45	1,32	2,29	1,27	2,14	1,01	2,33	1,20	2,14	1,15	2,23	1,17

U-participants (N=8)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Awareness	3,25	0,71	3,57	0,53	3,38	0,52	3,63	0,74	3,43	0,79	3,57	0,53	0,64	3,47
Comprehension	3,63	0,74	3,50	0,76	3,75	0,46	3,38	1,19	3,43	0,53	3,71	0,49	3,57	0,70
Caring	2,75	0,89	2,14	0,38	2,88	0,35	3,00	1,07	2,57	0,53	2,86	0,69	2,70	0,65
Agency	2,13	0,83	1,86	0,69	2,50	0,76	2,43	0,79	2,14	0,69	2,43	0,98	2,25	0,79

The results suggest similar high scores between the expert, the "f-participants" and the "u-participants" for awareness (respectively, mean = 3.67, mean = 3.52 and mean = 3.47) and comprehension (respectively, mean = 3.67, mean = 3.34 and mean = 3.57), and similar low scores for caring (respectively, mean = 2.00, mean = 2.79 and mean = 2.70) and sense of agency (respectively, mean = 2.17, mean = 2.23 and mean = 2.25). Based on the scores of item F2, participants perceived the CPS-GBL affordance "Self-defining goals" not as impactful as the expert analysis suggests, which is supported by the results ("F2") in Table 5.2. "F-participants", compared to "u-participants", felt that "Self-defining goals" was a more impactful CPS-GBL affordance, and that "Tackling complex problems" was not as impactful (Table 5.3).

Table 5.4, completes the answer to "*RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*", by comparing the scores from the expert, the "f-participants" and the "u-participants" on the effectiveness of CPS-GBL affordances (F1 - F6) to promote intrinsic motivation in *Stop Disasters* (i.e., to satisfy the need for autonomy, competence (need for challenge and sense of efficacy), and relatedness and presence).

Table 5.4 "Intrinsic motivation of GBL" scores

Expert Analysis (N=1)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M		M		M		M		M		M		M	SD
Challenge	4,00		4,00		2,00		2,00		3,00		2,00		2,83	0,98
Efficacy	4,00		4,00		4,00		1,00		3,00		1,00		2,83	1,47
Autonomy	3,00		4,00		4,00		1,00		3,00		1,00		2,67	1,37
Relatedness and Presence	3,00		2,00		2,00		1,00		2,00		2,00		2,00	0,63
F-participants (N=21)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Challenge	3,53	1,12	3,30	1,13	3,10	1,09	3,29	1,10	3,60	1,14	3,38	1,07	3,37	1,11
Efficacy	3,43	1,16	3,19	1,25	3,29	1,27	3,24	1,18	3,33	1,02	3,57	0,98	3,34	1,14
Autonomy	3,45	1,05	3,45	1,23	3,43	1,08	3,33	1,15	3,57	0,81	3,62	1,02	3,48	1,06
Relatedness and Presence	2,55	1,32	2,43	1,21	2,67	1,20	2,57	1,25	2,81	1,25	2,86	1,39	2,65	1,27
U-participants (N=8)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Challenge	2,88	1,13	2,57	0,79	3,13	0,83	3,29	0,95	3,14	0,90	3,43	0,79	3,07	0,90
Efficacy	3,29	1,11	3,00	0,82	3,38	0,74	3,25	1,04	3,29	0,49	3,00	0,82	3,20	0,84
Autonomy	3,13	0,64	3,14	0,69	3,50	0,53	3,88	0,64	3,43	0,53	3,57	0,53	3,44	0,59
Relatedness and Presence	2,25	0,71	2,00	0,63	2,75	0,71	3,00	0,82	3,00	1,00	3,14	1,07	2,69	0,82

The results indicate high scores for autonomy (mean = 2.67, mean = 3.48 and mean = 3.44) and low scores for relatedness and presence (mean = 2.00, mean = 2.65 and mean = 2.69). Compared to the expert, participants perceived “Tackling complex events”, “Evaluating consequences of game actions” and “Evaluating consequences of complex events” as more effective at promoting intrinsic motivation. The differences between "f-participants" and "u-participants" are found in item F1 and item F4 (Table 5.4).

Table 5.5 compares the scores from the expert, the "f-participants" and the "u-participants" on the effectiveness of key properties and functionalities of gameplay information flows to support CPS-GBL affordances (F1 - F6) in *Stop Disasters*.

Information flows may influence each of the six CPS-GBL affordances by communicating information to players that is: (a) “relevant to understand what could be done, how and/or why”, (b) “timely presented to the player”, (c) “presented repeatedly, as the game progressed”, (d) “easy to notice and relate to objects/events it refers to”, and (e) “relevant to understand what could help or hinder progress

Table 5.5 "Information Flows" scores

Expert Analysis (N=1)	F1: Interacting with game setting elements		F2: Self-defining goals		F3: Performing game actions		F4: Tackling complex events		F5: Evaluating consequences of game actions		F6: Evaluating consequences of complex events		Total	
	M		M		M		M		M		M		M	SD
Action-relevant	4,00		4,00		4,00		2,00		3,00		2,00		3,17	0,98
Timely	2,00		3,00		4,00		2,00		3,00		2,00		2,67	0,82
Repeated	3,00		2,00		2,00		2,00		3,00		2,00		2,33	0,52
Noticeable	3,00		3,00		3,00		3,00		4,00		3,00		3,17	0,41
Progress-relevant	4,00		4,00		2,00		2,00		3,00		2,00		2,83	0,98
F-participants (N=21)	**F1: Interacting with game setting elements**		**F2: Self-defining goals**		**F3: Performing game actions**		**F4: Tackling complex events**		**F5: Evaluating consequences of game actions**		**F6: Evaluating consequences of complex events**		**Total**	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Action-relevant	3,50	1,05	3,00	1,03	3,43	0,98	3,52	1,03	3,57	0,87	3,75	1,02	3,46	1,00
Timely	3,15	1,23	3,00	0,95	3,14	1,01	3,00	0,84	2,81	0,87	3,10	1,18	3,03	1,01
Repeated	3,43	1,08	3,00	0,89	3,24	1,22	3,38	0,92	3,33	0,86	3,43	1,03	3,30	1,00
Noticeable	3,29	1,10	3,05	1,16	3,15	1,18	3,33	1,06	3,00	1,18	3,05	1,10	3,15	1,13
Progress-relevant	3,85	0,93	3,14	1,11	3,24	1,26	3,29	1,10	3,19	1,17	3,57	1,12	3,38	1,12
U-participants (N=8)	**F1: Interacting with game setting elements**		**F2: Self-defining goals**		**F3: Performing game actions**		**F4: Tackling complex events**		**F5: Evaluating consequences of game actions**		**F6: Evaluating consequences of complex events**		**Total**	
	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD	M	SD
Action-relevant	3,75	0,71	3,57	0,53	3,63	0,52	3,14	0,69	3,43	0,98	3,57	0,53	3,52	0,66
Timely	3,50	1,07	3,43	0,53	3,63	0,52	3,14	0,69	3,00	0,58	3,29	0,76	3,33	0,69
Repeated	3,13	0,99	3,00	0,58	3,38	0,74	3,00	1,00	3,43	0,53	3,14	0,38	3,18	0,70
Noticeable	3,38	1,06	3,57	0,53	3,38	1,06	2,86	0,69	3,43	0,98	3,43	0,98	3,34	0,88
Progress-relevant	3,63	0,74	3,43	0,53	3,13	0,99	3,00	0,58	3,14	0,90	2,86	0,90	3,20	0,77

in the game". The results suggest high scores for relevance of information flows to potential actions (mean = 3.17, mean = 3.46 and mean = 3.52) and low scores for timeliness of information flows (mean = 2.67, mean = 3.03 and mean = 3.33). Overall, in comparison to the expert, participants felt that *Stop Disasters* presented appropriate information flows to support CPS-GBL affordances (Table 5.5).

5.4 Discussion

The CPS-GBL instrument (Figure 5.6 and Figure 5.7) addresses the need for new research tools that are suitable to balance the mechanisms of meaningful learning experiences and intrinsically-motivating complex environments in games [36]. To achieve this, the CPS-GBL instrument was developed to include 13 scales and 90 items that are relevant for the identification of gameplay features that may promote intrinsically motivating CPS processes in GBL environments (i.e., CPS-GBL affordances). The effectiveness of these CPS-GBL affordances (i.e., (a) interacting with game setting elements mimicking real-world scenarios, (b) self-defining goals, (c) performing game actions mimicking real-world actions, (d) tackling events that could not be fully known, controlled or predicted, (e) evaluating and/or predicting consequences of game actions, and (f) evaluating and/or predicting consequences of events that could not be controlled) to promote both GBL processes and intrinsic motivation are discussed in the following subsection.

5.4.1 Implications of exploratory evaluation

The most relevant implication for researchers and practitioners who may analyse and design games with the CPS-GBL instrument (Figure 5.6 and Figure 5.7), is that the most valuable use of the instrument could be the investigation of the effectiveness of all six CPS-GBL affordances to impact the awareness, comprehension, caring and sense of agency of players (Table 5.3). This observation is based on the similarities between the expert, the "f-participants" (i.e., students familiar with game design theories), and the "u-participants" (i.e., students unfamiliar with game design theories) in scoring the impacts of GBL on players (Table 5.3), despite the differences in the levels of game analysis experience between the expert and both groups of participants.

Further implications of the exploratory evaluation of the CPS-GBL instrument using the game *Stop Disasters* [101] include:

- CPS-GBL affordances were perceived, by both the expert and the participants, as suitable to satisfy the need for autonomy, but not the need for relatedness and presence (Table 5.3) in the game. A possible explanation for this is the single-player nature of *Stop Disasters* and the game's limitations concerning story and characters.

- *Stop Disasters* was perceived as more challenging, complex and restrictive by participants compared to the expert analysis (Table 5.2, Table 5.3 and Table 5.4), even though participants felt that the game provided sufficient information flows to support the CPS-GBL affordances (Table 5.5). This inconsistency could be due to the participants' lack of experience in analysing games.

- Participants familiar with game design theories ("f-participants"), in alignment with the expert analysis, perceived some CPS-GBL affordances (i.e., (a) interacting with game setting elements mimicking real-world scenarios (Table 5.2 and Table 5.4) and (b) self-defining goals (Table 5.3)) as more important and other affordances (i.e, tackling events that could not be fully known, controlled or predicted (Table 5.2, Table 5.3 and Table 5.4)) as less important, compared to participants with less game design knowledge ("u-participants"). This discrepancy between experts and novices is worth future investigation.

5.4.2 Strengths and limitations

The main strengths of the CPS-GBL instrument development process are that (a) it followed a rigorous method for the iterative formulation and revision of instrument items and scales [68], (b) it was based on conceptualisations from the CPS-GBL model (Figure 5.1) [96, 98], which integrated components from the CPS-IF conceptual model (Section 4.2) and the sound CPS-GBL theoretical framework (Section 2.3), and (c) it concluded with an exploratory evaluation of the CPS-GBL instrument which suggests that the instrument can be a practical tool for identifying CPS-GBL affordances and measuring their effectiveness.

The primary limitation of this study is that the small number of participants produces results that are not statistically significant on their own and are inconclusive in regards to some instrument items (e.g., properties of Information Flows (Table 5.5)). However, the homogeneity of the group of participants supports the contextualisation of the results for further improvements to the CPS-GBL instrument [76]. In addition to addressing the small number of participants, future research that expands the current study can (a) modify the instrument to solve issues related to the large number of instrument items (e.g., either focus on multiple effects of one specific CPS-GBL affordance or focus on one specific effect of multiple CPS-GBL affordances), (b) include games with characteristics that are different from the ones in *Stop Disasters* [101] to enhance the potential of the CPS-GBL instrument, and (c) enhance components of the CPS-GBL conceptual model (e.g., "External Activity Context" and "Designed Gameplay Process") to include more specific gameplay features and elements. These issues are tackled in the following Chapter 6.

5.5 Summary

This chapter presented a study aimed at addressing the lack of appropriate research tools to identify gameplay features that can make CPS processes intrinsically motivating to players in GBL environments (i.e., CPS-GBL affordances). This objective was completed by developing the CPS-GBL instrument (Figure 5.6 and Figure 5.7) [68] based on the conceptualised CPS-GBL model (Figure 5.1) [96, 98]. This instrument development process was guided by three research questions, which were answered in the following ways.

First, "*RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*" was answered by (a) the instrument items in Scale 1.1, Scale 2.1, Scale 3.1, Scale 4.1, Scale 5.1 and Scale 6.1, that are relevant to identify CPS-GBL affordances that may impact the GBL process (Figure 5.6 and Figure 5.7); and (b) Table 5.3 which presents the scores of the perceived effectiveness of CPS-GBL affordances to impact the GBL process in *Stop Disasters*.

Then, "*RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*" was answered by: (a) the instrument items in Scale 1.1, Scale 2.1, Scale 3.1, Scale 4.1, Scale 5.1 and Scale 6.1, regarding the identification of CPS-GBL affordances that may promote intrinsically motivating CPS processes (Figure 5.6 and Figure 5.7); and (b) Table 5.4 which reports the scores of the perceived effectiveness of CPS-GBL affordances to promote intrinsic motivation in *Stop Disasters*.

Finally, "*RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*" was answered by Scale 1.2, Scale 2.2, Scale 3.2, Scale 4.2, Scale 5.2 and Scale 6.2 which identify the properties and functionalities of gameplay information flows that support CPS-GBL affordances (Figure 5.6 and Figure 5.7).

The developed CPS-GBL instrument (Figure 5.6 and Figure 5.7) can support game experts to identify gameplay features that may promote intrinsically motivating CPS and GBL processes. The results from the exploratory evaluation of the CPS-GBL instrument can inform improvements to the CPS-GBL model (Figure 5.1). Additionally, researchers can use the CPS-GBL model to generate new tools and theories for the study of CPS processes in GBL environments. As an example, the following Chapter 6 adapts the CPS-GBL model to underpin a new instrument for the identification of gameplay features that may promote necessary cognitive CPS conditions, which is an important step on the path towards effectively analysing and design games that support the development of CPS skill and attitudes.

Chapter 6

Study III: GEFF-CPSC instrument

6.1 Introduction

Chapter 6 contains adapted sections from a published paper in [4].

This chapter describes a study that tries to address the stated research problem that available research tools are insufficient to map gameplay features to cognitive CPS conditions. Motivated by this problem, the research objective of this study is to develop an analysis instrument for the identification of specific gameplay features that may promote necessary cognitive CPS conditions. This objective is driven by the following research questions:

- *RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*
- *RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*
- *RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*

To satisfy these questions, first, the necessary cognitive CPS conditions [6], the gameplay features that may promote them and the game elements that may promote those gameplay features were all modeled based on the CPS-GBL theoretical framework (i.e., theoretical framework for complex problem-solving processes within game-based learning environments) (Section 2.3), the CPS-GBL conceptual model (i.e., model for complex problem-solving and game-based learning processes) (Section 5.2), and methods for the development of conceptual models [96, 98]. Then, the resulting GEFF-CPSC model (i.e., model of gameplay elements, features and functions promoting complex problem-solving conditions) was used, by following multi-stage approaches for instrument development and validation [68–70, 77, 78], to inform the creation of instrument items and scales related to the modeled game elements, gameplay features and cognitive CPS conditions. The formulated GEFF-CPSC instrument (i.e., instrument for gameplay elements, features and functions promoting complex problem-solving conditions), consisted of a questionnaire [99, 100]. Finally, for the preliminary validation stage of this development process [68–70, 77, 78] reviewers assessed the GEFF-CPSC instrument [104] and game analysts pre-tested it using the game *The Witness* [102]. The development process of the GEFF-CPSC instrument is reported in detail in Section 6.2.

The contribution of this study is the GEFF-CPSC instrument that can support researchers and practitioners to identify specific game elements, gameplay features and their functions to promote necessary cognitive CPS conditions. In addition, the GEFF-CPSC model that underpins the GEFF-CPSC instrument can be used to produce new research tools and develop new theories.

This chapter presents the methods for the development of the GEFF-CPSC instrument and the GEFF-CPSC model in Section 6.2, the results of that development process and of the preliminary validation of the GEFF-CPSC instrument in Section 6.3, and the implications of the findings in relation to the GEFF-CPSC instrument, and the contributions and limitations of the study in Section 6.4.

6.2 Methods

6.2.1 Development of GEFF-CPSC Model

To support the development of an instrument for the identification of game elements, gameplay features and their functions that may promote necessary cognitive CPS conditions, first, these concepts and their relationships should be modeled [96, 98]. The GEFF-CPSC model (Figure 6.1) was created by integrating complementary aspects from the CPS-GBL conceptual model (i.e., goal-directed gameplay feature and elements that promote intrinsically motivating GBL and CPS processes) (Section 5.2) and the sound CPS-GBL theoretical framework (i.e., the goal-directed theory of intention regulation consisting of cognitive CPS conditions, [6]) (Section 2.3).

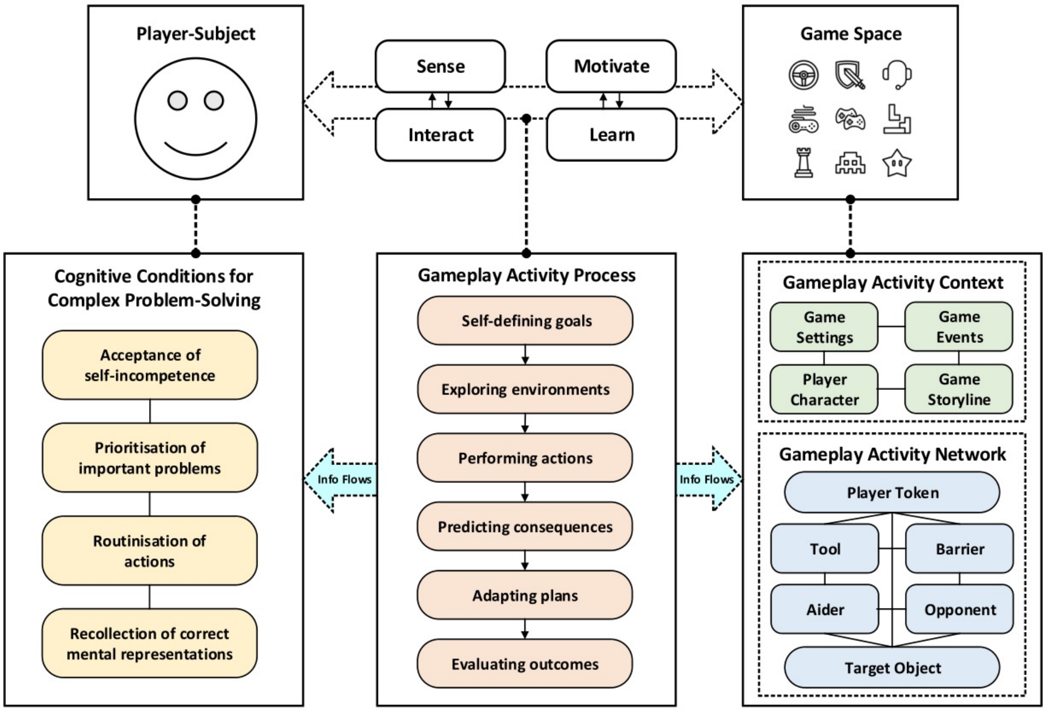

Fig. 6.1 GEFF-CPSC Model

The GEFF-CPSC model (Figure 6.1) conceptualises three main components: (a) cognitive CPS conditions necessary to engage and deal with complex problems [6], (b) features of the gameplay activity process, that are essential for game progression [3], and (c) elements of the gameplay activity context, gameplay activity network and information flows, that are essential for facilitating the gameplay activity process. These components of the GEFF-CPSC model and their relationships are described as follows.

First, the cognitive CPS conditions (i.e., acceptance of self-incompetence, prioritisation of important problems, routinisation of actions, and recollection of correct mental representations) are adapted from the theory of intention regulation [6] and may be influenced by gameplay features (Figure 6.1). Second, these gameplay features are modeled as the sub-phases of the gameplay activity process (i.e., self-defining goals, exploring environments, performing actions, predicting consequences, adapting plans, and evaluating outcomes) and can be supported by game elements. Third, these game elements include: (a) game settings, game events, game storyline, and player character (i.e., elements of the gameplay activity context); (b) a player token that interacts with a target object, tools and aiders that enable the interaction, and barriers and opponents that hinder the interaction (i.e., elements of the gameplay activity network); and (c) information flows that are produced by objects, that emerge from events, that are presented clearly, that appear timely, that are provided in close proximity to their source, and that are available recurringly (i.e., elements of information flows).

Finally, the GEFF-CPSC model (Figure 6.1) conceptualises the relationships between the described cognitive CPS conditions, gameplay features and game elements in the following way: (a) first, the player-subject senses appropriate information flows from elements of the gameplay activity context and the gameplay activity network in the game space; (b) then, the player-subject becomes motivated to interact with these game elements by enacting the features of the gameplay activity context; and (c) finally, through continuous interactions, the player-subject learns to develop the cognitive CPS conditions that are necessary to manage complex problems.

6.2.2 Development of GEFF-CPSC instrument

The purpose of the GEFF-CPSC instrument is to assist the identification of game elements that support specific gameplay features which may promote necessary cognitive CPS conditions. The GEFF-CPSC instrument was elaborated by following well-recognised multi-stage approaches of instrument development and validation [68–70] consisting of: (a) an item creation stage for content validity, (b) a scale development stage for construct validity, and (c) an instrument testing stage for reliability.

First stage: GEFF-CPSC instrument items

The goals of this stage of the GEFF-CPSC instrument development process were to (a) generate large pools of instrument items, (b) select instrument items from the pools, (c) modify the selected instrument items, and (d) further revise modified instrument items based on preliminary reviewer feedback [68–70, 77, 78].

First, large pools of instrument items were generated based on elements from the GEFF-CPSC model (Figure 6.1). Some instrument items were modified for clarity and to fit the questionnaire format (e.g., "Routinisation of actions" was revised to “Player ability in mastering and performing repeated game actions without thinking”). Other instrument items were created by expanding components of the GEFF-CPSC model based on the sound CPS-GBL theoretical framework (Section 2.3) (e.g., "Game settings" was expanded to "Physical game setting", "Historical game setting" and "Socio-cultural game setting).

Then, instrument items were selected from these large pools by excluding repeating and confusing items (e.g., (a) the item "Task goal" was excluded because it overlapped with the item "Self-define which goals to pursue", and (b) the item "Unknown, unpredictable, uncontrollable player-triggered events" was removed because it was too complicated).

Next, the selected instrument items were rephrased, in consideration for the research questions of this study, from being measured on a five-point Likert scale of agreement to being measured on (a) a five-point Likert scale of frequency (1: “Never”; 2: “Rarely”; 3: “Occasionally”; 4: “Frequently”; 5: “Always”) in order to identify how often a game may promote instrument items, and (b) a five-point Likert scale of likelihood (1: “not at all”; 2: “a little”; 3: “to some extent”; 4: “rather much”; 5: “very much”; with 0: “not applicable” as an option) in order to identify to what extent some items may promote other items.

Finally, two reviewers were invited to individually assess each instrument item and to provide feedback for the modification of items which can further improve their content validity [69, 70]. The first reviewer has experience with game design and analysis, while the second reviewer has experience with creating and conducting questionnaires in higher education. Both reviewers used a preliminary content validity form (Figure 6.2) to rate instrument items with a "yes" or "no" for each of the following criteria questions: (a) “*Q1: Is the item too vague to understand?*”; (b) “*Q2: Is the item too complex to understand?*”; (c) “*Q3: Is the item too long?*”; (d) “*Q4: Is the item overlapping with other items?*”; (e) “*Q5: Is the item investigating several concepts?*”; and (f) “*Q6: Would you change the item?*”. The reviewers could provide additional notes and suggestions for addressing problems related to each instrument item.

Based on the results of this preliminary content validity assessment, some modifications made to instrument items include: (a) "Gameplay tools" and "Gameplay aiders" were merged into "Gameplay enablers" to clarify their function; (b) "Gameplay barriers" and "Gameplay opponents" were integrated into "Gameplay hindrances" to clarify their function; (c) "Transformable target objects" was adapted to "Target objects transformable by players" to explain the source of transformation; and (d) "Nearby provision of information flows" was changed to "Close to source provision of information flows" to describe the focus on the physical proximity of information flows to their source.

#	Instrument Items	Review each insturment item (#1-#28) based on each criteria question (Q1-Q7). Rate your opinion according to the following scale: (0 = No; 1 = Yes)							Notes, suggestions, and changes to address problems with item
		Q1: Is the item too vague to understand?	Q2: Is the item too complex to understand?	Q3: Is the item too long?	Q4: Is the item overlapping with other items?	Q5: Is the item investigating several concepts?	Q6: Is the item relevant to its scale?	Q7: Would you change the item?	
1	Example 1								
2	Example 2								
3	Example 3								
4	Example 4								

Fig. 6.2 Preliminary content validity form

Second stage: GEFF-CPSC instrument scales

The aims of this stage of the GEFF-CPSC instrument development processes were to: (a) adapt components of the GEFF-CPSC model (Figure 6.1) into constructs and instrument scales, (b) organise instrument items, generated during the previous stage, into these scales, and (c) revise the resulting instrument based on feedback from a preliminary construct validity test [68–70, 77, 78].

First, the five main components of the GEFF-CPSC model (Figure 6.1) (i.e., "Cognitive conditions for CPS", "Gameplay Activity Process", "Gameplay Activity Context", "Gameplay Activity Network" and "Information Flows") were adapted into three constructs (i.e., "cognitive CPS conditions", "Gameplay features" and "Game elements").

Then, based on these constructs, instrument items were categorised into four scales: (a) "Scale 1: Cognitive complex problem-solving conditions (CPSC)", (b) "Scale 2: Gameplay features (GF)", (c) "Scale 3: Gameplay feature functions (GFF)", and (d) "Scale 4: Game element functions (GEF)". Scale 1 and Scale 2 measured instrument items on a five-point Likert scale of frequency, to identify how often a game may promote these items. Scale 3 and Scale 4 measured instrument items on a five-point Likert scale of likelihood, to identify to what extent (a) items of "Gameplay features" may promote items of "Cognitive CPS conditions", and (b) items of "Gameplay elements" facilitate items of "Gameplay features".

Finally, the two reviewers who assessed the content validity of instrument items in the previous stage were asked to evaluate the relevance of each item to its assigned construct [68–70]. Based on this construct validity assessment, the instrument item "Deal with unpredictable events" was rephrased to "Game events" and was moved from the construct "Gameplay features" to the construct "Game elements". The complete GEFF-CPSC instrument is presented in Figure 6.4, Figure 6.5, Figure 6.6 and Figure 6.7 in Subsection 6.3.1.

GEFF-CPSC instrument assessment

The objective of this stage of the GEFF-CPSC instrument development process was to assess the reliability of the instrument by conducting a pre-test [68–70, 77, 78]. Two game analysts, who represent the intended target group of potential users of the GEFF-CPSC instrument (i.e., researchers and practitioners who require tools to analyse and design games that may promote CPS processes in GBL environments), were invited to independently analyse the puzzle game *The Witness* [102] (Figure 6.3) for one hour by using the GEFF-CPSC instrument.

The Witness was selected for this pre-test because its characterised by: (a) self-guided exploration of a mysterious island (i.e., the player is required to self-define goals), (b) lack of explicit instructions for puzzle-solving (i.e., the player is required to solve ill-defined problems), and (c) problem-solving processes that are presented through environmental challenges (i.e., the player engages in contextualised problem-solving activities). The results of this reliability assessment are reported in Subsection 6.3.2.

Fig. 6.3 The Witness

6.3 Results

6.3.1 The GEFF-CPSC instrument

The GEFF-CPSC instrument is presented in four figures, one for each of the four instrument scales: (a) "Scale 1: Cognitive complex problem-solving conditions (CPSC)" (Figure 6.4), (b) "Scale 2: Gameplay features (GF)" (Figure 6.5), (c) "Scale 3: Gameplay feature functions (GFF)" (Figure 6.6), and (d) "Scale 4: Game element functions (GEF)" (Figure 6.7).

The purpose of Scale 1 (Figure 6.4) is to identify, by measuring on a five-point Likert scale of frequency, how often a game may promote the four necessary cognitive CPS conditions (i.e, (a) “Player ability in accepting and adapting to self-incompetence”, (b) “Player ability in anticipating and addressing important game challenges”, (c) “Player ability in mastering and performing repeated game actions without thinking”, and (d) “Player ability in developing and recalling correct mental representations of game objectives”).

The goal of Scale 2 (Figure 6.5) is to identify, by measuring on a five-point Likert scale of frequency, how often a game may promote the six gameplay features of the gameplay activity process in CPS scenarios (i.e., (a) “Self-define which goals

	Scale 1: Cognitive complex problem-solving conditions (CPSC) The game promotes:	Never	Rarely	Occasion-ally	Frequently	Always
		1	2	3	4	5
1	Player ability in accepting and adapting to self-incompetence					
2	Player ability in anticipating and addressing important game challenges					
3	Player ability in mastering and performing repeated game actions without thinking					
4	Player ability in developing and recalling correct mental representations of game objectives					

Fig. 6.4 GEFF-CPSC instrument - Scale 1

to pursue", (b) "Explore environments that mimic challenging scenarios impacting society"; (c) "Perform actions that mimic societally impactful activities", (d) "Predict the consequences of player actions", (e) "Adapt player plans to changes in the environment", and (f) "Evaluate the outcomes of player actions").

	Scale 2: Gameplay features (GF) The game requires players to:	Never	Rarely	Occasion-ally	Frequently	Always
		1	2	3	4	5
5	Self-define which goals to pursue					
6	Explore environments that mimic challenging scenarios impacting society					
7	Perform actions that mimic societally impactful activities					
8	Predict the consequences of player actions					
9	Adapt player plans to changes in the environment					
10	Evaluate the outcomes of player actions					

Fig. 6.5 GEFF-CPSC instrument - Scale 2

The aim of Scale 3 (Figure 6.6) is to identify, by measuring on a five-point Likert scale of likelihood, to what extent each of the six gameplay features from Scale 2 (Figure 6.5) may promote each of the four cognitive CPS conditions from Scale 1 (Figure 6.4). Items from Scale 1 and Scale 2 are rephrased to fit the questionnaire form of Scale 3, which answers the first research question of this study:

- *RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*

The objective of Scale 4 (Figure 6.6) is to identify, by measuring on a five-point Likert scale of likelihood, to what extent each of the 16 game elements may promote each of the six gameplay features from Scale 2 (Figure 6.5). The 16 game elements

	Scale 3: Gameplay feature functions (GFF) Indicate to what extent each gameplay feature (F1-F6) promotes each condition (C1-C4). Rate your opinion according to the following scale: (0 = not applicable; 1 = not at all; 2 = a little; 3 = to some extent; 4 = rather much; 5 = very much)	(C1) Promotes player ability in accepting and adapting to self-incompetence	(C2) Promotes player ability in anticipating and addressing larger game challenges	(C3) Promotes player ability in developing and recalling correct mental representations of game objectives	(C4) Promotes player ability in developing and recalling correct mental representations of game objectives
11	(F1) Self-defining which goals to pursue				
12	(F2) Exploring environments that mimic challenging scenarios impacting society				
13	(F3) Performing actions that mimic societally impactful activities				
14	(F4) Predicting the consequences of player actions				
15	(F5) Adapting player plans to changes in the environment				
16	(F6) Evaluating the outcomes of player actions				

Fig. 6.6 GEFF-CPSC instrument - Scale 3

are: “Physical game setting”, “Historical game setting”, “Socio-cultural game setting”, “Game events”, “Game storyline”, “Player character role”, “Player character aims”, “Gameplay enablers”, “Gameplay enablers”, “Target objects transformable by players”, “Information flows provided from objects”, “Information flows provided from events”, “Clear provision of information flows”, “Timely provision of information flows”, “Close to source provision of information flows”, and “Recurring provision of information flows”. Items from Scale 2 are rephrased to fit the questionnaire form of Scale 4, which answers the second (through elements (*E1*) to (*E10*)) and third (through elements (*E11*) to (*E16*)) research questions of this study:

- *RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*
- *RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*

6.3.2 Reliability assessment results

Data analysis aimed to calculate the inter-rater reliability between the two analysts based on their reliability assessment of all 130 items of the GEFF-CPSC instrument (i.e., 4 items in Scale 1 (Figure 6.4), six items in Scale 2 (Figure 6.5), 24 items in Scale 3 (Figure 6.6), and 96 items in Scale 4 (Figure 6.7)). Inter-rater reliability between the two analysts was calculated as “fair” (ICC = 0.58) [104]. Table 6.1, Table 6.2, Table 6.3 and Table 6.4 report the results of the reliability assessment of each scale of the GEFF-CPSC instrument.

	Scale 4: Game element functions (GEF) Indicate to what extent each game element (E1-E16) promotes each gameplay feature (F1-F6). Rate your opinion according to the following scale: (0 = not applicable; 1 = not at all; 2 = a little; 3 = to some extent; 4 = rather much; 5 = very much)	(F1) Promote(s) self-defining which goals to pursue	(F2) Promote(s) exploring environments that mimic challenging scenarios impacting society	(F3) Promote(s) performing actions that mimic societally impactful activities	(F4) Promote(s) predicting the consequences of player actions	(F5) Promote(s) adapting player plans to changes in the environment	(F6) Promote(s) evaluating the outcomes of player actions
17	(E1) Physical game setting						
18	(E2) Historical game setting						
19	(E3) Socio-cultural game setting						
20	(E4) Game events						
21	(E5) Game storyline						
22	(E6) Player character role						
23	(E7) Player character aims						
24	(E8) Gameplay enablers						
25	(E9) Gameplay hindrances						
26	(E10) Target objects transformable by players						
27	(E11) Information flows provided from objects						
28	(E12) Information flows provided from events						
29	(E13) Clear provision of information flows						
30	(E14) Timely provision of information flows						
31	(E15) Close to source provision of information flows						
32	(E16) Recurring provision of information flows						

Fig. 6.7 GEFF-CPSC instrument - Scale 4

Table 6.1 Reliability assessment results of Scale 1 of the GEFF-CPSC instrument

Frequency to which the game promotes core CPS conditions (C1-C4)	M	N	SD
(C1) Player ability in accepting and adapting to self-incompetence	5,00	2	0,00
(C2) Player ability in anticipating and addressing important game challenges	2,50	2	0,71
(C3) Player ability in mastering and performing repeated game actions without thinking	3,00	2	0,00
(C4) Player ability in developing and recalling correct mental representations of game objectives	5,00	2	0,00

Table 6.2 Reliability assessment results of Scale 1 of the GEFF-CPSC instrument

Frequency to which the game promotes core gameplay features (F1-F6)	M	N	SD
(F1) Self-define which goals to pursue	5,00	2	0,00
(F2) Explore environments that mimic challenging scenarios impacting society	3,00	2	0,00
(F3) Perform actions that mimic societally impactful activities	2,00	2	0,00
(F4) Predict the consequences of player actions	1,50	2	0,71
(F5) Adapt player plans to changes in the environment	4,00	2	0,00
(F6) Evaluate the outcomes of player actions	4,00	2	1,41

Table 6.3 Reliability assessment results of Scale 3 of the GEFF-CPSC instrument

Extent to which core gameplay features (F1-F6) promote core CPS conditions (C1-C4)	(C1) Promotes player ability in accepting and adapting to self-incompetence			(C2) Promotes player ability in anticipating and addressing larger game challenges			(C3) Promotes player ability in mastering and performing repeated game actions without thinking			(C4) Promotes player ability in developing and recalling correct mental representations of game objectives		
	M	N	SD	M	N	SD	M	N	SD	M	N	SD
(F1) Self-defining which goals to pursue	5,00	2	0,00	3,00	2	1,41	2,50	2	1,41	5,00	2	0,00
(F2) Exploring environments that mimic challenging scenarios impacting society	3,00	2	0,00	2,50	2	0,71	2,00	2	0,00	3,00	2	0,00
(F3) Performing actions that mimic societally impactful activities	2,00	2	0,00	3,00	2	1,41	2,00	2	0,00	2,00	2	1,41
(F4) Predicting the consequences of player actions	2,50	2	0,71	2,00	2	0,00	1,50	2	0,71	1,00	2	0,00
(F5) Adapting player plans to changes in the environment	4,00	2	0,00	2,50	2	0,71	3,00	2	0,00	4,00	2	0,00
(F6) Evaluating the outcomes of player actions	5,00	2	0,00	3,50	2	0,71	3,00	2	1,41	4,00	2	0,00

Table 6.4 Reliability assessment results of Scale 4 of the GEFF-CPSC instrument

Extent to which core game elements (E1-E16) promote core gameplay features (F1-F6)	(F1) Promote(s) self-defining which goals to pursue			(F2) Promote(s) exploring environments that mimic challenging scenarios impacting society			(F3) Promote(s) performing actions that mimic societally impactful activities			(F4) Promote(s) predicting the consequences of player actions			(F5) Promote(s) adapting player plans to changes in the environment			(F6) Promote(s) evaluating the outcomes of player actions		
	M	N	SD	M	N	SD	M	N	SD	M	N	SD	M	N	SD	M	N	SD
(E1) Physical game setting	5,00	2	0,00	4,00	2	0,00	3,50	2	0,71	2,00	2	0,00	5,00	2	0,00	5,00	2	0,00
(E2) Historical game setting	2,00	2	0,00	1,00	2	0,00	2,00	2	0,00	1,50	2	0,71	3,00	2	0,00	3,50	2	0,71
(E3) Socio-cultural game setting	1,00	2	0,00	1,50	2	0,71	1,00	2	0,00	2,00	2	0,00	3,00	2	0,00	4,00	2	0,00
(E4) Game events	4,00	2	0,00	2,00	2	0,00	1,50	2	0,71	1,50	2	0,71	4,00	2	0,00	3,50	2	0,71
(E5) Game storyline	2,50	2	0,71	2,00	2	0,00	1,50	2	0,71	2,00	2	1,41	2,50	2	0,71	4,00	2	0,00
(E6) Player character role	4,00	2	0,00	3,00	2	0,00	2,00	2	0,00	2,00	2	1,41	3,00	2	1,41	4,50	2	0,71
(E7) Player character aims	3,00	2	1,41	2,50	2	0,71	2,00	2	0,00	2,00	2	0,00	4,50	2	0,71	4,00	2	1,41
(E8) Gameplay enablers	5,00	2	0,00	3,50	2	0,71	3,00	2	0,00	2,50	2	0,71	5,00	2	0,00	5,00	2	0,00
(E9) Gameplay hindrances	3,00	2	1,41	2,00	2	0,00	2,50	2	0,71	2,50	2	0,71	4,00	2	0,00	4,50	2	0,71
(E10) Target objects transformable by players	4,00	2	0,00	4,00	2	0,00	3,00	2	1,41	3,00	2	0,00	3,50	2	0,71	4,00	2	0,00
(E11) Information flows provided from objects	4,00	2	0,00	3,00	2	1,41	2,00	2	1,41	2,50	2	0,71	5,00	2	0,00	4,00	2	1,41
(E12) Information flows provided from events	3,00	2	0,00	3,00	2	1,41	2,50	2	0,71	2,00	2	0,00	4,00	2	0,00	5,00	2	0,00
(E13) Clear provision of information flows	2,50	2	0,71	3,50	2	0,71	2,00	2	0,00	3,00	2	0,00	3,50	2	0,71	4,00	2	0,00
(E14) Timely provision of information flows	4,00	2	0,00	3,00	2	0,00	2,00	2	0,00	2,50	2	0,71	4,00	2	0,00	3,50	2	0,71
(E15) Close to source provision of information flows	4,00	2	0,00	4,00	2	0,00	2,00	2	1,41	3,00	2	0,00	3,50	2	0,71	4,50	2	0,71
(E16) Recurring provision of information flows	4,00	2	0,00	4,00	2	0,00	3,50	2	0,71	3,50	2	0,71	4,00	2	0,00	5,00	2	0,00

6.4 Discussion

The purpose of the developed GEFF-CPSC instrument (Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7) is to support the identification of gameplay features that may promote necessary cognitive CPS conditions and the identification of game elements that may promote those gameplay features. Respectively, Scale 3 (Figure 6.6) and Scale 4 (Figure 6.7) achieve these two goals. In addition, a rigorous instrument development process was followed [68–70, 77, 78] to ensure the content validity of instrument items, the construct validity of instrument scales, and the reliability of the instrument through assessment with reviewers and pre-testing with analysts. The results of the pre-test of the GEFF-CPSC instrument and the strengths and limitations of the study are discussed in the following subsections.

6.4.1 Implications of pre-test

The lower intraclass correlation coefficient (ICC = 0.58) can be explained by the difference between the two analysts' level of experience in evaluating games. In addition, the results of the pre-test are not statistically significant and are inconclusive on their own. However, the pre-test was designed as merely a step on the path towards the validation of the GEFF-CPSC instrument [68–70, 77, 78]. Consequently, this study will be expanded through future research by inviting more reviewers and analysts for further validation and reliability tests that include additional and diverse games.

6.4.2 Strengths and limitations

The key strengths of the development process presented in this study, that make the GEFF-CPSC instrument a promising tool which researchers and practitioners can use to analyse and design games that may promote CPS processes in GBL environments, include:

- ensuring initial content and construct validity by integrating and following well-recognised instrument elaboration approaches [68–70];
- conceptualising the GEFF-CPSC model (Figure 6.1) to support the generation of instrument items and the creation of instrument scales [96, 98];
- integrating complementary aspects from the sound CPS-GBL theoretical framework (Section 2.3) and the CPS-GBL conceptual model (Section 5.2) to underpin the GEFF-CPSC model;
- conducting a pre-test for the reliability of the instrument [68–70, 77, 78].

The main limitation of the study is its inconclusive results due to the low number of analysts and low number of analysed games. In addition, the GEFF-CPSC instrument needs other supplementary tools that can enhance its abilities to tackle the multi-dimensional nature of CPS processes in GBL environments [42]. Finally, the GEFF-CPSC conceptual model can be modified to include specific configurations of gameplay features and elements, by using the results of this study and future research (e.g., Chapter 7).

6.5 Summary

This chapter described a study designed to address the insufficiency of available research tools to identify specific gameplay features that may promote necessary cognitive CPS conditions. Consequently, the GEFF-CPSC instrument (Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7) was developed based on the GEFF-CPSC conceptual model (Figure 6.1) which was underpinned by the sound CPS-GBL theoretical framework (Section 2.3) and the CPS-GBL model (Section 5.2). This development process was driven by three research questions, which were answered in the following ways.

"*RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*" was answered by the functions of gameplay features in Scale 3 (Figure 6.6). The purpose of Scale 3 is to identify to what extent each of the six gameplay features (i.e., (a) “Self-define which goals to pursue”, (b) “Explore environments that mimic challenging scenarios impacting society”; (c) “Perform actions that mimic societally impactful activities”, (d) “Predict the consequences of player actions”, (e) “Adapt player plans to changes in the environment”, and (f) “Evaluate the outcomes of player actions”) from Scale 2 (Figure 6.5) may promote each of the four cognitive CPS conditions (i.e, (a) “Player ability in accepting and adapting to self-incompetence”, (b) “Player ability in anticipating and addressing important game challenges”, (c) “Player ability in mastering and performing repeated game actions without thinking”, and (d) “Player ability in developing and recalling correct mental representations of game objectives”) from Scale 1 (Figure 6.4).

"*RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*" and "*RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*" were answered by the functions of game elements in Scale 4 (Figure 6.7). The purpose of Scale 4 is to identify to what extent each of the 16 game elements (i.e., “Physical game setting”, “Historical game setting”, “Socio-cultural game setting”, “Game events”, “Game storyline”, “Player character role”, “Player character aims”, “Gameplay enablers”, “Gameplay enablers”, “Target objects transformable by players”, “Information flows provided from objects”, “Information flows provided from events”, “Clear provision of information flows”, “Timely provision of information flows”, “Close to source provision of information flows”, and “Recurring provision of information flows”) may promote each of the six gameplay features from Scale 2 (Figure 6.5).

The developed GEFF-CPSC instrument (Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7) can support game researchers and practitioners to map (a) specific features of the gameplay activity process which occurs in CPS scenarios to (b) cognitive CPS conditions necessary to engage and deal with complex problems. Furthermore, the GEFF-CPSC model (Figure 6.1) may assist the design of new tools and theories for CPS processes in games. For this purpose, the results from the reliability assessment and pre-test of the GEFF-CPSC instrument can be used to enhance the GEFF-CPSC model.

In addition to mapping gameplay features to cognitive CPS conditions, another important requirement for analysing and designing CPS processes in GBL environments is the ability to configure existing gameplay features in desirable ways (e.g., promoting cognitive CPS capabilities) which can be informed by the GEFF-CPSC instrument and the GEFF-CPSC model. This is the focus of the study presented in the following Chapter 7.

Chapter 7

Study IV: CPS-GFC guidelines

7.1 Introduction

This chapter presents a study that focuses on the specific research problem that existing research tools are inadequate to identify gameplay features that may promote both player engagement and cognitive CPS capabilities. To address this problem, the research objective of this study is to develop a set of guidelines for configuring gameplay features in ways that can simultaneously promote engagement in gameplay processes, and elicit and support cognitive CPS capabilities. The pursuit of this research objective is guided by the following research questions:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*
- *RQ4.2: How should gameplay features be configured to promote player engagement?*
- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

To answer these questions, the research strategy of this study involves conducting a systematic review [71] of available methodological frameworks for the analysis and design of entertainment games, with the aim of investigating specific gameplay features and configurations that are suitable to promote player engagement and cognitive CPS capabilities.

As we already stated, cognitive CPS capabilities can be defined as the ability to engage in the multi-phase uncertainty management process [2, 15, 19]. Accounting for this, this systematic review integratively analyses both game-centric gameplay features (i.e., structural game elements and gameplay mechanics that affect player engagement [3, 38, 106, 107]) and player-centric gameplay features (i.e., psychological processes and motivational affordances that drive player engagement [3, 38, 65, 108]) because their interactions create demands and support for the ability to engage in the uncertainty management process [43, 109]. To this end, gameplay features are analysed based on the Work System Theory (WST) [2], the Cognitive Work Analysis framework (CWA) [72] and the Cattell-Horn-Carroll theory of cognitive capabilities (CHC theory) [67], by an inductive approach of qualitative content analysis [73], and by adopting template analysis techniques [74, 75]. The use of these theories is outlined and justified in Section 7.2.

The contribution of this study is the resulting set of guidelines for configuring gameplay features to promote player engagement and cognitive CPS capabilities (i.e., the CPS-GFC guidelines). The CPS-GFC guidelines are operationalised based on (a) the analysis of gameplay features, (b) the concepts from the CPS-IF model (Subsection 4.2.1), the CPS-GBL model (Subsection 5.2.1) and the GEFF-CPSC model (Subsection 6.2.1), and the results from the exploratory testing of the the CPS-IF instrument (Subsection 4.2.2), the CPS-GBL instrument (Subsection 5.2.2) and the GEFF-CPSC instrument (Subsection 6.2.2). These guidelines are of great need and importance in research and practise [38, 110–114].

This chapter describes the methods for the systematic review in Section 7.2, the results of the systematic review in relation to the research questions in Section 7.3, and the implications of the findings in terms of the developed CPS-GFC guidelines, the contribution of the study, and its strengths and limitations in Section 7.4.

7.2 Methods

The CPS-GFC guidelines are developed using a systematic review method [71] that was planned and reported based on the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) checklist [115], presented in Appendix A.1. A systematic review method involves (a) first, defining eligibility criteria for inclusion and exclusion of studies (Subsection 7.2.1), (b) next, searching different information sources for articles (Subsection 7.2.2) by using key search terms as part of a search strategy (Subsection 7.2.3), (c) then, assessing the relevancy and eligibility of included records through a selection process (Subsection 7.2.4), and (d) finally, coding and extracting data (Subsection 7.2.5) from included records using suitable data categories and items (Subsection 7.2.6) and synthesising the coded, extracted and categorised data (Subsection 7.2.7) [71, 115–118]. A protocol for the systematic review was prospectively published in [119]. Hence, this section presents the published methods while highlighting changes made since the publication of the protocol.

7.2.1 Eligibility Criteria

The eligibility criteria of the systematic review were based on this study's research questions (i.e., *RQ4.1*, *RQ4.2* and *RQ4.3*) that were reintroduced in Section 7.1. Studies were included in the review if they:

1. presented a methodological framework for the analysis and design of entertainment games;
2. had been written in English;
3. were peer-reviewed journal articles, book chapters, or conference papers (thus, excluding editorials, abstracts, posters and panel discussions);
4. had been published between January 1, 2000 and December 31, 2021;
5. were demonstrably impactful papers that either (a) advanced empirical studies (e.g., an original or a modified methodology or instrument applied to conduct a case study), or (b) informed the formulation of other methodological papers (e.g., an extension of a theory or an adaptation of an instrument).

The focus of this study is set on entertainment games because *gameplay learning* processes in these games (a) can enable transferability of knowledge, attitudes, and skills developed in-game to real-world scenarios, depending on the game contextualisations (e.g., settings and narratives underpinning gameplay activities) [9, 39, 54–57], and (b) are completely intrinsically motivated by the game goals, contextualizations, and mechanics [53, 58–61]. Both of these factors are essential for the development of cognitive CPS skills and attitudes, which is the aim of this thesis.

7.2.2 Information sources

ACM Digital Library, IEEE Xplore, Scopus, and Web of Science were the four databases searched for eligible studies on 4 - 8 April 2022. The reference lists of the included articles were manually searched on 11 - 13 April 2022 to identify other eligible studies [115, 116].

7.2.3 Search strategy

The search strategy followed an iterative approach [117] consisting of generating and revising: (a) a pool of key search terms, (b) generic query strings based on the identified key search terms, and (c) the syntax for each database based on the generic query strings. First, the pool of key search terms was formulated by analysing titles, abstracts and keywords of articles in Scopus that present methodological frameworks for the analysis and design of entertainment games (e.g., [63, 120, 121]). Next, these search terms were conceptually organised based on the research questions (e.g., games, features, framework, analysis, design, etc.) and were iteratively expanded to include synonyms, variants, and related terms (e.g., videogames and gameplay, models and approaches, elements and mechanics, development and evaluation, etc.). Lastly, considering the inclusion criteria and based on the expanded search terms, generic query strings were created and translated into the required database syntax. The full search strategy is presented in Appendix A.2.

7.2.4 Selection process

The selection of studies for review was done by two reviewers in two stages (i.e., title and abstract screening and full-text review), following the steps suggested in the PRISMA checklist [115]. First, duplicates were removed and records were consolidated in a Zotero [122] database. Then, the titles and abstracts of the remaining articles were independently screened by two reviewers based on the eligibility criteria. Next, for each remaining study, a full-text assessment and a research impact evaluation were collaboratively performed by both reviewers. Finally, to identify additional relevant articles, the list of references of each selected study was analysed [116, 118]. Disagreements were resolved through discussion between the two reviewers and evaluated by a third independent reviewer when necessary [79, 80].

7.2.5 Data extraction

The included studies were examined through an inductive qualitative content analysis approach [73] and by adopting a template analysis technique [74, 75]. Template analysis is a form of thematic analysis that uses an iteratively developed hierarchical coding template to identify, classify and relate themes in the extracted data [74, 75]. To improve the reliability of the data extraction process [123–127], two reviewers collaborated to iteratively develop and use a coding schema. A third reviewer independently validated the coding schema and the extracted data [79, 80]. The purpose of the coding schema was to identify gameplay features that may promote both player engagement (i.e., engagement in goal-directed and action-mediated gameplay process [3]) and cognitive CPS capabilities (i.e., ability to engage in the uncertainty management process [15, 19]). The two reviewers developed the coding schema supported by the CPS-GBL theoretical framework (i.e., theoretical framework for complex problem-solving processes within game-based learning environments) (Section 2.3), and specifically based on the WST [2], the CWA framework [72], and the CHC theory [67]. The rationale for this choice is the following.

WST was used to classify and analyse gameplay features considered by each methodological framework because: (a) it models goal-directed activities as task processes, defined by key environmental conditions and performed by actors who use tools and knowledge to achieve their goals [2]; and (b) it provides formal approaches for analysing key work system elements and their function to enable or hinder task performance [2]. The goal-directed and action-mediated perspective of WST [2] informed the development of the coding schema categories without dictating it. In addition, work system elements [2] were adapted and mapped to gameplay system elements [3], as presented in (Fig 7.1). The CWA framework was selected because it provides formal methods for identifying: (a) cognitive processes involved in work activities, and (b) how interacting elements in a work environment may facilitate or hamper the identified cognitive processes [72]. CHC theory was used to define the necessary phases of the uncertainty management processes (i.e., (a) perception, (b) hypotheses formulation, (c) hypothesis choice, and (d) hypothesis testing) that should be demanded or supported for the development of cognitive CPS capabilities. Based on this rationale, the WST, the CWA framework, and the CHC theory [67], were used to analyse each of the selected methodological frameworks by investigating:

(a) gameplay features, their configurations and functions, that may promote player engagement, (b) relevant cognitive CPS capabilities (i.e., ability to engage in the four phases of the uncertainty management process) involved in the gameplay activity, and (c) how gameplay features may demand or support the ability to engage in the uncertainty management process.

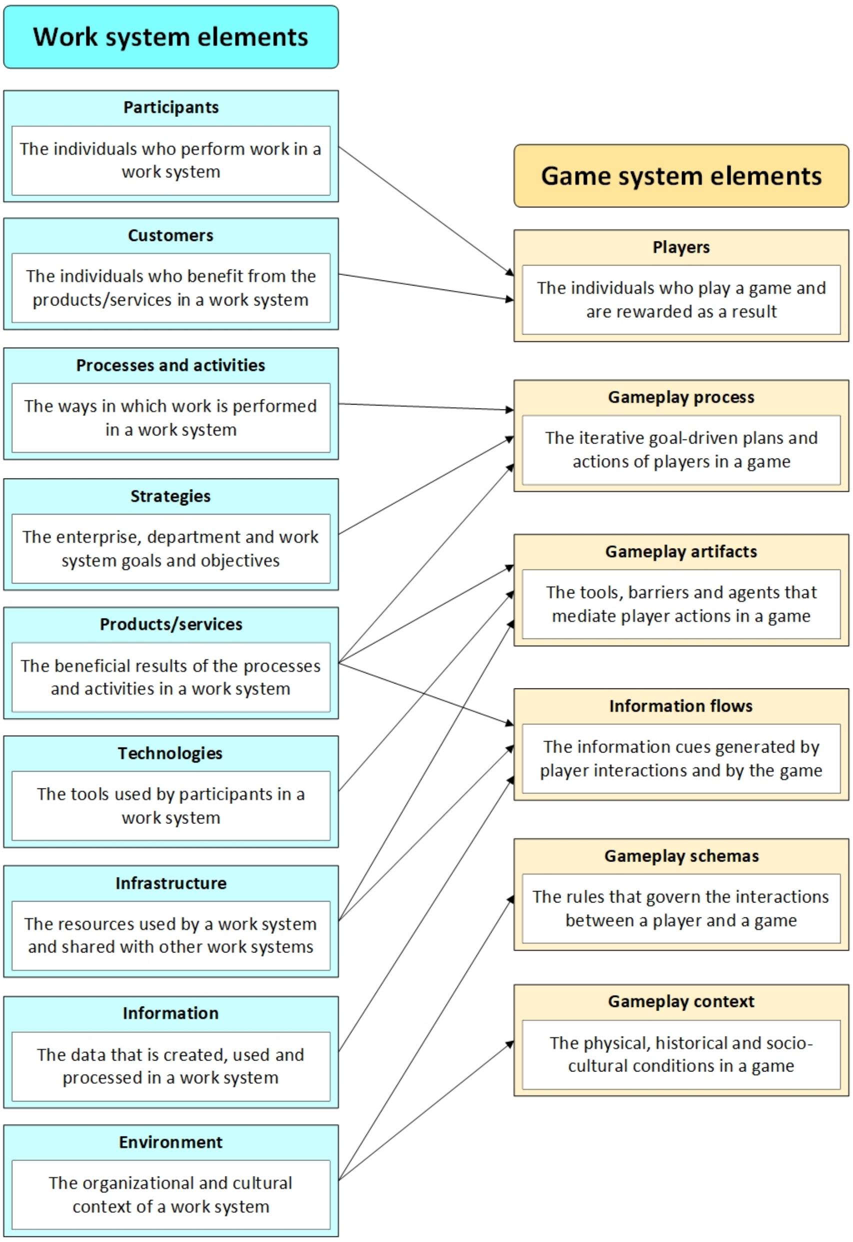

Fig. 7.1 Adapted work system elements to gameplay system elements [2–5]

7.2.6 Data items

The following data items from each study were extracted: (a) authors, (b) year of publication, (c) name of framework, (d) lens or perspective of framework, (e) purpose of framework, (f) theoretical or conceptual underpinning of framework, (g) impact of framework, (h) target games of framework. In addition, six data categories, characterising gameplay features that may promote player engagement in the gameplay process and the ability to engage in the uncertainty management process, were iteratively extracted using the developed coding schema. These data categories were formulated based on (a) the study's research questions (i.e., *RQ4.1*, *RQ4.2* and *RQ4.3*), and (b) the theories underpinning the coding schema (i.e., WST [2], CWA framework [72], and CHC theory [67]). The six data categories were conceptually defined as follows:

- *Gameplay feature*: Structural game elements (i.e., the building blocks of the game), gameplay mechanics (i.e., the rules of the game), and psychological processes (i.e., aspects of the player experience).
- *Engagement configuration of gameplay feature*: The necessary conditions for structural game elements and gameplay mechanics to promote player engagement in the gameplay process.
- *Engagement function of gameplay feature*: The specific psychological processes emerging from player interactions with structural game elements and gameplay mechanics that promote player engagement in the gameplay process.
- *Adapted work system elements of gameplay feature*: The adapted work system elements into gameplay system elements that categorise the engagement configuration of a gameplay feature.
- *Uncertainty management configuration of gameplay feature*: The aspects of structural game elements and gameplay mechanics that increase or decrease uncertainty during the gameplay process.
- *Uncertainty management function of gameplay feature*: The effects that increased or decreased uncertainty has on, respectively, demanding or supporting the ability to engage in the uncertainty management process.

Data extraction for each of these categories was guided by the following questions:

- *Gameplay feature*: What is the definition of the gameplay feature according to the study?
- *Engagement configuration of gameplay feature*: How should the gameplay feature be configured (i.e., modifying its attributes and behaviour) to promote player engagement in the gameplay process according to the study?
- *Engagement function of gameplay feature*: How may the configuration of the gameplay feature promote player engagement in the gameplay process according to the study?
- *Adapted work system elements of gameplay feature*: What adapted work system elements does the configuration of the gameplay feature refer to?
- *Uncertainty management configuration of gameplay feature*: How should the gameplay feature be configured to decrease or increase uncertainty?
- *Uncertainty management function of gameplay feature*: How may the configuration of the gameplay feature promote the ability to engage in the uncertainty management process?

7.2.7 Data synthesis

Two reviewers collaboratively analysed the extracted data in the coding schema through a theory-based inductive analysis [81], while a third reviewer independently verified the results of the data synthesis process [79, 80]. All reviewers were familiar with the concepts and theories (i.e., WST [2], CWA framework [72], and CHC theory [67]) of the coding schema. The data synthesis process consisted of a descriptive stage and an interpretative stage [74, 75].

First, in the **descriptive stage**, items were extracted from articles under the following categories: (a) definition of gameplay feature, (b) engagement configuration of gameplay feature, and (c) engagement function of gameplay feature. Since the descriptions of the definitions, configurations and functions of gameplay features were different in different methodological frameworks, a coding syntax was used to standardise the items for each category, respectively:

- "**Gameplay Feature X** refers to ..." (e.g., "Relatedness" refers to the player's need for social connection with other players and artificial intelligence, [65]);
- "**Gameplay Feature X** should be configured to provide ..." or "**Gameplay Feature X** should emerge from game elements that provide ..." (e.g., "Relatedness" should emerge from game elements that provide player-player and player-AI (artificial intelligence) interactions, [65]);
- "The configuration of **Gameplay Feature X** may enable players to ..." (e.g., The configuration of "Relatedness" may enable players to feel connected with other players and AI, [65]).

These descriptive categories and items were synthesised using the coding schema [74, 75] and presented in different tables in Section 7.3.

Next, the **interpretative stage** started with assessing the descriptive sufficiency of the extracted configurations and functions from the previous stage, guided by the following question: "Does the study report sufficient information to understand how the gameplay feature configuration can promote player engagement?" Next, the gameplay features that were assessed as suitable described configurations were categorised based on the work system elements from Figure 7.1 adapted to a gameplay system (i.e., "Players", "Gameplay process", "Gameplay artifacts", "Gameplay schemas", "Gameplay context" and "Information flows"). Finally, based on the CPS-GBL theoretical framework (Section 2.3), interpretative codes were generated beyond the original data for the: (a) uncertainty management configuration of gameplay feature, and (b) uncertainty management function of gameplay feature. Similar to the descriptive stage, a standardised coding syntax was used for each of the items in both categories:

- "If the *presence*, *causes*, *effects*, or *rules* of the **uncertainty management phenomena X** are *concealed* or *revealed* ..." (e.g., If the causes and effects of the relationship between the local and global game context are revealed ..., [3]);
- "... then players may be *enabled* or *required* to *perceive*, *formulate a set of hypotheses about*, *choose one from the set of hypotheses about*, or *test the chosen hypothesis about* the hidden *presence*, *causes*, *effects*, or *rules*

of the **uncertainty management phenomena X**" (e.g., ... then players may be required to formulate a set of hypotheses about the hidden rules of the relationships between the local and global context, [3]).

These interpretative categories and related items were synthesised using the coding schema [74, 75] and presented in different tables in Section 7.3.

7.3 Results

7.3.1 Study selection

A total of 7,879 records were identified across the four databases searched. The searches in Scopus, Web of Science, IEEE Xplore, and ACM Digital Library resulted in 3,928, 2,774, 965, and 212 identified records, respectively. In addition, 9 records were identified through other sources. This total of 7,888 records was first reduced to 4,314 by removing duplicates. Afterward, by screening titles and abstracts, 4,186 records were excluded. The remaining 128 articles were assessed by following the eligibility criteria from Subsection 7.2.1. By reviewing these 128 articles, 68 were excluded because they did not present a new methodological framework for the analysis and design of entertainment games, and 38 were excluded because the methodological frameworks they presented had no demonstrable impact (e.g., to either advance empirical studies or inform the formulation of other methodological papers). The remaining 22 studies were included in the template analysis and qualitative synthesis for the systematic review. Details of the selection process are summarised in the PRISMA flow diagram shown in Figure 7.2 [115].

7.3.2 Study characteristics

Table 7.1 summarises the characteristics of the selected articles according to the following categories, highlighted in Subsection 7.2.6: (a) authors, (b) year of publication, (c) name of framework, (d) lens of framework, (e) purpose of framework, (f) target games of framework, (g) impact of framework, and (h) theoretical or conceptual underpinning of framework.

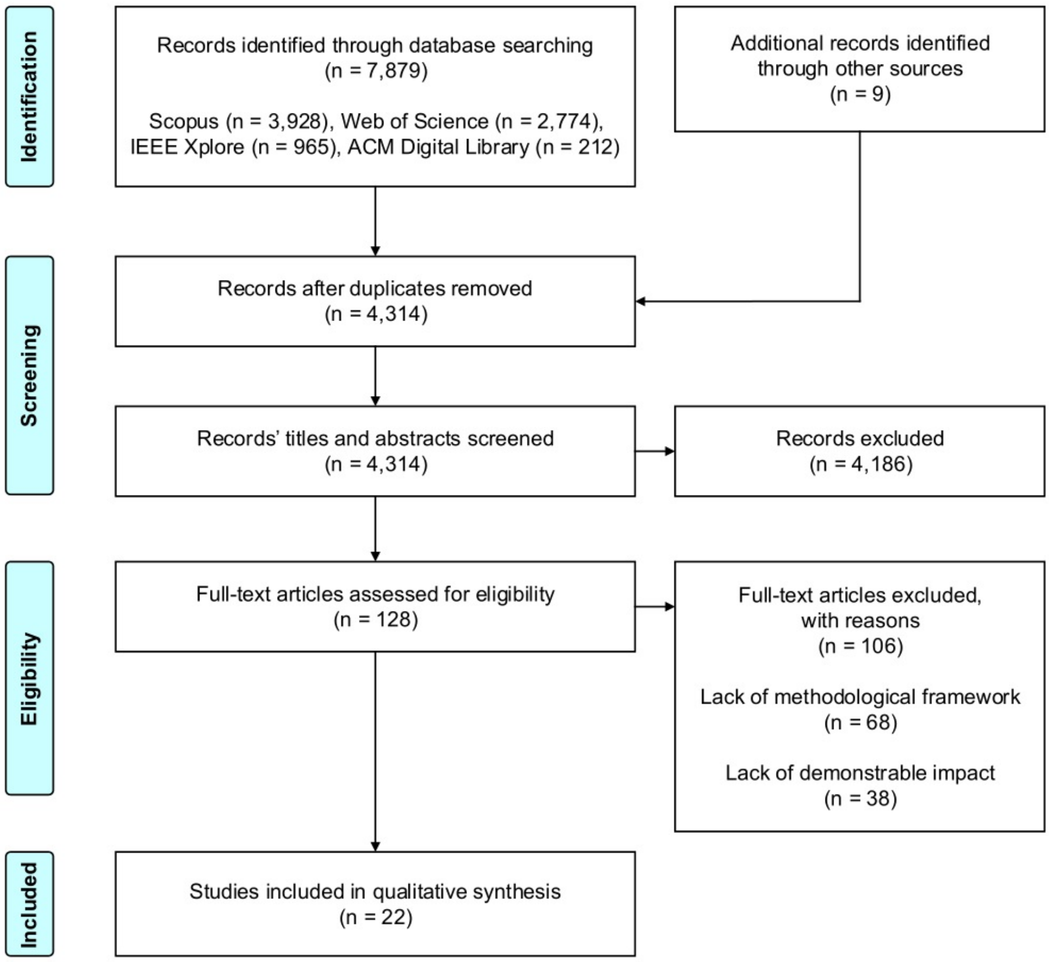

Fig. 7.2 PRISMA flow diagram of study selection process

The 22 included studies were published between 2000 and 2019. In terms of the lens of the reviewed frameworks, 11 had a player-centric (P) perspective [65, 120, 121, 128, 132, 138, 141, 144, 154, 161, 171], 7 had a game-centric (G) perspective [63, 151, 152, 159, 165, 175, 179], and 4 had an integrative (I) perspective [3, 135, 136, 174]. Regarding the purpose of the frameworks, all 22 were intended for the design (D) of games, while 13 were also aimed at the analysis (A) of games [3, 63, 65, 120, 128, 135, 136, 138, 141, 154, 161, 165, 171]. Even though all 22 frameworks targeted digital games, the following sub-categories of digital games were specified: (a) two frameworks were not restricted to only digital games (Digital (+)) (e.g., board games, card games, and sports) [63, 128], (b) two frameworks were targeting only computer games (Digital (C)) [120, 121], (c) two frameworks were focused

Table 7.1 Study characteristics

Author, Year	Framework	Lens	Purpose	Games	Underpinning	Impact
Costello and Edmonds, 2009 [128]	Play framework	P	A, D	Digital (+)	C [63], T [129, 130]	E [131], M [132]
De Byl, 2015 [121]	Conceptual affective design framework	P	D	Digital (C)	T [133]	M [134]
Desurvire and Wiberg, 2009 [135]	Game usability heuristics (PLAY)	I	A, D	Digital	C [136]	E [137], M [137]
Desurvire et al., 2004 [136]	Heuristics for evaluating playability (HEP)	I	A, D	Digital	N/A	E [137], M [137]
Dillon, 2011 [138]	6-11 Framework	P	A, D	Digital	C [63], T [139]	E [140]
Ermi and Mäyrä, 2005 [141]	Sensory, challenge-based, and imaginative immersion (SCI) model	P	A, D	Digital	N/A	E [142], M [143]
Fabricatore, 2007 [144]	Architectural model for game mechanics	P	D	Digital	N/A	E [145], M [145]
Fabricatore, 2018 [3]	Activity theory-based framework of meaning-making	I	A, D	Digital	T [146–150]	E [38], M [12]
Fabricatore et al., 2002 [151]	Model of playability in action videogames	G	D	Digital	N/A	M [144]
Harris et al., 2016 [152]	Framework of asymmetric elements	G	D	Digital (MP)	C [63]	M [153]
Hochleitner et al., 2015 [154]	Heuristic framework for user experience	P	A, D	Digital	C [155]	E [156]
Hunicke et al., 2004 [63]	Mechanics, Dynamics, and Aesthetics (MDA) framework	G	A, D	Digital (+)	N/A	E [157], M [158]
Khalifa et al., 2019 [159]	Level design patterns	G	D	Digital	N/A	E [160]
Pereira and Roque, 2012 [132]	Participation-centered game design model	P	D	Digital	C [128, 141, 161], T [129, 162, 163]	E [164], M [164]
Ralph and Monu, 2015 [165]	Unified theory of digital games	G	A, D	Digital	C [63, 166]	M [112]
Ryan et al., 2006 [65]	Self-determination theory-based (SDT) model	P	A, D	Digital	T [167]	E [5], M [168]
Sweetser and Wyeth, 2005 [120]	GameFlow model	P	A, D	Digital (C)	T [169]	E [64], M [170]
Tondello et al., 2017 [171]	Framework and taxonomy of player preferences	P	A, D	Digital	N/A	E [172], M [173]
Walk et al., 2017 [174]	Design, Dynamics, Experience (DDE) framework	I	D	Digital	C [63, 158, 166]	M [112]
Xu et al., 2011 [175]	Design pre-patterns	G	D	Digital (HAR)	N/A	E [176], M [177]
Yee, 2006 [161]	Player motivations model	P	A, D	Digital (OL)	T [162]	E [178]
Zagal et al., 2000 [179]	Model of the characteristics of a multiplayer game	G	D	Digital (MP)	T [180]	E [181], M [181]

on multiplayer games (Digital (MP)) [152, 179], (d) one framework was aimed at handheld augmented reality games (Digital (HAR)) [175], and (e) one framework was meant for online games (Digital (OL)) [161]. Concerning the underpinnings of different frameworks, 6 frameworks had theoretical (T) underpinnings (e.g., self-determination theory [167] and flow theory [169]) [3, 65, 120, 121, 161, 179], 5 frameworks had conceptual (C) underpinnings (e.g., the MDA framework [63] and the Elemental Tetrad [166]) [135, 152, 154, 165, 174], 3 frameworks had both theoretical and conceptual underpinnings [128, 132, 138], and 8 frameworks had neither theoretical nor conceptual underpinnings (N/A) and were based on either the experience of authors, the results of player surveys, or the observations of gameplay experiments [63, 136, 141, 144, 151, 159, 171, 175]. Relating to the demonstrable impact of each framework, 4 had advanced empirical (E) studies [138, 154, 159, 161], 5 had informed methodological (M) articles [121, 151, 152, 165, 174], and 13 had lead to both empirical and methodological papers [3, 63, 65, 120, 128, 132, 135, 136, 141, 144, 171, 175, 179].

7.3.3 Gameplay features of methodological frameworks

The findings were synthesised and organised in the following tables: (a) Analysed gameplay features (Table 7.2), (b) Examples of excluded gameplay features (Table 7.3), (c) Included gameplay features (Table 7.4), (d) Configured gameplay features for player engagement (Table 7.5), and (e) Configured gameplay features for uncertainty management (Table 7.6, Table 7.7, and Table 7.8).

Table 7.2 presents all 184 extracted and analysed gameplay features from the 22 frameworks. As defined in Subsection 7.2.6, a gameplay feature is either a structural game element (e.g., "Entity" [151]), a gameplay mechanics (e.g., "Branching" [159]), or a psychological process (e.g., "Emotional Experience" [121]). For each gameplay feature, a configuration and a function for promoting engagement in the gameplay processes were extracted from the provided description in their respective studies.

Table 7.3 offers three examples of excluded gameplay features (i.e., "Self Identification" [138], "Dynamics" [63], and "Interface" [174]), that were configured to provide only the presence of a game elements (i.e., characters, feedback and assets) without descriptions of the ways that attributes and behaviour of the gameplay feature can be modified for player engagement, which is the working definition of a

Table 7.2 Analysed gameplay features

Framework	Gameplay features
Costello and Edmonds, 2009 [128]	Creation, Exploration, Discovery, Difficulty, Competition, Danger, Captivation, Sensation, Sympathy, Simulation, Fantasy, Camaraderie, Subversion
De Byl, 2015 [121]	Mind-Body Interaction, Fast Primary Emotions, Cognitive Appraisals, Emotional Behaviour, Emotional Experience
Desurvire and Wiberg, 2009 [135]	Enduring Play, Challenge, Strategy and Pace, Consistency in Game World, Goals, Variety of Players and Game Styles, Players Perception of Control, Emotional Connection, Coolness/Entertainment, Humor, Immersion, Documentation/Tutorial, Status and Score, Game Provides Feedback, Terminology, Burden On Player, Screen Layout, Navigation, Error prevention, Game Story Immersion
Desurvire et al., 2004 [136]	Game Play, Game Story, Game Mechanics, Game Usability
Dillon, 2011 [138]	Fear, Anger, Joy / Happiness, Pride, Sadness, Excitement, Survival, Self Identification, Collecting, Greed, Protection / Care / Nurture, Aggressiveness, Revenge, Competition, Communication, Exploration / Curiosity, Color Appreciation
Ermi and Mäyrä, 2005 [141]	Sensory immersion, Challenge-based immersion, Imaginative immersion
Fabricatore, 2007 [144]	Core gameplay, Core game mechanics, Core meta-gameplay, Satellite game mechanics, Peripheral gameplay
Fabricatore, 2018 [3]	Game play activity, Game task, Game context, Core schemas
Fabricatore et al., 2002 [151]	Entity, Scenario, Hierarchy of goals
Harris et al., 2016 [152]	Asymmetry of Ability, Asymmetry of Challenge, Asymmetry of Interface, Asymmetry of Information, Asymmetry of Investment, Asymmetry of Goal/Responsibility, Mirrored Dependence, Unidirectional Dependence, Bidirectional Dependence (AKA Symbiosis), Asynchronous Timing, Sequential (Disjoint) Timing, Expected Timing, Concurrent Timing, Coincident Timing
Hochleitner et al., 2015 [154]	Goals, Motivation, Challenge, Learning, Control, Consistency, Game story, Feedback, Visual appearance, Interaction, Customization, Menu and interface elements (HUD)
Hunicke et al., 2004 [63]	Mechanics, Dynamics, Aesthetics
Khalifa et al., 2019 [159]	Guidance, Safe Zone, Foreshadowing, Layering, Branching, Pace Breaking
Pereira and Roque, 2012 [132]	Playfulness, Challenge, Embodiment, Sociability, Sensemaking, Sensoriality
Ralph and Monu, 2015 [165]	Game mechanics, Narrative mechanics, Technology, Embedded narratives, Dynamics, Emergent narrative, Aesthetics, Interpreted narrative
Ryan et al., 2006 [65]	Autonomy, Competence, Relatedness, Presence
Sweetser and Wyeth, 2005 [120]	Concentration, Challenge, Player Skills, Control, Clear Goals, Feedback, Immersion, Social Interaction
Tondello et al., 2017 [171]	Strategic resource management, Puzzle, Artistic movement, Sports and cards, Role-playing, Virtual goods, Simulation, Action, Progression, Multiplayer, Abstract interaction, Solo play, Competitive community
Walk et al., 2017 [174]	Blueprint, Mechanics, Interface, Dynamics, Senses, Cerebellum, Cerebrum, Player-Subject, Perception
Xu et al., 2011 [175]	Device metaphors, Control mapping, Seamful design, World consistency, Landmarks, Living creatures, Personal presence, Body constraints, Hidden information
Yee, 2006 [161]	Advancement, Mechanics, Competition, Socializing, Relationships, Teamwork, Discovery, Role-playing, Customization, Escapism
Zagal et al., 2000 [179]	Rules and Goals, Props and Tools, Player, Social Interaction, Competition and Cooperation, Synchronicity, Coordination, Prop and Tool Dependence, Existence of Meta-Gaming

gameplay configuration for this specific study and overall for this thesis. A total of 172 gameplay features were excluded because the descriptions of their gameplay configurations and functions to promote engagement in the gameplay process were assessed as insufficient. Consequently, interpretations for the possibility to configure these gameplay features to support the ability to engage in the uncertainty management process cannot be made.

Table 7.3 Examples of excluded gameplay features

Ref.	Gameplay feature	Engagement configuration	Engagement function
[138]	"Self Identification" refers to an instinct that pushes players to admire successful and smart characters.	Provide relatable and capable characters in the game.	Enable players to model themselves based on game characters.
[63]	"Dynamics" refers to the behaviours of mechanics that respond to player input or to the output of other mechanics.	Provide workflow and feedback systems to players.	Enable players to have aesthetic experiences.
[174]	"Interface" refers to game elements that communicate the game world to the player.	Provide a report system, graphic assets, sound assets, cut scenes, and text on display.	Enable players to perceive every element of the game world.

The complete coding schema, consisting of all 184 gameplay features (12 included and 172 excluded) and their engagement configurations and functions, can be found in Appendix A.3.

During the descriptive stage and the interpretative stage of the data synthesis process (Subsection 7.2.7), the 12 included gameplay features were assessed as suitable to promote player engagement and cognitive CPS capabilities. **Table 7.4** presents the 12 included gameplay features (*GF1 - GF12*) that may promote engagement in the gameplay process and the ability to engage in the uncertainty management process (i.e., "Emotional Experience", "Core schemas", "Entity", "Scenario", "Hierarchy of goals", "Challenge", "Guidance", "Safe Zone", "Foreshadowing", "Layering", "Branching", "Pace Breaking"), their definitions and their categorisation based on the work system elements adapted to a gameplay system from Figure 7.1. The identified *GF1 - GF12* (Table 7.4) effectively answer the first research question of this specific study:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*

Table 7.5 organises the configurations and functions of *GF1 - GF12* for promoting player engagement (e.g., **entities** should be configured to have **coherent**

Table 7.4 Included gameplay features

Ref.	Gameplay feature	Definition	Work system elements
[121]	(*GF1*) Emotional Experience	The present and continuous emotions of players.	Players, Gameplay artifacts, Gameplay schemas, Information flows
[3]	(*GF2*) Core schemas	The patterns that govern interactions, conditions, and effects of game state changes.	Players, Gameplay schemas, Information flows
[151]	(*GF3*) Entity	The role, attitude, resources, items, and behaviours of entities that the player interacts with.	Players, Gameplay artifacts, Gameplay schemas, Information flows
	(*GF4*) Scenario	The point of view of players, unexpected events, scenario transitions, and interactions with entities.	Players, Gameplay process, Gameplay context
	(*GF5*) Hierarchy of goals	The variety, levels of linearity, and information about goals and sub-goals in games.	Players, Gameplay process, Information flows
[154]	(*GF6*) Challenge	The aspects related to game pacing, game difficulty, and player skills.	Players, Gameplay artifacts, Gameplay schemas, Information flows
[159]	(*GF7*) Guidance	The use of non-verbal game elements to guide players in an intended direction.	Players, Gameplay process, Game artifacts, Information flows
	(*GF8*) Safe Zone	The use of game areas to protect players from negative interactions.	Players, Gameplay process, Game schemas, Gameplay context, Information flows
	(*GF9*) Foreshadowing	Introducing a game element in a controlled environment that later becomes more important.	Players, Game artifacts, Gameplay schemas, Gameplay context, Information flows
	(*GF10*) Layering	Combining multiple known objects and strategies to create new experiences.	Players, Game artifacts, Gameplay context, Information flows
	(*GF11*) Branching	Using multiple pathways for achieving an objective.	Players, Game artifacts, Gameplay schemas, Gameplay context, Information flows
	(*GF12*) Pace Breaking	Increasing or decreasing the dramatic tension in the game from one scene to the next.	Players, Information flows

roles, that can be perceived through relevant **contextual, explicit, audio and visual information**, which may enable players to **predict entities' behaviours**, leading to sustained player engagement). Some features have multiple configurations and functions. The configurations and functions in Table 7.5 address the second research question of this study:

- *RQ4.2: How should gameplay features be configured to promote player engagement?*

Table 7.6, **Table 7.7** and **Table 7.8** present the ways that *GF1* - *GF12* can be configured (*UMC*) to function (*UMF*) to either support or demand the ability to engage in the uncertainty management process. Most features have multiple configurations and functions, since uncertainty management is a multi-phase process. Gameplay features can be configured to either decrease or increase uncertainty in the game (e.g., the effects of unpredictable behaviours of entities can be either revealed (decreasing uncertainty) or concealed (increasing uncertainty)). When uncertainty is decreased by revealing information related to the presence, causes, effects, or rules of gameplay phenomena, then players may be supported to engage in one of the four phases of the uncertainty management process (i.e., (a) perception, (b) hypotheses formulation, (c) hypothesis choice, and (d) hypothesis testing, [67, 182, 183]). On the other hand, if uncertainty is increased by concealing information related to the presence, causes, effects, or rules of gameplay phenomena, then players may be demanded to engage in the uncertainty management process. Accordingly, Table 7.6, Table 7.7 and Table 7.8 articulate the configurations and functions as *if-then statements*. The presented uncertainty management configurations and functions answer the third research question of this study:

- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

7.4 Discussion

The systematic review method used in this study was a necessary step towards exploring the potential of existing methodological frameworks for game analysis and

Table 7.5 Configured gameplay features for player engagement

Ref.	Gameplay feature	Engagement configuration	Engagement function
[121]	(*GF1*) Emotional Experience	Provide display of the inventory, screenshots of significant events, signs of battles on the avatar, and persistent effects of player actions on the game world.	Enable players to recall emotions from their gaming journey.
		Provide NPCs that either help players complete tasks or form long-term relationships with players.	Enable players to become emotionally attached to NPCs.
[3]	(*GF2*) Core schemas	Provide causal-mechanistic schemas that govern player interactions and game events.	Enable players to understand their actions and game events.
		Provide socio-cultural schemas that govern the social interactions and cultural expectations in the game.	Enable players to understand how to interact with other players and characters.
		Provide workflow schemas that define the dependency between game goals.	Enable players to understand and choose how to progress.
		Provide timely and reiterated feedback schemas.	Enable players to accept goals, plan task performance, evaluate contextual conditions, and understand aspects of the local and global game context.
[151]	(*GF3*) Entity	Provide coherent roles, abilities, behaviours, and attitudes of entities with related contextual and explicit, audio and visual information.	Enable players to identify, customise, and have realistic expectations about an entity's roles, abilities, behaviours, and attitudes.
		Provide unique pieces of equipment that are available at an appropriate time and place with related contextual and explicit, audio and visual information.	Enable players to feel compelled by the different pieces of equipment, to feel appropriately challenged by the availability of equipment, and to understand the type, function, aim, range, status of equipment.
		Provide entities with non-disruptive logical behaviours, changing behaviours with evident causes, or unpredictable behaviours with identifiable causes and rules.	Enable players to identify and understand the causes and rules for the behaviour of entities.
	(*GF4*) Scenario	Provide unexpected events that affect the interaction with the scenario.	Enable players to feel challenged.
		Provide information about task progression before transitioning to a new scenario.	Enable players to understand the state of their progress.
	(*GF5*) Hierarchy of goals	Provide clear and non-repetitive goals.	Enable players to be entertained and engaged.
		Provide clear and explorable links in the nonlinear hierarchy of goals.	Enable players to understand and explore the links in the nonlinear hierarchy of goals.
		Provide clear, precise, always accessible, and helpful information about the nature of game goals, progress, and objectives.	Enable players to understand, remember, be immersed, and learn information about game goals, progress, and objectives.
[154]	(*GF6*) Challenge	Provide a reasonable, visible, consistent but unpredictable AI.	Enable players to feel appropriately challenged.
[159]	(*GF7*) Guidance	Provide a target direction based on the shape of levels, placement of collectibles, presence of enemies, and changes of environmental cues.	Enable players to explore the environment, progress in the game, and avoid bad decisions.
	(*GF8*) Safe Zone	Provide undisturbed time in an identifiable protection area based on the patterns of nearby hazards and enemies.	Enable players to analyse their surroundings and plan their next actions.
	(*GF9*) Foreshadowing	Provide a game mechanic that, once learned, will be used in a future challenge.	Enable players to become curious and excited about future possibilities.
	(*GF10*) Layering	Provide new and harder challenges by combining familiar game elements in unfamiliar ways.	Enable players to overcome fair challenges and create new strategies.
	(*GF11*) Branching	Provide unlimited access to all pathways, allowing levels to be beaten with starting tools.	Enable players to feel empowered and explore the environment.
		Provide access to some pathways only after specific conditions have been reached through other pathways.	Enable players to become curious.
		Provide safe pathways with small rewards and dangerous pathways with big rewards.	Enable players to take risks for greater reward.
	(*GF12*) Pace Breaking	Provide an unavoidable hazard of obvious difficulty with accompanying audio and visual cues.	Enable players to become more tense and focused.
		Provide free time and space for interacting with different aspects of the game.	Enable players to become more calm and relaxed.

Table 7.6 Configured gameplay features for uncertainty management (GF1-GF3)

Ref	Gameplay feature	Uncertainty management configuration	Uncertainty management function
[121]	(*GF1*) Emotional Experience	(*UMC1.1*) If the effects of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed	(*UMF1.1.1*) then players may be required to perceive the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
			(*UMF1.1.2*) then players may be required to formulate a set of hypotheses about the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
			(*UMF1.1.3*) then players may be required to choose one from the set of hypotheses about the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
		(*UMC1.2*) If the effects of changes in the inventory, to the state of the avatar, or in the persistent game world are revealed	(*UMF1.2.1*) then players may be enabled to perceive the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
			(*UMF1.2.2*) then players may be enabled to formulate a set of hypotheses about the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
			(*UMF1.2.3*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of changes in the inventory, to the state of the avatar, or in the persistent game world are concealed.
[3]	(*GF2*) Core schemas	(*UMC2.1*) If the causes and effects of the relationship between the local and global game context are concealed	(*UMF2.1.1*) then players may be required to perceive the hidden rules of the relationships between the local and global context.
			(*UMF2.1.2*) then players may be required to formulate a set of hypotheses about the hidden rules of the relationships between the local and global context.
			(*UMF2.1.3*) then players may be required to choose one from the set of hypotheses about the hidden rules of the relationships between the local and global context.
			(*UMF2.1.4*) then players may be required to test the chosen hypothesis about the hidden rules of the relationships between the local and global context.
		(*UMC2.2*) If the causes and effects of the relationship between the local and global game context are revealed	(*UMF2.2.1*) then players may be enabled to perceive the hidden rules of the relationships between the local and global context.
			(*UMF2.2.2*) then players may be enabled to formulate a set of hypotheses about the hidden rules of the relationships between the local and global context.
			(*UMF2.2.3*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of the relationships between the local and global context.
			(*UMF2.2.4*) then players may be enabled to test the chosen hypothesis about the hidden rules of the relationships between the local and global context.
[151]	(*GF3*) Entity	(*UMC3.1*) If the effects of unpredictable behaviours of entities are concealed	(*UMF3.1.1*) then players may be required to formulate a set of hypotheses about the hidden causes and rules of unpredictable behaviours of entities.
			(*UMF3.1.2*) then players may be required to choose one from the set of hypotheses about the hidden causes and rules of unpredictable behaviours of entities.
			(*UMF3.1.3*) then players may be required to test the chosen hypotheses about the hidden causes and rules of unpredictable behaviours of entities.

Table 7.7 Configured gameplay features for uncertainty management (GF3-GF6)

Ref	Gameplay feature	Uncertainty management configuration	Uncertainty management function
[151]	(*GF3*) Entity	(*UMC3.2*) If the effects of unpredictable behaviours of entities are revealed	(*UMF3.2.1*) then players may be enabled to formulate a set of hypotheses about the hidden causes and rules of unpredictable behaviours of entities.
			(*UMF3.2.2*) then players may be enabled to choose one from the set of hypotheses about the hidden causes and rules of unpredictable behaviours of entities.
			(*UMF3.2.3*) then players may be enabled to test the chosen hypotheses about the hidden causes and rules of unpredictable behaviours of entities.
[151]	(*GF4*) Scenario	(*UMC4.1*) If the causes of unexpected events are concealed	(*UMF4.1.1*) then players may be required to formulate a set of hypotheses about the hidden effects and rules of interaction with the scenario.
			(*UMF4.1.2*) then players may be required to choose one from the set of hypotheses about the hidden effects and rules of interaction with the scenario.
			(*UMF4.1.3*) then players may be required to test the chosen hypotheses about the hidden effects and rules of interaction with the scenario.
		(*UMC4.2*) If the causes of unexpected events are revealed	(*UMF4.2.1*) then players may be enabled to formulate a set of hypotheses about the hidden effects and rules of interaction with the scenario.
			(*UMF4.2.2*) then players may be enabled to choose one from the set of hypotheses about the hidden effects and rules of interaction with the scenario.
			(*UMF4.2.3*) then players may be enabled to test the chosen hypotheses about the hidden effects and rules of interaction with the scenario.
	(*GF5*) Hierarchy of goals	(*UMC5.1*) If the rules of exploring and backtracking are revealed	(*UMF5.1.1*) then players may be enabled to formulate a set of hypotheses about the hidden rules of the branches of nonlinear hierarchy of goals.
			(*UMF5.1.2*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of the branches of nonlinear hierarchy of goals.
			(*UMF5.1.3*) then players may be enabled to test the chosen hypothesis about the hidden rules of the branches of nonlinear hierarchy of goals.
[154]	(*GF6*) Challenge	(*UMC6.1*) If the effects of unpredictable AI behaviours are concealed	(*UMF6.1.1*) then players may be required to perceive the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.1.2*) then players may be required to formulate a set of hypotheses about the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.1.3*) then players may be required to choose one from the set of hypotheses about the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.1.4*) then players may be required to test the chosen hypothesis about the hidden causes and rules of the unpredictable AI behaviours.
		(*UMC6.2*) If the effects of unpredictable AI behaviours are revealed	(*UMF6.2.1*) then players may be enabled to perceive the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.2.2*) then players may be enabled to formulate a set of hypotheses about the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.2.3*) then players may be enabled to choose one from the set of hypotheses about the hidden causes and rules of the unpredictable AI behaviours.
			(*UMF6.2.4*) then players may be enabled to test the chosen hypothesis about the hidden causes and rules of the unpredictable AI behaviours.

Table 7.8 Configured gameplay features for uncertainty management (GF7-GF12)

Ref	**Gameplay feature**	**Uncertainty management configuration**	**Uncertainty management function**
[159]	(*GF7*) Guidance	(*UMC7.1*) If the presence of collectibles, enemies, and environmental cues is revealed	(*UMF7.1.1*) then players may be enabled to perceive the hidden presence of desirable progression pathways.
	(*GF8*) Safe Zone	(*UMC8.1*) If the rules of undisturbed time in protection area are revealed	(*UMFF8.1.1*) then players may be enabled to perceive the hidden rules of nearby hazards and enemies.
			(*UMFF8.1.2*) then players may be enabled to formulate a set of hypotheses about the hidden rules of nearby hazards and enemies.
			(*UMFF8.1.3*) then players may be enabled to choose from the set of hypotheses about the hidden rules of nearby hazards and enemies.
	(*GF9*) Foreshadowing	(*UMC9.1*) If the rules of a learned game mechanic are revealed	(*UMF9.1.1*) then players may be enabled to formulate a set of hypotheses about the hidden rules of future challenges.
			(*UMF9.1.2*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of future challenges.
			(*UMF9.1.3*) then players may be enabled to test the chosen hypothesis about the hidden rules of future challenges.
	(*GF10*) Layering	(*UMC10.1*) If the rules of familiar game elements is revealed	(*UMF10.1.1*) then players may be enabled to formulate a set of hypotheses about the hidden rules of newer and harder challenges.
			(*UMF10.1.2*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of newer and harder challenges.
			(*UMF10.1.3*) then players may be enabled to test the chosen hypothesis about the hidden rules of newer and harder challenges.
	(*GF11*) Branching	(*UMC11.1*) If the rules of accessibility of pathways are revealed	(*UMF11.1.1*) then players may be enabled to formulate a set of hypotheses about the hidden rules of opening inaccessible pathways.
			(*UMF11.1.2*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of opening inaccessible pathways.
			(*UMF11.1.3*) then players may be enabled to test the chosen hypothesis about the hidden rules of opening inaccessible pathways.
		(*UMC11.2*) If the rules of safety of pathways are revealed	(*UMF11.2.1*) then players may be enabled to formulate a set of hypotheses about the hidden rules of the size of rewards.
			(*UMF11.2.2*) then players may be enabled to choose one from the set of hypotheses about the hidden rules of the size of rewards.
			(*UMF11.2.3*) then players may be enabled to test the chosen hypothesis about the hidden rules of the size of rewards.
	(*GF12*) Pace Breaking	(*UMC12.1*) If the presence of intensive audio and visual cues is revealed	(*UMF12.1.1*) then players may be enabled to perceive the hidden presence of an incoming difficult hazard.
			(*UMF12.1.2*) then players may be enabled to formulate a set of hypotheses about the hidden presence of an incoming difficult hazard.
			(*UMF12.1.3*) then players may be enabled to choose one from the set of hypotheses about the hidden presence of an incoming difficult hazard.

design to provide gameplay features that can be configured to promote both player engagement and cognitive CPS capabilities. Through the systematic review process, 12 such gameplay features were identified: "Emotional Experience", "Core schemas", "Entity", "Scenario", "Hierarchy of goals", "Challenge", "Guidance", "Safe Zone", "Foreshadowing", "Layering", "Branching", and "Pace Breaking". Additionally, descriptive and interpretative categories and items of these features' configurations and functions for promoting engagement in the gameplay process and the ability to engage in the the uncertainty management process were coded, extracted and presented in different tables (Table 7.5, Table 7.6, Table 7.7 and Table 7.8) in Section 7.3. In the following subsections, the implications of these results and the contribution, strengths and limitations of the study are discussed.

7.4.1 Implications for practice and research

Implications of the CPS-GFC guidelines

The key contribution of this study are the operational **CPS-GFC guidelines** (i.e., guidelines for configuring gameplay features to promote both player engagement and cognitive CPS capabilities) in Table 7.9.

Even though, as stated above, Table 7.5, Table 7.6, Table 7.7 and Table 7.8 present configurations and functions of gameplay features to promote player engagement and cognitive CPS capabilities, these tables have limited operational usefulness. This is because the tables (a) include gameplay features from different methodological frameworks using **different conceptualisations**, (b) provide **separately configured** gameplay features for player engagement and for cognitive CPS capabilities, (c) describe gameplay features with **overlapping configurations and functions**, and (d) present **descriptive and not prescriptive** information. Therefore, to formulate the findings of the systematic review method into operational guidelines for practitioners and researchers to use, the following modifications were made:

- Gameplay features, configurations and functions were rephrased based on the CPS-GBL theoretical framework (Section 2.3), the CPS-IF model (Section 4.2), the CPS-GBL model (Section 5.2) and the GEFF-CPSC model (Section 6.2) so that the CPS-GFC guidelines (Table 7.9) are internally consistent and are complementary to the other instruments produced by this thesis (i.e., (a) the CPS-IF instrument (i.e., instrument for information flows for complex problem-solving), (b) the CPS-GBL instrument (i.e., instrument for complex problem-solving and game-based learning processes), and (c) the GEFF-CPSC instrument (i.e., instrument for gameplay elements, features and functions promoting complex problem-solving conditions));

- Configurations of gameplay features for both player engagement and cognitive CPS capabilities were presented together in a more concise and clear manner;
- Gameplay features with overlapping configurations and functions were merged;
- Configurations were rephrased to provide prescriptive information and to serve as guidelines that can be followed.

This operationalisation of Table 7.5, Table 7.6, Table 7.7 and Table 7.8, resulted in 10 gameplay features (i.e., "Persistent game world", "Unexpected game events", "Unpredictable characters", "Game goals", "Guiding game environment", "Safe planning", "Prospective learning", "Unfamiliar challenges", "Risk-reward" and "Warning information flows"), each suggesting one configuration to promote player engagement and one configuration to promote cognitive CPS capabilities, presented as the CPS-GFC guidelines in Table 7.9.

Three gameplay features (i.e., "Persistent game world", "Unexpected game events" and "Unpredictable characters") can be configured to either conceal or reveal information because they were adapted from features (i.e., "Emotional Experience", "Core schemas", "Entity", "Scenario" and "Challenge") which can be configured to either increase or decrease uncertainty in a game (Table 7.6 and Table 7.7). Seven gameplay features (i.e., "Game goals", "Guiding game environment", "Safe planning", "Prospective learning", "Unfamiliar challenges", "Risk-reward" and "Warning information flows") can be configured to only reveal information because they were operationalised from features (i.e., "Hierarchy of goals", "Guidance", "Safe Zone", "Foreshadowing", "Layering", "Branching" and "Pace Breaking") which were interpreted as suitable to only decrease uncertainty in a game and thus to support the ability of players to engage in the uncertainty management process (Table 7.7 and Table 7.8).

Even though the CPS-GFC guidelines (Table 7.9) consist of 10 gameplay features that may be configured to reveal information to players and only three gameplay features that may be configured to conceal information from players, game researchers and practitioners can select and integrate, based on the needs of their projects, specific combinations of gameplay features that systemically generate complex scenarios in games by both increasing and decreasing uncertainty. This balance of simultaneously demanding and supporting engagement with the uncertainty management process, by increasing and decreasing uncertainty, is necessary for the development of cognitive CPS capabilities [15, 19]. Therefore, the systemtic relationships and dynamics between different gameplay features may require further investigation beyond the scope of this study.

In addition to the CPS-GFC guidelines which game experts can use to analyse and design games that are suitable to promote CPS skills and attitudes, this study provides four key insights, based on the results of the systematic review, that can be useful for future research.

Implications of the aspects of uncertainty management phenomena

The first significant observation was made concerning how the aspects (i.e. presence, causes, effects and rules, [67, 182, 183]) of uncertainty management phenomena affect different attributes or behaviours of the configured gameplay features. The specific observation is that players can hypothesise about one aspect of an uncertainty management phenomenon only based on information regarding the same aspect of another uncertainty management phenomenon. This point can be exemplified by using Table 7.8: "If the **rules** of accessibility of pathways are revealed, then players may be enabled to formulate a set of hypotheses about the hidden **rules** of opening inaccessible pathways". In this example, "accessibility of pathways" is one uncertainty management phenomenon (i.e., an attribute of the gameplay feature), while "opening inaccessible pathways" is another uncertainty management phenomenon (i.e., a behaviour of the gameplay feature). This pattern has been observed with each configured gameplay feature and it can be outlined the following way:

- If the **presence** of attribute A1 or behaviour B1 are revealed or concealed, then players may be enabled or required to engage in one of the four phases of the uncertainty management process regarding the **presence** of attribute A2 or behaviour B2.

Table 7.9 CPS-GFC guidelines

Gameplay feature	Configuration of gameplay feature to promote player engagement (PE) and cognitive CPS capabilities (CPS)
Persistent game world	(*PE*) Should provide display of the inventory, screenshots of significant events, signs of battles on the avatar, and persistent effects of player actions on the game world.
	(*CPS*) Should conceal or reveal the effects of changes in the inventory, to the state of the avatar, or in the persistent game world.
Unexpected game events	(*PE*) Should provide schemas that govern player interactions and unexpected game events.
	(*CPS*) Should conceal or reveal the causes and effects of the relationship between the unexpected local and global game events.
Unpredictable characters	(*PE*) Should provide reasonable, visible, consistent entities with unpredictable behaviours.
	(*CPS*) Should conceal or reveal the effects of unpredictable behaviours of entities.
Game goals	(*PE*) Should provide clear and explorable links in the nonlinear hierarchy of goals.
	(*CPS*) Should reveal the rules of exploring and backtracking.
Guiding game environment	(*PE*) Should provide a target direction based on the shape of levels, placement of collectibles, presence of enemies, and changes of environmental cues.
	(*CPS*) Should reveal the presence of collectibles, enemies, and environmental cues.
Safe planning	(*PE*) Should provide undisturbed time in an identifiable protection area based on the patterns of nearby hazards and enemies.
	(*CPS*) Should reveal the rules of undisturbed time in protection area.
Prospective learning	(*PE*) Should provide a game mechanic that, once learned, will be used in a future challenge.
	(*CPS*) Should reveal the rules of a learned game mechanic.
Unfamiliar challenges	(*PE*) Should provide new and harder challenges by combining familiar game elements in unfamiliar ways.
	(*CPS*) Should reveal the rules of familiar game elements.
Risk-reward	(*PE*) Should provide conditional access to safe pathways with small rewards and dangerous pathways with big rewards.
	(*CPS*) Should reveal the rules of accessibility and safety of pathways.
Warning information flows	(*PE*) Should provide an unavoidable hazard of obvious difficulty with accompanying audio and visual cues.
	(*CPS*) Should reveal the presence of intensive audio and visual cues.

- If the **causes** of attribute A1 or behaviour B1 are revealed or concealed, then players may be enabled or required to engage in one of the four phases of the uncertainty management process regarding the **causes** of attribute A2 or behaviour B2.

- If the **effects** of attribute A1 or behaviour B1 are revealed or concealed, then players may be enabled or required to engage in one of the four phases of the uncertainty management process regarding the **effects** of attribute A2 or behaviour B2.

- If the **rules** of attribute A1 or behaviour B1 are revealed or concealed, then players may be enabled or required to engage in one of the four phases of the uncertainty management process regarding the **rules** of attribute A2 or behaviour B2.

Therefore, the types of aspects of uncertainty management phenomena that are concealed or revealed are important for engaging players in appropriate and desirable phases of the uncertainty management process and for developing cognitive CPS capabilities. This articulation can provide game designers with knowledge about which specific aspect of the game they should adjust and how, to support players to engage in the uncertainty management process. For example, if the goal is to encourage players to hypothesise about the **rules** of an *unexpected weather event* (e.g., a hurricane) in a game, then providing them with information about the **rules** of a *different weather event* (e.g., a tornado) would be a suitable design choice.

The second significant observation that was made based on the results of the systematic review was also related to the aspects of uncertainty management phenomena. To be specific, it was ascertained that if a gameplay feature is configured to reveal one of the three aspects (i.e., causes, effects and rules, [67, 182, 183]) of an uncertainty management phenomenon, then players may be enabled to hypothesise about the other two aspects of the same uncertainty management phenomenon. For example: "If the **effects** of *unpredictable AI behaviours* are concealed, then players may be required to perceive the hidden **causes** and **rules** of the *unpredictable AI behaviours*". This pattern maps to key conceptualisations of the relationships between effects, causes and rules from the literature on abductive reasoning and uncertainty management [67, 182, 183]). This observation may support researchers and practitioners to analyse and design games suitable to engage players in the uncertainty management process and to promote cognitive CPS capabilities. For example, using the previously described game scenario, if the goal is to encourage players to hypothesise about the **rules** of an *unexpected weather event* (e.g., a hurricane) in a game, then providing them with information about the **causes** or **effects** of the *same weather event* would also be a suitable design choice.

Implications of the game (work) system elements

The third significant observation of this study is related to the categorisation (Table 7.4) of the gameplay features based on the adapted work system elements into game system elements (i.e., "Players", "Gameplay process", "Gameplay artifacts", "Gameplay schemas", "Gameplay context", and "Information flows") from Figure 7.1. Majority of identified gameplay features involve "Players", "Gameplay artifacts", "Gameplay schemas" and "Information flows" elements. These results are coherent with the study's conceptualisation of games as goal-directed work systems [2], consisting of gameplay features (i.e. game elements, their properties and interactions) ("**Gameplay artifacts**" and "**Gameplay schemas**") that can be configured to function in multiple ways to influence players' ("**Players**") pursuit of goals while making decisions based on a continuous assessment of the game state ("**Information flows**") [3, 38]. In contrast, excluded gameplay features often involved only one game element (i.e., gameplay features not being conceptualised as part of a system) and rarely involved "Gameplay schemas" or "Information flows" (i.e., dynamics, interactions and configurations not being part of the description of a gameplay feature and not being communicated to players).

Therefore, to be able to configure specific gameplay features in appropriate ways (e.g., for promoting player engagement or for promoting cognitive CPS capabilities), those gameplay features should be viewed as part of a game system and should refer to multiple elements of that game system (e.g., gameplay schemas and information flows). This insight may support researchers and practitioners to analyse and design gameplay features that are configured to function in different intended ways by focusing their attention on the dynamics and interactions within a game and on the information provided to players regarding those dynamics and interactions.

The fourth significant observation of the results of this study is the confirmed validity of WST [2] to classify gameplay features (Table 7.4). The adapted work system elements to gameplay system elements (Figure 7.1) were sufficient to classify all gameplay features as presented in Table 7.4. Because no additional theories or concepts were needed for this successful classification, Figure 7.1 can be used by researchers as a reference to analyse games and classify their gameplay features.

7.4.2 Strengths and limitations

The CPS-GFC guidelines were formulated by using a systematic review method [71] and by modifying the findings of the review (Table 7.5, Table 7.6, Table 7.7 and Table 7.8), as presented in Subsection 7.4.1. The strengths of this research approach for developing guidelines include:

- the systematic review method [71] that was based on a prospectively published protocol [119] and that represents the first review in the field of games studies that systematically analyses existing methodological frameworks of entertainment games for specific gameplay features that may promote both player engagement and cognitive CPS capabilities;
- the study selection criterion for the demonstrable impact of included articles that guaranteed that the game frameworks either advanced empirical studies or informed the formulation of other methodological papers;
- the comprehensive search strategy [117] and exhaustive selection process [115] involving relevant databases and reference lists [116, 118];
- the rigorous methodological approaches and techniques for data extraction [73–75], coding schema development [123–127], data synthesis [81], and their independent validation [79, 80];
- the sound theoretical underpinnings of the coding schema that provided formal methods for the analysis of gameplay features (i.e., WST [2], CWA framework [72], and CHC theory [67]).

The limitations of this study and relevant justifying and mitigating factors are described as follows.

The scope of this study was deliberately restricted to methodological frameworks for the analysis and design of entertainment games, because of the educational potentialities that entertainment games offer [55, 57, 184–186] and the lack of knowledge to exploit these potentialities [38, 110–114].

Another limitation of this study is the interpretative nature of the qualitative content analysis that introduces an element of subjectivity in the systematic review process. To mitigate reliability risks, rigorous data extraction and synthesis processes [73–75, 79–81, 123–127] were adopted.

7.5 Summary

This chapter presented a study aimed at addressing the lack of suitable research tools for identifying gameplay features that may promote both player engagement and cognitive CPS capabilities. This was achieved by developing the CPS-GFC guidelines (Table 7.9) through a systematic review method [71]. The systematic review of available methodological frameworks for the analysis and design of entertainment games was guided by the following research questions:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*
- *RQ4.2: How should gameplay features be configured to promote player engagement?*
- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

These research questions were addressed by synthesising, presenting and discussing extracted gameplay features, engagement configurations, engagement functions, uncertainty management configurations, and uncertainty management functions in tables in Section 7.3 (i.e., Table 7.4, Table 7.5, Table 7.6, Table 7.7 and Table 7.8). These tables were then operationalised, with the support of the CPS-IF model (Section 4.2), the CPS-GBL model (Section 5.2) and the GEFF-CPSC model (Section 6.2), to formulate the CPS-GFC guidelines (Table 7.9). The developed CPS-GFC guidelines can support game researchers and practitioners to analyse and design games that can simultaneously engage players in the gameplay process and support the ability to engage in the uncertainty management process (i.e., cognitive

CPS capabilities). Together with the CPS-GFC guidelines, the study discussed significant observations made based on the results of the systematic review related to aspects of the uncertainty management phenomena and to game (work) system elements that can have implications for future research. A summary of the results of this study and the previous studies and their implications for future work are provided in following Chapter 8.

Chapter 8

Conclusion

Countless complex systems around us generate environmental, social and economic phenomena that threaten human wellbeing [7–12]. These real-world complex problems are characterised by multiple interacting elements, uncertain system states, unpredictable emergent effects and uncontrollable system dynamics [6, 12, 13, 15, 18, 19]. Because it is necessary to learn to manage such complex problems, for decades, the international community has encouraged modern education to prioritise and promote CPS [9, 26, 29], i.e., the ability to achieve desirable state transformations in dynamically changing and uncertain environments while pursuing ill-defined goals [15, 31]. However, reductionist educational approaches to problem-solving in formal learning environments have been unsuitable to meet these needs for the development of CPS skills and attitudes [9, 15, 44].

During the search for new and suitable learning environments that can promote CPS capabilities [6, 32, 44, 48, 49], games have emerged as a promising alternative to traditional classrooms and virtual simulations [3, 33, 37], because of their ability through *gameplay learning* to (a) simulate real-world CPS dynamics in complex situations, (b) to promote intrinsically motivating CPS processes, and (c) to holistically engage learners in such CPS scenarios [3, 9, 15, 31–38]. This potential of games is yet to be fully realised, because existing research tools are inadequate to identify gameplay features that may engage players in both CPS and GBL processes that are intrinsically motivating and that result in the development of CPS skills and attitudes [33, 36, 41, 42]. Motivated by this research problem, the aim of this study was to develop a set of complementary tools that can support researchers and practitioners to analyse and design games that can promote CPS capabilities.

This chapter describes: (a) the research objectives that were formulated to achieve the stated aim, the related research questions that were answered and the involved methods and activities (Section 8.1); (b) the significance of the study consisting of its main contributions and implications for researchers and practitioners (Section 8.2); (c) the key limitations of the study (Section 8.3); and (d) suggestions for future research (Section 8.4).

8.1 Research Discussion

For the purposes of this study and based on a review of relevant concepts and theories from the literature, the CPS-GBL theoretical framework (i.e., theoretical framework for complex problem-solving processes within game-based learning environments) (Section 2.3) was formulated. The CPS-GBL theoretical framework integrated components of:

- the framework of activity theory-based gameplay system [3],
- CPS theory [6, 15, 31],
- constructivist learning [44, 50],
- the game-based learning human factors framework (HF-GBL framework) [9],
- the self-determination theory (SDT) [65],
- the Work System Theory (WST) [2],
- the Cattel-Horn-Carroll theory of cognitive capabilities (CHC theory) [67].

This integration was used to support the research objectives of this study.

8.1.1 Research Objective I

The first objective of this thesis was to address the specific research problem of lack of research tools that can support the identification of simulated gameplay aspects of real-world CPS scenarios and the properties and functionalities of gameplay information flows that may influence those aspects [41]. This objective was achieved by the development of the CPS-IF instrument (i.e., instrument for information flows for complex problem-solving) (Figure 4.6 and Figure 4.7), because its five scales and 34 items represent (a) simulated gameplay aspects of the game context, gameplay process and gameplay tasks, (b) general properties of gameplay information flows, and (c) the ways that information flows affect those gameplay aspects and the player. These instrument scales and items were generated based on the CPS-IF model (i.e., model of information flows for complex problem-solving) (Figure 4.1 and Figure 4.2), which conceptualised key CPS aspects of a gameplay activity system by combining appropriate components of the CPS-GBL theoretical framework (Section 2.3). The development process of CPS-IF instrument items and scales followed a rigorous instrument development method [68] that was guided by the following research questions:

- *RQ1.1: Which gameplay aspects should GBL environments simulate to foster CPS processes?*
- *RQ1.2: Which properties and functionalities of gameplay information flows may support the comprehension of and interactions with simulated gameplay aspects and how?*
- *RQ1.3: How do key properties and functionalities of gameplay information flows impact the thoughts, feelings and behaviours of players engaged in CPS and GBL processes?*

RQ1.1 was answered by Scale 1 ("Game Context Structure"), Scale 2 ("Gameplay Process"), Scale 3 ("Gameplay tasks") and their 25 instrument items (Figure 4.6 and Figure 4.7). *RQ1.2* was answered by Scale 4 ("Information Flows general properties"), its six instrument items and their relationships with Scale 1, Scale 2, Scale 3 and their 25 items (Figure 4.7). *RQ1.3* was answered by Scale 5 ("Player Impacts"), its three instrument items and their relationships with Scale 4 and its six items (Figure 4.7).

The research activities and methods involved in answering these research questions were: (a) development of the CPS-IF conceptual model (Figure 4.1 and Figure 4.2) [96, 98], (b) development of the CPS-IF instrument (Figure 4.6 and Figure 4.7) [68], and (c) exploratory testing of the instrument performed by three game analysis experts who used the game *Stop Disasters* [101].

8.1.2 Research Objective II

The second objective of this thesis was to address the need for suitable research tools that can support the identification of gameplay features (CPS-GBL affordances) that may promote intrinsically motivating CPS processes in GBL environments (i.e., (a) interacting with game setting elements mimicking real-world scenarios, (b) self-defining goals, (c) performing game actions mimicking real-world actions, (d) tackling events that could not be fully known, controlled or predicted, (e) evaluating and/or predicting consequences of game actions, and (f) evaluating and/or predicting consequences of events that could not be controlled) [36]. To achieve this objective, the CPS-GBL instrument (i.e., instrument for complex problem-solving and game-based learning processes) (Figure 5.6 and Figure 5.7) was developed. The 13 scales and 90 items of the instrument identify these CPS-GBL affordances and evaluate their effectiveness to both impact GBL processes and to promote intrinsically motivating CPS processes. These instrument scales and items were created based on the components and elements of the previously developed CPS-GBL conceptual model (i.e., model for complex problem-solving and game-based learning processes) (Figure 5.1) [96, 98], which was supported by integrating suitable theories and concepts from the CPS-GBL theoretical framework (Section 2.3) and the CPS-IF model (Figure 4.1 and Figure 4.2). This development process of the CPS-GBL instrument was driven by three research questions which were answered in the following way:

- "*RQ2.1: Which gameplay features may promote GBL processes and how effective are they?*" was answered by (a) the instrument items in Scale 1.1, Scale 2.1, Scale 3.1, Scale 4.1, Scale 5.1 and Scale 6.1, that identify CPS-GBL affordances that may impact the GBL process (Figure 5.6 and Figure 5.7); and (b) Figure **??** which presented the scores of the perceived effectiveness of CPS-GBL affordances to impact the GBL process in *Stop Disasters*;
- "*RQ2.2: Which gameplay features may promote intrinsic motivation and how effective are they?*" was answered by: (a) the instrument items in Scale 1.1,

Scale 2.1, Scale 3.1, Scale 4.1, Scale 5.1 and Scale 6.1, that identify CPS-GBL affordances that may promote intrinsically motivating CPS processes (Figure 5.6 and Figure 5.7); and (b) Figure **??** which reported the scores of the perceived effectiveness of CPS-GBL affordances to promote intrinsic motivation in *Stop Disasters*;

- "*RQ2.3: How do key properties and functionalities of gameplay information flows support gameplay features that may promote both GBL processes and intrinsic motivation?*" was answered by Scale 1.2, Scale 2.2, Scale 3.2, Scale 4.2, Scale 5.2 and Scale 6.2 which identify the properties and functionalities of gameplay information flows that support CPS-GBL affordances (Figure 5.6 and Figure 5.7).

The key research activities performed to answer these research questions and the relevant methods used were: (a) development of the CPS-GBL conceptual model (Figure 5.1) [96, 98], (b) development of the CPS-GBL instrument (Figure 5.6 and Figure 5.7) [68], and (c) exploratory evaluation of the instrument by 29 university game design students and one game expert, who all analysed the the game *Stop Disasters* [101].

8.1.3 Research Objective III

The third objective of this thesis was to address the need for research tools that can support the identification of gameplay features that may promote necessary cognitive CPS conditions and the identification of game elements that may promote those gameplay features. This objective was achieved by developing the GEFF-CPSC instrument (i.e., instrument for gameplay elements, features and functions promoting complex problem-solving conditions) which consisted of four scales and 130 items (Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7). The instrument scales and items were: (a) generated by following a rigorous instrument development process [68–70, 77, 78] that ensured the initial content validity of instrument items, construct validity of instrument scales, and reliability of the GEFF-CPSC instrument through assessment with reviewers and pre-testing with analysts; and (b) based on the developed GEFF-CPSC conceptual model (i.e., model of gameplay elements, features and functions promoting complex problem-solving conditions) (Figure 6.1) which was underpinned by complementing concepts and theories from the CPS-GBL theoretical framework (Section 2.3) and the CPS-GBL model (Section 5.2). This instrument development process was guided by three research questions which were addressed as follows:

- "*RQ3.1: Which gameplay features may promote necessary cognitive CPS conditions and how?*" was answered by Scale 3 of the GEFF-CPSC instrument (Figure 6.6) by identifying to what extent each of the six gameplay features (i.e., (a) “Self-define which goals to pursue”, (b) “Explore environments that mimic challenging scenarios impacting society”; (c) “Perform actions that mimic societally impactful activities”, (d) “Predict the consequences of player actions”, (e) “Adapt player plans to changes in the environment”, and (f) “Evaluate the outcomes of player actions”) may promote each of the four cognitive CPS conditions (i.e, (a) “Player ability in accepting and adapting to self-incompetence”, (b) “Player ability in anticipating and addressing important game challenges”, (c) “Player ability in mastering and performing repeated game actions without thinking”, and (d) “Player ability in developing and recalling correct mental representations of game objectives”);
- "*RQ3.2: Which gameplay elements support specific gameplay features that may promote necessary cognitive CPS conditions and how?*" and "*RQ3.3: How do key properties and functionalities of gameplay information flows support specific gameplay features that may promote necessary cognitive CPS conditions?*" were answered by Scale 4 of the GEFF-CPSC instrument (Figure 6.7) by identifying to what extent each of the 16 game elements (i.e., “Physical game setting”, “Historical game setting”, “Socio-cultural game setting”, “Game events”, “Game storyline”, “Player character role”, “Player character aims”, “Gameplay enablers”, “Gameplay enablers”, “Target objects transformable by players”, “Information flows provided from objects”, “Information flows provided from events”, “Clear provision of information flows”, “Timely provision of information flows”, “Close to source provision of information flows”, and “Recurring provision of information flows”) may promote each of the six gameplay features that were previously described.

The main research activities that were performed and methods that were used to answer these research questions were: (a) development of the GEFF-CPSC conceptual model (Figure 6.1) [96, 98], (b) development of the GEFF-CPSC instrument

(Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7) [68–70, 77, 78], and (c) reliability assessment of the instrument by conducting a pre-test [68–70, 77, 78] with two game analysts using the game *The Witness* [102].

8.1.4 Research Objective IV

The fourth objective of this thesis was to address the insufficiency of existing research tools to identify gameplay features that may promote both player engagement and cognitive CPS capabilities. This objective was achieved by using a systematic review method [71], which identified 12 such gameplay features (i.e., "Emotional Experience", "Core schemas", "Entity", "Scenario", "Hierarchy of goals", "Challenge", "Guidance", "Safe Zone", "Foreshadowing", "Layering", "Branching", and "Pace Breaking"), that were then operationalised, resulting in the development of the CPS-GFC guidelines (i.e., guidelines for complex problem-solving capabilities elicited and supported by configurations of gameplay features) (Table 7.9). The CPS-GFC guidelines (a) consist of 10 gameplay features (i.e., "Persistent game world", "Unexpected game events", "Unpredictable characters", "Game goals", "Guiding game environment", "Safe planning", "Prospective learning", "Unfamiliar challenges", "Risk-reward" and "Warning information flows") and (b) suggest ways that these 10 gameplay features can be configured to function to promote both player engagement and cognitive CPS capabilities (i.e., the ability to engage in phases of the uncertainty management process). To develop these guidelines, existing methodological frameworks for game analysis and design were systematically reviewed, guided by the following research questions:

- *RQ4.1: Which gameplay features are suitable to simultaneously promote player engagement and cognitive CPS capabilities?*
- *RQ4.2: How should gameplay features be configured to promote player engagement?*
- *RQ4.3: How should gameplay features be configured to promote cognitive CPS capabilities?*

RQ4.1 was answered by Table 7.4 which synthesised the 12 included gameplay features that may promote both player engagement and cognitive CPS capabilities.

RQ4.2 was answered by Table 7.5 which organised the configurations and functions of these features to promote player engagement. *RQ4.3* was answered by Table 7.6, Table 7.7 and Table 7.8 which presented the ways that the gameplay features can be configured to demand or support the ability to engage in phases of the uncertainty management process. Based on these synthesised tables the CPS-GFC guidelines were formulated.

In order to answer these research questions and to formulated the CPS-GFC guidelines, the following research activities were performed and methods were used: (a) a systematic review protocol was prospectively published in [119]; (b) a systematic review was conducted to analyse gameplay features in methodological frameworks based on the WST [2], the Cognitive Work Analysis framework (CWA) [72] and the CHC theory [67], through an inductive approach of qualitative content analysis [73], and by adopting template analysis techniques [74, 75]; and (c) the CPS-GFC guidelines were formulated by using a systematic review method [71] and by modifying the findings of the review.

8.2 Significance of the study

Based on the performed research activities, used methods, completed objectives and answered research questions, this study contributes to the research and practice of game design and analysis by providing suitable instruments for the identification of simulated gameplay aspects, gameplay information flows, gameplay features and game elements that can promote cognitive CPS conditions and capabilities and can make CPS processes in GBL environments intrinsically motivating to players. The main contributions of this thesis are presented as follows.

The main contributions of Study I (Chapter 4) are the CPS-IF instrument (Figure 4.6 and Figure 4.7) and the CPS-IF conceptual model (Figure 4.1 and Figure 4.2). Results from the development process of this instrument and model and from the exploratory testing of the instrument suggest that (a) the CPS-IF instrument can support game researchers and practitioners to identify simulated gameplay aspects of real-world CPS scenarios and properties and functionalities of gameplay information flows that communicate to players those gameplay aspects; (b) the CPS-IF model, as part of the CPS-GAME (i.e., Complex Problem-Solving in Games) conceptual framework that also includes the CPS-GBL model and the GEFF-CPSC model, may assist the development of new instruments and theories that are relevant for CPS processes in GBL environments. In addition, the results of this study confirmed the acknowledged importance of gameplay information flows to support player comprehension of gameplay elements and dynamics [3, 38].

The key contributions of Study II (Chapter 5) are the CPS-GBL instrument (Figure 5.6 and Figure 5.7) and the CPS-GBL conceptual model (Figure 5.1). The results from the development process and exploratory evaluation of the instrument indicate that the CPS-GBL instrument can be a practical tool for researchers and practitioners to identify gameplay features that may function to promote both GBL and CPS processes that are intrinsically motivating (i.e., CPS-GBL affordances) and to measure the effectiveness of these affordances. Furthermore, the CPS-GBL model, as part of the CPS-GAME conceptual framework that also includes the CPS-IF model and the GEFF-CPSC model, can be used by researchers to generate new tools and theories for the study of CPS processes in GBL environments. Finally, in consideration for practitioners that may use the CPS-GBL instrument, the results of the exploratory evaluation suggest that the most valuable use of the instrument could be analysing the impact of CPS-GBL affordances on the awareness, comprehension, caring and sense of agency of players.

The main contribution of Study III (Chapter 6) are the GEFF-CPSC instrument (Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7) and the GEFF-CPSC conceptual model (Figure 6.1). The results from the rigorous development process and reliability assessment of the instrument imply that the GEFF-CPSC instrument can be used by game researchers and practitioners to identify and match specific gameplay features of CPS scenarios to necessary cognitive CPS conditions in games. Additionally, the developed GEFF-CPSC conceptual model, as part of the CPS-GAME conceptual framework that also includes the CPS-IF model and the CPS-GBL model, may support the design of new research tools and the formulation of new theories related to CPS processes in GBL environments.

The key contribution of Study IV (Chapter 7) are the CPS-GFC guidelines (Table 7.9). The CPS-GFC guidelines can be used by researchers and practitioners to analyse and design gameplay features and their configurations that can be made so that those features may promote both player engagement and cognitive CPS capabilities. Besides the CPS-GFC guidelines, Study IV provides important observations related to the way aspects of the uncertainty management process (i.e.

presence, causes, effects and rules) may affect different attributes or behaviours of the configured gameplay features and different phases of the uncertainty management process (i.e., (a) perception, (b) hypotheses formulation, (c) hypothesis choice, and (d) hypothesis testing), which can influence the use of the proposed guidelines. Finally, the results from the systematic review confirmed the approach of this thesis for conceptualising games (i.e., games are goal-directed work systems, consisting of gameplay features that can be configured to function in multiple ways to influence the players' pursuit of goals while making decisions based on a continuous assessment of the game state) and the validity of WST to classify gameplay features.

8.3 Limitations of the study

The studies that produced the previously described contributions also have limitations. The scope of each study was intentionally limited to digital games for the purposes of this thesis, because of the ability of digital games to accurately simulate real-world CPS scenarios and to provide high-quality information flows to players [3, 9, 12, 36, 37, 39, 40].

Another limitation of all studies of this thesis was that each of them explored partial aspects and relationships of CPS processes in GBL environments (e.g., simulated gameplay aspects and their information flows were explored in one study; intrinsic motivation and GBL impacts were explored in another study; gameplay features promoting cognitive CPS conditions were explored in a third study; and configurations of gameplay features to promote cognitive CPS capabilities were explored in the final study). This was done for practical reasons, in order to conceptualise, operationalise and measure the specific aspects, relationships and effects of CPS processes in games. The limitation of this approach is that the developed instruments from each study can be valuable for their specifically designed purposes, but in order to tackle the multi-dimensional nature of CPS [42], using the instruments in complementary ways would be their most appropriate implementation.

A final shared limitation of all studies is the interpretative nature of the instrument development processes, the conceptualisation of models and the qualitative content analysis of the systematic review method. Risks involved with these processes and methods were mitigated by adopting rigorous approaches for instrument development based on conceptual models [68–70, 77, 78, 96, 98], and data extraction and synthesis [73–75, 79–81, 123–127].

In addition to these shared limitations each study has its own specific ones:

- The key limitations of Study I (Chapter 4) are: (a) the exploratory nature of the reliability test of the CPS-IF instrument, involving only three analysts and one selected game; and (b) studying information flows in isolation is insufficient for making conclusions about player engagement in CPS process.
- The main limitation of Study II (Chapter 5) is the exploratory evaluation of the instrument, involving small numbers of participants which produced results that are not statistically significant and are inconclusive for some instrument items.
- The key limitation of Study III (Chapter 6) is the pre-testing nature of the reliability assessment stage, which involved low number of analysts and one selected game.
- The main limitation of Study IV (Chapter 7) is restricting methodological frameworks for the analysis and design of only entertainment games due to their unexploited educational potentialities [55, 57, 184–186].

8.4 Suggestions for future research

Based on the described contributions and limitations of this study, the following directions for future research are discussed.

The preliminary validation tests and reliability assessments of the instruments were part of an initial stage of a multi-stage development process [68–70, 77, 78]. which will continue with future research that will (a) involve more reviewers and participants, (b) include more and diverse games for testing, (c) iteratively continue to improve the instruments based on the received feedback, and (d) integrate the instruments in order to test their complementary use to explore whether games presenting the identified features effectively promote CPS. These planned steps for the next stages of the development and validation processes of the instruments are expanded and detailed as follows:

- *Involving more reviewers and participants* - Following the pre-testing stage of the instruments and in order to further improve their reliability and validity [68–70, 77, 78], more game analysis and design experts who (a) are from the target population, and (b) are blind to the development of the instruments, will be invited to review the instrument items and scales.

- *Including and testing diverse games* - Additional games to the ones used in the initial stage of the development process of instruments (i.e., *Stop Disasters* [101] and *The Witness* [102]) will be selected and tested in the instrument application stage [68, 70]. For example, related works to wicked problem management [12] and adaptive problem-management [187] propose design guidelines for gameplay features that promote skills and attitudes which are relevant to CPS (e.g., adaptivity, systems thinking, abductive reasoning, social skill sets, etc.) by analysing and designing games of different genres (i.e., social adventure game, sandbox survival game, and collaborative augmented reality serious game). Other similar games that consist of gameplay features that may simulate complex scenarios and promote CPS processes (e.g. a changing game world, unpredictable game objects and agents, competing social interests, etc.) will be evaluated and used to iteratively improve the instruments.

- *Iteratively improving instruments* - Results from the exploratory testing of the CPS-IF instrument (Chapter 4), the exploratory evaluation of the CPS-GBL instrument (Chapter 5), the reliability assessment of the GEFF-CPSC instrument (Chapter 6), and the operationalisation of the CPS-GFC guidelines (Chapter 7) will be used to revise the CPS-IF model, the CPS-GBL model, the GEFF-CPSC model, and each of the contributing research tools of the study [68, 70]. For example, the CPS-GFC guidelines indicate the need to expand the category of gameplay features that increase uncertainty in games (i.e., gameplay features that can be configured to conceal information from players). This issue can be tackled by further iterating on and improving the CPS-IF model and the CPS-IF instrument because they conceptualise and support the identification of simulated gameplay aspects of real-world CPS scenarios which typically increase uncertainty.

- *Integrating and testing complementary use of instruments* - By inviting more reviewers, including new games, and iterating on the integration and improvement of instruments and models, then the reliability, validity and effectiveness of the CPS-IF instrument and model (Chapter 4), the CPS-GBL instrument and model (Chapter 5), the GEFF-CPSC instrument and model (Chapter 6), and the CPS-GFC guidelines (Chapter 7) can be examined through a confirmatory factor analysis [68, 70].

Based on the results of the studies, the following are worth investigating in the future: (a) the discrepancy between experts and novices when analysing CPS processes in GBL environments [41], (b) the cultural background of players which may impact the ways that they solve problems [15], (c) the suitability of following a value-added approach [188] for instrument development towards more conclusive results, (d) the configurations of gameplay features that can make them function as much-needed motivational affordances, and (e) the gameplay features of multiplayer games that may promote collaborative CPS skills and attitudes.

Finally, the one of the central perspectives of this study (i.e., to view games as dynamic systems, in which the configurations of one gameplay feature can affect the way other gameplay features function) may be adopted by research and practitioners to create more descriptively accurate and prescriptively useful tools for analysing and designing games.

8.5 Summary

Considering the importance of tools that can assist researchers and practitioners in analysing and designing games that may foster CPS skills and attitudes, this study aimed to develop suitable instruments for the identification of simulated gameplay aspects, gameplay information flows, gameplay features and game elements that can promote cognitive CPS conditions and capabilities and can make CPS processes in GBL environments intrinsically motivating to players.

This chapter concluded the study by highlighting the performed research activities, the used methods, the completed objectives and the answered research questions that were involved in achieving the stated aim. Specifically, based on the results of the study, the developed CPS-IF instrument and CPS-IF model, CPS-GBL instrument and CPS-GBL model, GEFF-CPSC instrument and GEFF-CPSC model, and CPS-GFC guidelines can be practical tools for game experts who are interested in

(a) identifying gameplay features in existing games that may promote CPS process, (b) designing new GBL environments that consist of simulated gameplay aspects of real-world CPS scenarios and related information flows, (c) creating new research tools for measuring effects of CPS-GBL processes, and (d) formulating new theories related to games as complex systems and suitable learning environments. In addition, the chapter included a summary of the limitations of the studies that produced these instruments and models.

Finally, based on the reported limitations, directions for future work were discussed as a conclusion to this thesis and as a guide for the next steps on the path towards effectively analysing and designing games that may promote CPS capabilities through GBL.

References

[1] Mark Saunders, Philip Lewis, and Adrian Thornhill. Research methods for business students eight edition. *QualitativeMarket Research: An International Journal*, 2019.

[2] Steven Alter. Work system theory: overview of core concepts, extensions, and challenges for the future. *Journal of the Association for Information Systems*, page 72, 2013.

[3] Carlo Fabricatore. *Underneath and beyond mechanics: An activity-theoretical perspective on meaning-making in gameplay*. Columbia University Press, United States, December 2018.

[4] Dimitar Gyaurov, Carlo Fabricatore, and Andrea Bottino. Development of an instrument to analyse gameplay features promoting complex problem-solving conditions. In *European Conference on Games Based Learning*, pages 296–XVI. Academic Conferences International Limited, 2021.

[5] Dimitar Gyaurov, Carlo Fabricatore, and Ximena Lopez. Cps-gbl framework to evaluate game systems promoting intrinsically-motivating complex problem-solving processes. In *ECGBL 2020 14th European Conference on Game-Based Learning*, page 220. Academic Conferences limited, 2020.

[6] Dietrich Dörner and Alex J Wearing. Complex problem solving: Toward a (computersimulated) theory. *Complex problem solving: The European perspective*, pages 65–99, 1995.

[7] Crawford S. Holling. Understanding the complexity of economic, ecological, and social systems. *Ecosystems*, 4:390–405, 2001.

[8] John D. Sterman. System dynamics modeling: Tools for learning in a complex world. *California Management Review*, 43(4):8–25, 2001.

[9] Carlo Fabricatore and Maria Ximena Lopez. Game-based learning as a meaning making-driven activity process: a human factors perspective. In *ECGBL 2019 13th European Conference on Game-Based Learning*, page 218. Academic Conferences and publishing limited, 2019.

[10] Tim Jackson. Prosperity without growth?: The transition to a sustainable economy. 2009.

[11] Klaus Schwab. *The fourth industrial revolution*. Currency, 2017.

[12] Carlo Fabricatore, Dimitar Gyaurov, and Ximena Lopez. Rethinking serious games design in the age of covid-19: Setting the focus on wicked problems. In *Joint International Conference on Serious Games*, pages 243–259. Springer, 2020.

[13] Sholom Glouberman, Brenda Zimmerman, et al. Complicated and complex systems: what would successful reform of medicare look like? 2002.

[14] Franciszek Grabowski and Dominik Strzalka. Simple, complicated and complex systems – the brief introduction. In *2008 Conference on Human System Interactions*, pages 570–573, 2008.

[15] Dietrich Dörner and Joachim Funke. Complex problem solving: What it is and what it is not. *Frontiers in psychology*, 8:1153, 2017.

[16] Carlo Fabricatore, Ximena López, Carlo Fabricatore, and In C Busch. A model to identify affordances for game-based sustainability learning. In *Proceedings of the 8th European Conference on Games Based Learning (ECGBL 2014)*, volume 1, pages 99–109, 2014.

[17] Karl Duncker and Lynne S Lees. On problem-solving. *Psychological monographs*, 58(5):i, 1945.

[18] Joachim Funke. Complex problem solving. *Encyclopedia of the Sciences of Learning (682-685). Heidelberg: Springer*, 2012.

[19] Andreas Fischer, Samuel Greiff, and Joachim Funke. The process of solving complex problems. *Journal of Problem Solving*, 4(1):19–42, 2011.

[20] Jianguo Liu, Harold Mooney, Vanessa Hull, Steven J Davis, Joanne Gaskell, Thomas Hertel, Jane Lubchenco, Karen C Seto, Peter Gleick, Claire Kremen, et al. Systems integration for global sustainability. *Science*, 347(6225):1258832, 2015.

[21] Ville-Pekka Niskanen, Mikko Rask, and Harri Raisio. Wicked problems in africa: A systematic literature review. *SAGE Open*, 11(3):21582440211032163, 2021.

[22] Kaare Christensen, Gabriele Doblhammer, Roland Rau, and James W Vaupel. Ageing populations: the challenges ahead. *The lancet*, 374(9696):1196–1208, 2009.

[23] Wan He, Daniel Goodkind, Paul R Kowal, et al. An aging world: 2015, 2016.

[24] Sylvie Corbet and Elaine Ganley. "france's macro risks his government to raise retirement age.", 17 March 2023.

[25] Warren Weaver. Science and complexity. *American scientist*, 36(4):536–544, 1948.

[26] Hasan Ozbekhan, E Jantsch, and AN Christakis. The predicament of mankind: A quest for structured responses to growing world-wide complexities and uncertainties. *Proposal to the Club of Rome*, 1970.

[27] ODDS Cf. Transforming our world: the 2030 agenda for sustainable development. *United Nations: New York, NY, USA*, 2015.

[28] Jerome C Glenn, Elizabeth Florescu, Millennium Project Team, et al. Sof2017-download-full. 2017.

[29] Gillian Bowser, Ulrike Gretzel, Elizabeth Davis, and Mark Brown. Educating the future of sustainability. *Sustainability*, 6(2):692–701, 2014.

[30] Carlo Fabricatore and Ximena López. Education in a complex world: nurturing chaordic agency through game design. In *Seeking Understanding*, pages 325–353. Brill, 2019.

[31] Peter A Frensch and Joachim Funke. *Definitions, traditions, and a general framework for understanding complex problem solving*. Universitätsbibliothek der Universität Heidelberg, 1995.

[32] John D Sterman. Learning in and about complex systems. *System dynamics review*, 10(2-3):291–330, 1994.

[33] Deniz Eseryel, Victor Law, Dirk Ifenthaler, Xun Ge, and Raymond Miller. An investigation of the interrelationships between motivation, engagement, and complex problem solving in game-based learning. *Journal of Educational Technology & Society*, 17(1):42–53, 2014.

[34] Yona Sipos, Bryce Battisti, and Kurt Grimm. Achieving transformative sustainability learning: engaging head, hands and heart. *International journal of sustainability in higher education*, 9(1):68–86, 2008.

[35] Nicola Whitton. *Digital games and learning: Research and theory*. Routledge, 2014.

[36] Alysson Diniz dos Santos, Francesco Strada, and Andrea Bottino. Approaching sustainability learning via digital serious games. *IEEE Transactions on Learning Technologies*, 12(3):303–320, 2018.

[37] Lloyd P Rieber. Seriously considering play: Designing interactive learning environments based on the blending of microworlds, simulations, and games. *Educational technology research and development*, 44(2):43–58, 1996.

[38] Carlo Fabricatore, Dimitar Gyaurov, and Ximena Lopez. An exploratory study of the relationship between meaning-making and quality in games. *Multimedia Tools and Applications*, 78(10):13539–13564, 2019.

[39] Elizabeth A Boyle, Thomas Hainey, Thomas M Connolly, Grant Gray, Jeffrey Earp, Michela Ott, Theodore Lim, Manuel Ninaus, Claudia Ribeiro, and João Pereira. An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, 94:178–192, 2016.

[40] Thomas M Connolly, Elizabeth A Boyle, Ewan MacArthur, Thomas Hainey, and James M Boyle. A systematic literature review of empirical evidence on computer games and serious games. *Computers & education*, 59(2):661–686, 2012.

[41] Samuel Greiff, Andreas Fischer, Matthias Stadler, and Sascha Wüstenberg. Assessing complex problem-solving skills with multiple complex systems. *Thinking & Reasoning*, 21(3):356–382, 2015.

[42] Joachim Funke, Andreas Fischer, and Daniel V Holt. Competencies for complexity: problem solving in the twenty-first century. In *Assessment and teaching of 21st century skills*, pages 41–53. Springer, 2018.

[43] Allen Newell, Herbert Alexander Simon, et al. *Human problem solving*, volume 104. Prentice-hall Englewood Cliffs, NJ, 1972.

[44] David H Jonassen and Lucia Rohrer-Murphy. Activity theory as a framework for designing constructivist learning environments. *Educational technology research and development*, 47(1):61–79, 1999.

[45] Andreas Fischer, Samuel Greiff, and Joachim Funke. The history of complex problem solving. 2017.

[46] Cathy Mae Toquero. Challenges and opportunities for higher education amid the covid-19 pandemic: The philippine context. *Pedagogical Research*, 5(4), 2020.

[47] Maureen Tam. Constructivism, instructional design, and technology: Implications for transforming distance learning. *Journal of Educational Technology & Society*, 3(2):50–60, 2000.

[48] David H Jonassen. Toward a design theory of problem solving. *Educational technology research and development*, 48(4):63–85, 2000.

[49] David H Jonassen. Thinking technology: Toward a constructivist design model. *Educational technology*, 34(4):34–37, 1994.

[50] Peter C Honebein. Seven goals for the design of constructivist learning environments. *Constructivist learning environments: Case studies in instructional design*, pages 11–24, 1996.

[51] David H Jonassen. Learning as activity. *Educational technology*, 42(2):45–51, 2002.

[52] D Schon. The reflective practitioner (new york, basic books). *Schon, The Reflective Practitioner, 1983*, 1983.

[53] James Paul Gee. What video games have to teach us about learning and literacy. *Computers in entertainment (CIE)*, 1(1):20–20, 2003.

[54] Mike Hobbs, Elaine Brown, and Marie Gordon. Using a virtual world for transferable skills in gaming education. *Innovation in teaching and learning in information and computer sciences*, 5(3):1–13, 2006.

[55] Katie Larsen McClarty, Aline Orr, Peter M Frey, Robert P Dolan, Victoria Vassileva, and Aaron McVay. A literature review of gaming in education. *Gaming in education*, pages 1–35, 2012.

[56] Isabela Granic, Adam Lobel, and Rutger CME Engels. The benefits of playing video games. *American psychologist*, 69(1):66, 2014.

[57] Douglas B Clark, Emily E Tanner-Smith, and Stephen S Killingsworth. Digital games, design, and learning: A systematic review and meta-analysis. *Review of educational research*, 86(1):79–122, 2016.

[58] Carlo Fabricatore. Learning and videogames: an unexploited synergy. pages 1–17, 2000. Paper presented at the workshop *In Search of the Meaning of Learning*, conducted at the *Annual Convention of the Association for Educational Communications and Technology (AECT)*, Long beach, California, February 17, 2000.

[59] Marc Prensky. The motivation of gameplay: The real twenty-first century learning revolution. *On the horizon*, 2002.

[60] Alice Mitchell and Carol Savill-Smith. The use of computer and video games for learning. *A review of the literature*, 2004.

[61] Simon Egenfeldt-Nielsen. Overview of research on the educational use of video games. *Nordic Journal of Digital Literacy*, 1(3):184–214, 2006.

[62] Jean-Nicolas Proulx, Margarida Romero, and Sylvester Arnab. Learning mechanics and game mechanics under the perspective of self-determination theory to foster motivation in digital game based learning. *Simulation & Gaming*, 48(1):81–97, 2017.

[63] Robin Hunicke, Marc Leblanc, and Robert Zubek. Mda: A formal approach to game design and game research. volume WS-04-04, 2004.

[64] Penelope Sweetser, Daniel Johnson, Peta Wyeth, Aiman Anwar, Yan Meng, and Anne Ozdowska. Gameflow in different game genres and platforms. *Computers in Entertainment (CIE)*, 15(3):1–24, 2017.

[65] Richard M. Ryan, C. Scott Rigby, and Andrew Przybylski. The motivational pull of video games: A self-determination theory approach. *Motivation and Emotion*, 30, 2006.

[66] Sebastian Deterding. The lens of intrinsic skill atoms: A method for gameful design. *Human–Computer Interaction*, 30(3-4):294–335, 2015.

[67] W. Joel Schneider and Kevin S. McGrew. The Cattell–Horn–Carroll theory of cognitive abilities. In Dawn P. Flanagan and Erin M. McDonough, editors, *Contemporary intellectual assessment: Theories, tests, and issues*, pages 73–163. Guilford Press, New York, NY, 4th edition, 2018.

[68] Gary C Moore and Izak Benbasat. Development of an instrument to measure the perceptions of adopting an information technology innovation. *Information systems research*, 2(3):192–222, 1991.

[69] Alice E Davis. Instrument development: getting started. *Journal of Neuroscience Nursing*, 28(3):204–208, 1996.

[70] Sarah Zelt, Jan Recker, Theresa Schmiedel, and Jan Vom Brocke. Development and validation of an instrument to measure and manage organizational process variety. *PloS one*, 13(10):e0206198, 2018.

[71] Hannah Snyder. Literature review as a research methodology: An overview and guidelines. *Journal of business research*, 104:333–339, 2019.

[72] Emilie Roth and Ann Bisantz. Cognitive work analysis. In John D. Lee and Alex Kirlik, editors, *The Oxford handbook of cognitive engineering*, pages 240–260. Oxford University Press, New York, NY, 2013.

[73] Hsiu Fang Hsieh and Sarah E. Shannon. Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9):1277–1288, 2005.

[74] Nigel King. Template analysis. 1998.

[75] Nigel King. Doing template analysis. *Qualitative organizational research: Core methods and current challenges*, 426:77–101, 2012.

[76] David JA Edwards. Types of case study work: A conceptual framework for case-based research. *Journal of humanistic psychology*, 38(3):36–70, 1998.

[77] Gordon B Willis and Judith T Lessler. Question appraisal system qas-99. *National Cancer Institute*, 1999.

[78] Jennifer Rothgeb, Gordon Willis, and Barbara Forsyth. Questionnaire pretesting methods: Do different techniques and different organizations produce similar results? *Bulletin of Sociological Methodology/Bulletin de Méthodologie Sociologique*, 96(1):5–31, 2007.

[79] R. S. Barbour. Checklists for improving rigour in qualitative research: A case of the tail wagging the dog? *British Medical Journal*, 322(7294):1115–1117, 2001.

[80] Lynda Berends and Jennifer Johnston. Using multiple coders to enhance qualitative analysis: The case of interviews with consumers of drug treatment. *Addiction Research and Theory*, 13(4):373–381, 2005.

[81] David R Thomas. A general inductive approach for analyzing qualitative evaluation data. *American journal of evaluation*, 27(2):237–246, 2006.

[82] David Farrell and David Moffat. Applying the self determination theory of motivation in games based learning. In *European conference on games based learning*, volume 1, page 118. Academic Conferences International Limited, 2014.

[83] Jose Quesada*, Walter Kintsch, and Emilio Gomez. Complex problem-solving: a field in search of a definition? *Theoretical issues in ergonomics science*, 6(1):5–33, 2005.

[84] Mark Guzdial, J Kolodner, Cindy Hmelo, Hari Narayanan, David Carlson, Noel Rappin, Roland Hübscher, Jennifer Turns, and Wendy Newstetter. Computer support for learning through complex problem solving. *Communications of the ACM*, 39(4):43–45, 1996.

[85] Michael Engelhart, Joachim Funke, and Sebastian Sager. A web-based feedback study on optimization-based training and analysis of human decision making. *Journal of Dynamic Decision Making*, 3:2–2, 2017.

[86] Tammi Sinha, Susanne Clarke, and Lois Farquharson. Shrek, saunders and the onion myth: Using myths, metaphors and storytelling. In *Proceedings of the 17th European Conference on Research Methodology for Business and Management Studies*, page 366, 2018.

[87] Ryan Alturki. Research onion for smart iot-enabled mobile applications. *Scientific Programming*, 2021:1–9, 2021.

[88] Mohammadreza Zolfagharian, Bob Walrave, Rob Raven, and A Georges L Romme. Studying transitions: Past, present, and future. *Research Policy*, 48(9):103788, 2019.

[89] Salim Musabah Bakhit Al-Zefeiti and Noor Azmi Mohammad. Methodological considerations in studying transformational leadership and its outcomes. *International Journal of Engineering Business Management*, 7(Godište 2015):7–10, 2015.

[90] John R Venable. Incorporating design science research and critical research into an introductory business research methods course. *Electronic Journal of Business Research Methods*, 9(2):pp119–129, 2011.

[91] Aleksandras Melnikovas. Towards an explicit research methodology: Adapting research onion model for futures studies. *Journal of futures Studies*, 23(2):29–44, 2018.

[92] Peter Dalsgaard. Pragmatism and design thinking. *International Journal of design*, 8(1), 2014.

[93] Peter Dalsgaard. Instruments of inquiry: Understanding the nature and role of tools in design. *International Journal of Design*, 11(1), 2017.

[94] Anna Dubois and Lars-Erik Gadde. Systematic combining: an abductive approach to case research. *Journal of business research*, 55(7):553–560, 2002.

[95] John W Creswell and J David Creswell. *Research design: Qualitative, quantitative, and mixed methods approaches*. Sage publications, 2017.

[96] Yosef Jabareen. Building a conceptual framework: philosophy, definitions, and procedure. *International journal of qualitative methods*, 8(4):49–62, 2009.

[97] Susan A Lynham. The general method of theory-building research in applied disciplines. *Advances in developing human resources*, 4(3):221–241, 2002.

[98] Jack Meredith. Theory building through conceptual methods. *International Journal of Operations & Production Management*, 13(5):3–11, 1993.

[99] Kathleen M Eisenhardt. Building theories from case study research. *Academy of management review*, 14(4):532–550, 1989.

[100] Victor P Seidel and Sebastian K Fixson. Adopting design thinking in novice multidisciplinary teams: The application and limits of design methods and reflexive practices. *Journal of Product Innovation Management*, 30:19–33, 2013.

[101] Stop Disasters (2007). United Nations Office for Disaster Risk Reduction.

[102] The Witness (2016). Thekla Inc.

[103] Dimitar Gyaurov, Carlo Fabricatore, and Ximena Lopez. An analysis instrument for gameplay information flows supporting sustainability complex problem-solving. In *13th European Conference on Games Based Learning*, pages 863–871. Academic Conferences and Publishing International, 2019.

[104] Domenic V Cicchetti. Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology. *Psychological assessment*, 6(4):284, 1994.

[105] James J Gibson. The theory of affordances. *Perceiving, acting, and knowing. Toward an an ecological psychology*, pages 67–82, 1977.

[106] Miguel Sicart. Defining game mechanics. *Game Studies*, 8(2):1–14, 2008.

[107] Bjarke Alexander Larsen and Henrik Schoenau-Fog. The narrative quality of game mechanics. In *International Conference on Interactive Digital Storytelling*, pages 61–72. Springer, 2016.

[108] Regina Bernhaupt. User experience evaluation in entertainment. In *Evaluating user experience in games*, pages 3–7. Springer, 2010.

[109] Thomas J D'zurilla and Marvin R Goldfried. Problem solving and behavior modification. *Journal of abnormal psychology*, 78(1):107, 1971.

[110] Katharine Neil. Game design tools: Time to evaluate. *Proceedings of 2012 DiGRA Nordic*, 2012.

[111] Loïc Caroux, Katherine Isbister, Ludovic Le Bigot, and Nicolas Vibert. Player–video game interaction: A systematic review of current concepts. *Computers in Human Behavior*, 48:366–381, 2015.

[112] Gabriel C Natucci and Marcos AF Borges. The experience, dynamics and artifacts framework: Towards a holistic model for designing serious and entertainment games. In *2021 IEEE Conference on Games (CoG)*, pages 1–8. IEEE, 2021.

[113] Rabail Tahir and Alf Inge Wang. Insights into design of educational games: Comparative analysis of design models. In *Proceedings of the Future Technologies Conference*, pages 1041–1061. Springer, 2018.

[114] Pedro Pinto Neves and Nelson Zagalo. Game design as an autonomous research subject. *Information*, 12(9):367, 2021.

[115] Matthew J Page, Joanne E McKenzie, Patrick M Bossuyt, Isabelle Boutron, Tammy C Hoffmann, Cynthia D Mulrow, Larissa Shamseer, Jennifer M Tetzlaff, Elie A Akl, Sue E Brennan, et al. The prisma 2020 statement: an updated guideline for reporting systematic reviews. *International Journal of Surgery*, 88:105906, 2021.

[116] Tanya Horsley, Orvie Dingwall, and Margaret Sampson. Checking reference lists to find additional studies for systematic reviews. *Cochrane Database of Systematic Reviews*, (8), 2011.

[117] Craig Lockwood, K Porrit, Zachary Munn, Leslie Rittenmeyer, Susan Salmond, Merete Bjerrum, Heather Loveday, Judith Carrier, Daphne Stannard, et al. Systematic reviews of qualitative evidence. *Joanna Briggs Institute reviewer's manual [Internet]. Adelaide: The Joanna Briggs Institute*, 2017.

[118] David Moher, Larissa Shamseer, Mike Clarke, Davina Ghersi, Alessandro Liberati, Mark Petticrew, Paul Shekelle, and Lesley A Stewart. Preferred reporting items for systematic review and meta-analysis protocols (prisma-p) 2015 statement. *Systematic reviews*, 4(1):1–9, 2015.

[119] Dimitar Gyaurov, Carlo Fabricatore, and Andrea Bottino. Features of entertainment digital games for learning and developing complex problem-solving skills: A protocol for a systemic review. *International Journal of Qualitative Methods*, 21:16094069221128491, 2022.

[120] Penelope Sweetser and Peta Wyeth. Gameflow: A model for evaluating player enjoyment in games. *ACM Computers in Entertainment*, 3, 2005.

[121] Penny de Byl. A conceptual affective design framework for the use of emotions in computer game design. *Cyberpsychology*, 9, 2015.

[122] Corporation for Digital Scholarship (2022). Zotero 6.0.9 [computer software].

[123] William D Perreault Jr and Laurence E Leigh. Reliability of nominal data based on qualitative judgments. *Journal of marketing research*, 26(2):135–148, 1989.

[124] Andrew K Shenton. Strategies for ensuring trustworthiness in qualitative research projects. *Education for information*, 22(2):63–75, 2004.

[125] Flora Cornish, Alex Gillespie, and Tania Zittoun. Collaborative analysis of qualitative data. *The SAGE handbook of qualitative data analysis*, 79:93, 2013.

[126] Michael Quinn Patton. *Qualitative research & evaluation methods: Integrating theory and practice*. Sage publications, 2014.

[127] K Andrew R Richards and Michael A Hemphill. A practical guide to collaborative qualitative data analysis. *Journal of Teaching in Physical Education*, 37(2):225–231, 2018.

[128] Brigid Costello and Ernest Edmonds. A tool for characterizing the experience of play. 2009.

[129] Roger Caillois. *Man, play, and games*. University of Illinois press, 2001.

[130] Karl Groos. *The play of man*. Appleton, 1901.

[131] Brigid Costello and Ernest Edmonds. A study in play, pleasure and interaction design. In *Proceedings of the 2007 conference on Designing pleasurable products and interfaces*, pages 76–91, 2007.

[132] Luis Lucas Pereira and Licínio Roque. Towards a game experience design model centered on participation. 2012.

[133] Rosalind W Picard. Affective computing for hci. In *HCI (1)*, pages 829–833. Citeseer, 1999.

[134] Yoones A Sekhavat, Milad Jafari Sisi, and Samad Roohi. Affective interaction: Using emotions as a user interface in games. *Multimedia Tools and Applications*, 80:5225–5253, 2021.

[135] Heather Desurvire and Charlotte Wiberg. Game usability heuristics (play) for evaluating and designing better games: The next iteration. volume 5621 LNCS, 2009.

[136] Heather Desurvire, Martin Caplan, and Jozsef A. Toth. Using heuristics to evaluate the playability of games. 2004.

[137] Mikki H Phan, Joseph R Keebler, and Barbara S Chaparro. The development and validation of the game user experience satisfaction scale (guess). *Human factors*, 58(8):1217–1247, 2016.

[138] Roberto Dillon. The 6-11 framework: A new methodology for game analysis and design. 2011.

[139] Robert Plutchik. A general psychoevolutionary theory of emotion. In *Theories of emotion*, pages 3–33. Elsevier, 1980.

[140] Frieska Angelia et al. Improving english learning through game using 6–11 mda framework. In *2019 12th International Conference on Information & Communication Technology and System (ICTS)*, pages 21–26. IEEE, 2019.

[141] Laura Ermi and Frans Mäyrä. Fundamental components of the gameplay experience: Analysing immersion. 2005.

[142] Mingmin Zhang, Mingliang Xu, Lizhen Han, Yong Liu, Pei Lv, and Gaoqi He. Virtual network marathon with immersion, scientificalness, competitiveness, adaptability and learning. *Computers & Graphics*, 36(3):185–192, 2012.

[143] Cesar Lucho Lingan, Meng Li, and Arnold POS Vermeeren. The immersion cycle: Understanding immersive experiences through a cyclical model. *Proceedings of the Design Society*, 1:3011–3020, 2021.

[144] Carlo Fabricatore. Gameplay and game mechanics: a key to quality in videogames. 2007.

[145] Pejman Sajjadi, Joachim Vlieghe, and Olga De Troyer. Evidence-based mapping between the theory of multiple intelligences and game mechanics for the purpose of player-centered serious game design. In *2016 8th International Conference on Games and Virtual Worlds for Serious Applications (VS-GAMES)*, pages 1–8. IEEE, 2016.

[146] Gregory Z Bedny, Waldemar Karwowski, and One-Jang Jeng. The situational reflection of reality in activity theory and the concept of situation awareness in cognitive psychology. *Theoretical Issues in Ergonomics Science*, 5(4):275–296, 2004.

[147] Gregory Bedny and Waldemar Karwowski. *A systemic-structural theory of activity: Applications to human performance and work design*. CRC press, 2006.

[148] Yrjö Engeström. Learning by expanding: An activity-theoretical approach to developmental research. *Orienta konsultit, Helsinki, FI.*, 1987.

[149] Victor Kaptelinin and Bonnie A Nardi. *Acting with technology: Activity theory and interaction design*. MIT press, 2006.

[150] Aleksei Leontiev. Activity, consciousness, and personality. *Englewood Cliffs, NJ: Prentice Hall.*, 1978.

[151] Carlo Fabricatore, Miguel Nussbaum, and Ricardo Rosas. Playability in action videogames: A qualitative design model. *Human-Computer Interaction*, 17:311–368, 12 2002.

[152] John Harris, Mark Hancock, and Stacey D. Scott. Leveraging asymmetries in multiplayer games: Investigating design elements of interdependent play. 2016.

[153] Kaitlyn M Ouverson and Stephen B Gilbert. A composite framework of co-located asymmetric virtual reality. *Proceedings of the ACM on Human-Computer Interaction*, 5(CSCW1):1–20, 2021.

[154] Christina Hochleitner, Wolfgang Hochleitner, Cornelia Graf, and Manfred Tscheligi. A heuristic framework for evaluating user experience in games. 2015.

[155] Christina Koeffel, Wolfgang Hochleitner, Jakob Leitner, Michael Haller, Arjan Geven, and Manfred Tscheligi. Using heuristics to evaluate the overall user experience of video games and advanced interaction games. *Evaluating user experience in games: Concepts and Methods*, pages 233–256, 2010.

[156] Francisco Regalado, Tânia Ribeiro, and Ana Isabel Veloso. Fez game–an heuristic evaluation.

[157] Gede Putra Kusuma, Evan Kristia Wigati, Yesun Utomo, and Louis Khrisna Putera Suryapranata. Analysis of gamification models in education using mda framework. *Procedia Computer Science*, 135:385–392, 2018.

[158] Brian M Winn. The design, play, and experience framework. In *Handbook of research on effective electronic gaming in education*, pages 1010–1024. IGI Global, 2009.

[159] Ahmed Khalifa, Fernando De Mesentier Silva, and Julian Togelius. Level design patterns in 2d games. volume 2019-August, 2019.

[160] Anirudh Ganesh, Chinenye Ndulue, and Rita Orji. Permarun-a persuasive game to improve user awareness and self-efficacy towards secure smartphone behaviour. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*, pages 1–7, 2021.

[161] Nick Yee. Motivations for play in online games. volume 9, 2006.

[162] Richard Bartle. Hearts, clubs, diamonds, spades: Players who suit muds. *Journal of MUD research*, 1(1):19, 1996.

[163] Nicole Lazzaro. Why we play: affect and the fun of games. *Human-computer interaction: Designing for diverse users and domains*, 155:679–700, 2009.

[164] Luís Lucas Pereira, Rui Craveirinha, and Licinio Roque. A canvas for participation-centered game design. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, pages 521–532, 2019.

[165] Paul Ralph and Kafui Monu. Toward a unified theory of digital games. *The Computer Games Journal*, 4, 2015.

[166] Jesse Schell. *The Art of Game Design: A book of lenses*. CRC press, 2008.

[167] Richard M Ryan and Edward L Deci. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American psychologist*, 55(1):68, 2000.

[168] Andrew K Przybylski, C Scott Rigby, and Richard M Ryan. A motivational model of video game engagement. *Review of general psychology*, 14(2):154–166, 2010.

[169] M Csikszentmihalyi. Flow. the psychology of optimal experience. new york (harperperennial) 1990. 1990.

[170] Kalle Jegers. Pervasive game flow: understanding player enjoyment in pervasive gaming. *Computers in Entertainment (CIE)*, 5(1):9–es, 2007.

[171] Gustavo F. Tondello, Rina R. Wehbe, Rita Orji, Giovanni Ribeiro, and Lennart E. Nacke. A framework and taxonomy of videogame playing preferences. 2017.

[172] Gustavo F Tondello and Lennart E Nacke. Player characteristics and video game preferences. In *Proceedings of the Annual Symposium on Computer-Human Interaction in Play*, pages 365–378, 2019.

[173] Gustavo F Tondello, Karina Arrambide, Giovanni Ribeiro, Andrew Jian-lan Cen, and Lennart E Nacke. “i don’t fit into a single type”: A trait model and scale of game playing preferences. In *Human-Computer Interaction–INTERACT 2019: 17th IFIP TC 13 International Conference, Paphos, Cyprus, September 2–6, 2019, Proceedings, Part II 17*, pages 375–395. Springer, 2019.

[174] Wolfgang Walk, Daniel Görlich, and Mark Barrett. Design, dynamics, experience (dde): An advancement of the mda framework for game design. *Game Dynamics: Best Practices in Procedural and Dynamic Game Content Generation*, 2017.

[175] Yan Xu, Evan Barba, Iulian Radu, Maribeth Gandy, Richard Shemaka, Brian Schrank, Blair MacIntyre, and Tony Tseng. Pre-patterns for designing embodied interactions in handheld augmented reality games. 2011.

[176] Ingo Börsting, Bastian Fischer, and Volker Gruhn. Ar scribble: Evaluating design patterns for augmented reality user interfaces. In *Augmented Reality, Virtual Reality, and Computer Graphics: 8th International Conference, AVR 2021, Virtual Event, September 7–10, 2021, Proceedings 8*, pages 169–177. Springer, 2021.

[177] Ingo Börsting, Can Karabulut, Bastian Fischer, and Volker Gruhn. Design patterns for mobile augmented reality user interfaces–an incremental review. *Information*, 13(4):159, 2022.

[178] Jen-Her Wu, Shu-Ching Wang, and Ho-Huang Tsai. Falling in love with online games: The uses and gratifications perspective. *Computers in Human Behavior*, 26(6):1862–1871, 2010.

[179] José Pablo Zagal, Miguel Nussbaum, and Ricardo Rosas. A model to support the design of multiplayer games. *Presence: Teleoperators and Virtual Environments*, 9, 2000.

[180] Greg Costikyan. I have no words & i must design. *Interactive Fantasy*, Issue 2, 1994.

[181] Marco Villalta, Ignacio Gajardo, Miguel Nussbaum, Juan José Andreu, Alejandro Echeverría, and Jan L Plass. Design guidelines for classroom multiplayer presential games (cmpg). *Computers & Education*, 57(3):2039–2053, 2011.

[182] Lorenzo Magnani. *Abductive cognition: The epistemological and eco-cognitive dimensions of hypothetical reasoning*, volume 3. Springer, 2009.

[183] Douglas Walton. *Abductive reasoning*. University of Alabama Press, 2014.

[184] R Jayakanthan. Application of computer games in the field of education. *The electronic library*, 2002.

[185] Fotini Paraskeva, Sofia Mysirlaki, and Aikaterini Papagianni. Multiplayer online games as educational tools: Facing new challenges in learning. *Computers & Education*, 54(2):498–505, 2010.

[186] Léa Martinez, Manuel Gimenes, and Eric Lambert. Entertainment video games for academic learning: A systematic review:. *https://doi.org/10.1177/07356331211053848*, 2022:1–27, 1 2022.

[187] Francesco Strada, Maria Ximena Lopez, Carlo Fabricatore, Alysson Diniz dos Santos, Dimitar Gyaurov, Edoardo Battegazzorre, and Andrea Bottino. Leveraging a collaborative augmented reality serious game to promote sustainability awareness, commitment and adaptive problem-management. *International Journal of Human-Computer Studies*, 172:102984, 2023.

[188] Richard E Mayer. Multimedia learning and games. 2011.

Appendix A

Systematic review materials

A.1 PRISMA Checklist

Section and Topic	Item #	Checklist item
TITLE		
Title	1	Identify the report as a systematic review.
ABSTRACT		
Abstract	2	See the PRISMA 2020 for Abstracts checklist.
INTRODUCTION		
Rationale	3	Describe the rationale for the review in the context of existing knowledge.
Objectives	4	Provide an explicit statement of the objective(s) or question(s) the review addresses.
METHODS		
Eligibility criteria	5	Specify the inclusion and exclusion criteria for the review and how studies were grouped for the syntheses.
Information sources	6	Specify all databases, registers, websites, organisations, reference lists and other sources searched or consulted to identify studies. Specify the date when each source was last searched or consulted.
Search strategy	7	Present the full search strategies for all databases, registers and websites, including any filters and limits used.
Selection process	8	Specify the methods used to decide whether a study met the inclusion criteria of the review, including how many reviewers screened each record and each report retrieved, whether they worked independently, and if applicable, details of automation tools used in the process.
Data collection process	9	Specify the methods used to collect data from reports, including how many reviewers collected data from each report, whether they worked independently, any processes for obtaining or confirming data from study investigators, and if applicable, details of automation tools used in the process.
Data items	10a	List and define all outcomes for which data were sought. Specify whether all results that were compatible with each outcome domain in each study were sought (e.g. for all measures, time points, analyses), and if not, the methods used to decide which results to collect.
	10b	List and define all other variables for which data were sought (e.g. participant and intervention characteristics, funding sources). Describe any assumptions made about any missing or unclear information.
Study risk of bias assessment	11	Specify the methods used to assess risk of bias in the included studies, including details of the tool(s) used, how many reviewers assessed each study and whether they worked independently, and if applicable, details of automation tools used in the process.

Fig. A.1 PRISMA Checklist 1

Section and Topic	Item #	Checklist item
Effect measures	12	Specify for each outcome the effect measure(s) (e.g. risk ratio, mean difference) used in the synthesis or presentation of results.
Synthesis methods	13a	Describe the processes used to decide which studies were eligible for each synthesis (e.g. tabulating the study intervention characteristics and comparing against the planned groups for each synthesis (item #5)).
	13b	Describe any methods required to prepare the data for presentation or synthesis, such as handling of missing summary statistics, or data conversions.
	13c	Describe any methods used to tabulate or visually display results of individual studies and syntheses.
	13d	Describe any methods used to synthesize results and provide a rationale for the choice(s). If meta-analysis was performed, describe the model(s), method(s) to identify the presence and extent of statistical heterogeneity, and software package(s) used.
	13e	Describe any methods used to explore possible causes of heterogeneity among study results (e.g. subgroup analysis, meta-regression).
	13f	Describe any sensitivity analyses conducted to assess robustness of the synthesized results.
Reporting bias assessment	14	Describe any methods used to assess risk of bias due to missing results in a synthesis (arising from reporting biases).
Certainty assessment	15	Describe any methods used to assess certainty (or confidence) in the body of evidence for an outcome.
RESULTS		
Study selection	16a	Describe the results of the search and selection process, from the number of records identified in the search to the number of studies included in the review, ideally using a flow diagram.
	16b	Cite studies that might appear to meet the inclusion criteria, but which were excluded, and explain why they were excluded.
Study characteristics	17	Cite each included study and present its characteristics.
Risk of bias in studies	18	Present assessments of risk of bias for each included study.
Results of individual studies	19	For all outcomes, present, for each study: (a) summary statistics for each group (where appropriate) and (b) an effect estimate and its precision (e.g. confidence/credible interval), ideally using structured tables or plots.
Results of syntheses	20a	For each synthesis, briefly summarise the characteristics and risk of bias among contributing studies.
	20b	Present results of all statistical syntheses conducted. If meta-analysis was done, present for each the summary estimate and its precision (e.g. confidence/credible interval) and measures of statistical heterogeneity. If comparing groups, describe the direction of the effect.
	20c	Present results of all investigations of possible causes of heterogeneity among study results.
	20d	Present results of all sensitivity analyses conducted to assess the robustness of the synthesized results.
Reporting biases	21	Present assessments of risk of bias due to missing results (arising from reporting biases) for each synthesis assessed.
Certainty of evidence	22	Present assessments of certainty (or confidence) in the body of evidence for each outcome assessed.

Fig. A.2 PRISMA Checklist 2

Section and Topic	Item #	Checklist item
DISCUSSION		
Discussion	23a	Provide a general interpretation of the results in the context of other evidence.
	23b	Discuss any limitations of the evidence included in the review.
	23c	Discuss any limitations of the review processes used.
	23d	Discuss implications of the results for practice, policy, and future research.
OTHER INFORMATION		
Registration and protocol	24a	Provide registration information for the review, including register name and registration number, or state that the review was not registered.
	24b	Indicate where the review protocol can be accessed, or state that a protocol was not prepared.
	24c	Describe and explain any amendments to information provided at registration or in the protocol.
Support	25	Describe sources of financial or non-financial support for the review, and the role of the funders or sponsors in the review.
Competing interests	26	Declare any competing interests of review authors.
Availability of data, code and other materials	27	Report which of the following are publicly available and where they can be found: template data collection forms; data extracted from included studies; data used for all analyses; analytic code; any other materials used in the review.

Fig. A.3 PRISMA Checklist 3

A.2 Search strategy for systematic review

Search Strategy		
Database	**Meta query**	**Query string**
ACM Digital Library	Title:((Game category of search terms) AND (Feature category of search terms and Framework category of search terms) AND (Analysis / Design category of search terms))	Title:(("game" OR "games" OR "videogame" OR "videogames" OR "gameplay" OR "gaming" OR "gameful" OR "game-based" OR "playability") AND ("feature" OR "features" OR "element" OR "elements" OR "mechanic" OR "mechanics" OR "affordance" OR "affordances" OR "pattern" OR "patterns" OR "system" OR "systems" OR "framework" OR "frameworks" OR "model" OR "models" OR "approach" OR "approaches" OR "tool" OR "tools" OR "toolkit" OR "guideline" OR "guidelines" OR "technique" OR "techniques" OR "principle" OR "principles" OR "heuristic" OR "heuristics") AND ("analy*" OR "design*" OR "develop*" OR "evaluat*" OR "identif*"))
IEEE Xplore	("Document Title":"Game category of search terms"...) AND ("Document Title":"Feature category of search terms and Framework category of search terms"...) AND ("Document Title":"Analysis / Design category of search terms"...)	("Document Title":"game" OR "Document Title":"games" OR "Document Title":"videogame" OR "Document Title":"videogames" OR "Document Title":"gameplay" OR "Document Title":"gaming" OR "Document Title":"gameful" OR "Document Title":"game-based" OR "Document Title":"playability") AND ("Document Title":"feature" OR "Document Title":"features" OR "Document Title":"element" OR "Document Title":"elements" OR "Document Title":"mechanic" OR "Document Title":"mechanics" OR "Document Title":"affordance" OR "Document Title":"affordances" OR "Document Title":"pattern" OR "Document Title":"patterns" OR "Document Title":"system" OR "Document Title":"systems" OR "Document Title":"framework" OR "Document Title":"frameworks" OR "Document Title":"model" OR "Document Title":"models" OR "Document Title":"approach" OR "Document Title":"approaches" OR "Document Title":"tool" OR "Document Title":"tools" OR "Document Title":"toolkit" OR "Document Title":"guideline" OR "Document Title":"guidelines" OR "Document Title":"technique" OR "Document Title":"techniques" OR "Document Title":"principle" OR "Document Title":"principles" OR "Document Title":"heuristic" OR "Document Title":"heuristics") AND ("Document Title":"analy*" OR "Document Title":"design*" OR "Document Title":"develop*" OR "Document Title":"evaluat*" OR "Document Title":"identif*")
Scopus	TITLE((Game category of search terms) AND (Feature category of search terms and Framework category of search terms) AND (Analysis / Design category of search terms))	TITLE(("game" OR "games" OR "videogame" OR "videogames" OR "gameplay" OR "gaming" OR "gameful" OR "game-based" OR "playability") AND ("feature" OR "features" OR "element" OR "elements" OR "mechanic" OR "mechanics" OR "affordance" OR "affordances" OR "pattern" OR "patterns" OR "system" OR "systems" OR "framework" OR "frameworks" OR "model" OR "models" OR "approach" OR "approaches" OR "tool" OR "tools" OR "toolkit" OR "guideline" OR "guidelines" OR "technique" OR "techniques" OR "principle" OR "principles" OR "heuristic" OR "heuristics") AND ("analy*" OR "design*" OR "develop*" OR "evaluat*" OR "identif*"))
Web of Science	TI=((Game category of search terms) AND (Feature category of search terms and Framework category of search terms) AND (Analysis / Design category of search terms))	TI=(("game" OR "games" OR "videogame" OR "videogames" OR "gameplay" OR "gaming" OR "gameful" OR "game-based" OR "playability") AND ("feature" OR "features" OR "element" OR "elements" OR "mechanic" OR "mechanics" OR "affordance" OR "affordances" OR "pattern" OR "patterns" OR "system" OR "systems" OR "framework" OR "frameworks" OR "model" OR "models" OR "approach" OR "approaches" OR "tool" OR "tools" OR "toolkit" OR "guideline" OR "guidelines" OR "technique" OR "techniques" OR "principle" OR "principles" OR "heuristic" OR "heuristics") AND ("analy*" OR "design*" OR "develop*" OR "evaluat*" OR "identif*"))

Fig. A.4 Search Strategy

A.3 Coding Schema

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Costello and Edmonds, 2009 [cite]	"Creation" refers to the pleasure of having the control to create something.	(1) Provide interactive elements for manipulation.	(1) Enable players to enjoy expressing themselves; (2) Enable players to enjoy feeling in control.
	"Exploration" refers to the pleasure of exploring unfamiliar situations.	(1) Provide interactive elements for exploration.	(1) Enable players to enjoy exploring unfamiliar game situations.
	"Discovery" refers to the pleasure of making a discovery or figuring something out.	(1) Provide interactive elements with concealed properties.	(1) Enable players to enjoy discovering concealed properties of game elements.
	"Difficulty" refers to the pleasure of developing or exercising a skill.	(1) Provide activities that are not too easy; (2) Provide elements that require skill to understand them.	(1) Enable players to enjoy performing difficult and complex activities.
	"Competition" refers to the pleasure of achieving a defined goal.	(1) Provide game-defined or player-defined goals; (2) Provide other players, NPCs, game systems for competition.	(1) Enable players to enjoy competing with or against others.
	"Danger" refers to the pleasure of feeling scared, being in danger, or taking risks.	(1) Provide unclear and threatening game situations.	(1) Enable players to enjoy feeling the sense of unease and thrill of danger.
	"Captivation" refers to the pleasure of feeling mesmerized or controlled by something.	(1) Provide spellbinding game elements.	(1) Enable players to enjoy feeling controlled and driven by game elements.
	"Sensation" refers to the pleasure of performing physical actions.	(1) Provide game elements that promote different physical actions.	(1) Enable players to enjoy performing physical actions.
	"Sympathy" refers to the pleasure of sharing emotional or physical feelings.	(1) Provide relatable game entities.	(1) Enable players to enjoy relating to and sharing with game entities.
	"Simulation" refers to the pleasure of perceiving real-world representations in the game.	(1) Provide game elements that simulate real-world scenarios.	(1) Enable players to enjoy perceiving game elements that mimic real-world scenarios.
	"Fantasy" refers to the pleasure of perceiving imaginative creations.	(1) Provide fantastical game elements.	(1) Enable players to enjoy perceiving fantastical game elements.
	"Camaraderie" refers to the pleasure of developing friendships or fellowships.	(1) Provide other players or NPCs; (2) Provide a game environment that encourages social interaction.	(1) Enable players to enjoy conversing and interacting with other players and game entities.
	"Subversion" refers to the pleasure of breaking rules or twisting the meaning of something.	(1) Provide game elements that allow subverting game or real life rules.	(1) Enable players to enjoy behaving in a way that breaks the rules.
De Byl, 2015 [cite]	"Mind-Body Interaction" refers to the primordial emotions that drive behaviour governed by bodily needs.	(1) Provide biometric readings of the emotional state of players; (2) Provide avatar expressions that reflect the emotional state of players; (3) Provide NPCs which react to the emotional state of players; (4) Provide opportunities for player body movement.	(1) Enable players to express their emotions; (2) Enable players feel immersed; (3) Enable players feel more engaged; (4) Enable players to recognize their own emotions.
	"Fast Primary Emotions" refers to the quick acting emotions that serve as an initial response to a stimulus and act as a survival mechanism.	(1) Provide stimuli that exploit player instincts; (2) Provide diegetic information about player avatars; (3) Provide NPCs with flight or fight behaviours; (4) Provide unexpected narrative events.	(1) Enable players to act based on stimuli; (2) Enable players to act to save their avatars; (3) Enable players to react to believable NPC behaviours; (4) Enable players to react to surprising narrative events.
	"Cognitive Appraisals" refers to the resulting emotions from an activity or an encounter.	(1) Provide clear information about the avatar state, NPCs, goals, and game environment status; (2) Provide avatars with the ability to self-process emotions; (3) Provide NPCs with the ability to self-process emotions; (4) Provide clear character personality and background story.	(1) Enable players to interpret game stimuli; (2) Enable players to interact with believable avatars; (3) Enable players to interact with believable NPCs; (4) Enable players to take on the role of characters.
	"Emotional Behaviour" refers to the emotions that may motivate actions, beliefs and goals.	(1) Provide seamless interaction mechanism, intuitive controls, clear interface designs, and game feedback; (2) Provide avatars with behaviours informed by self-processed emotions; (3) Provide NPCs with behaviors informed by self-processed emotions; (4) Provide adaptive plotlines and monitors for the emotional behaviour of players.	(1) Enable players to suspend disbelief and to be emotionally closer to the game; (2) Enable players to interact with believable avatars; (3) Enable players to interact with believable NPCs; (4) Enable players to experience different emotional states.
	"Emotional Experience" refers to the present and continuous emotions of players.	(1) Provide display of the inventory and screenshots of significant game events; (2) Provide signs of battles on the clothes of avatars and through their movement; (3) Provide NPCs that either help players complete tasks or form long-term relationships with players; (4) Provide a seamless game environment and game world lore.	(1) Enable players to remember their gaming journey; (2) Enable players to become emotionally attached to NPCs; (3) Enable players to become engaged and immersed; (4) Enable players to experience different emotional states.
Desurvire and Wiberg, 2009 [cite]	"Enduring Play" refers to continuous, fair, fun, and varied tasks and activities.	(1) Provide continuous, fair, fun, and varied tasks and activities.	(1) Enable players to engage with continuous, fair, fun, and varied tasks and activities.
	"Challenge, Strategy and Pace" refers to balanced challenges, the required mastery to overcome them, and different strategies for appropriate AI difficulty.	(1) Provide balanced challenges and AI.	(1) Enable players to feel like challenges are easy to learn and harder to master; (2) Enable players to want to play more; (3) Enable players to try different strategies against tough AI.
	"Consistency in Game World" refers to the game reactions to player actions.	(1) Provide a game world that reacts with persistent changes to player actions.	(1) Enable players to feel their impact in the game world.
	"Goals" refers to the game goals, the required skills to achieve them, and the rewards of the game.	(1) Provide clear goals, overriding goals, and short-term goals; (2) Provide new skills to players; (3) Provide immersive rewards that increase player capabilities and customization.	(1) Enable players to pursue goals; (2) Enable players to learn new skills; (3) Enable players to feel immersed and more capable.
	"Variety of Players and Game Styles" refers to the game styles, multiple ways to win, obvious initial actions, different levels of AI difficulty.	(1) Provide a variety of game styles; (2) Provide multiple ways to win; (3) Provide obvious initial actions; (4) Provide different levels of AI difficulty.	(1) Enable players to experience a variety of game styles; (2) Enable players to win in multiple ways; (3) Enable players to have obvious initial actions to perform when starting the game; (4) Enable players to choose appropriate level of AI difficulty.
	"Players Perception of Control" refers to players feeling in control over the game world.	(1) Provide opportunities for player control and influence in the game.	(1) Enable players to feel in control.
	"Emotional Connection" refers to the emotional connection between the player and the game world and their avatar.	(1) Provide a relatable game world and player avatar.	(1) Enable players to feel emotionally connected to the game world and their avatar.
	"Coolness/Entertainment" refers to triggering and sustaining player interest with something new.	(1) Provide new and interesting things in the game.	(1) Enable players to begin and continue feeling interested in the game.
	"Humor" refers to the humor in the game.	(1) Provide good uses of humor.	(1) Enable players to laugh.
	"Immersion" refers to the visual and audio elements that further the immersion of players.	(1) Provide immersive visual and audio elements.	(1) Enable players to feel immersed.
	"Documentation/Tutorial" refers to non-essential manuals and tutorials for players to play the game.	(1) Provide opportunities for players to play the game without needed a manual or tutorial.	(1) Enable players to feel like they can play the game without a manual or tutorial.
	"Status and Score" refers to the available status and score of players and the controllers of the game.	(1) Provide easily identifiable score and status of players; (2) Provide naturally-mapped, standardized, and customizable controllers.	(1) Enable players to easily identify their score and status; (2) Enable players to intuitively and quickly learn the controls of the game.
	"Game Provides Feedback" refers to provided feedback to player actions.	(1) Provide consistent, immediate, challenging, and exciting audio/visual/visceral feedback to players' actions.	(1) Enable players to feel challenged and excited by the immediate game reaction to their actions.
	"Terminology" refers to the game goals, the required skills to achieve them, and the rewards of the game.	(1) Provide clear goals, overriding goals, and short-term goals; (2) Provide new skills to players; (3) Provide immersive rewards that increase player capabilities and customization.	(1) Enable players to pursue goals; (2) Enable players to learn new skills; (3) Enable players to feel immersed and more capable.
	"Burden On Player" refers to easy to learn controllers that can be expanded for advanced players.	(1) Provide basic controllers that can be expanded with advanced options.	(1) Enable players to easily and quickly learn basic controllers; (2) Enable advanced players to expand controllers with advanced options.
	"Screen Layout" refers to the user interface and recognizable art in the game.	(1) Provide consistent user interface that has an efficient and visually pleasing layout in the game; (2) Provide recognizable art with afforded function.	(1) Enable players to experience consistent user interface that has an efficient and visually pleasing layout in the game; (2) Enable players to recognize art and its afforded function.
	"Navigation" refers to the navigation in the game.	(1) Provide consistent, logical and minimalist navigation.	(1) Enable players to experience consistent, logical and minimalist navigation.
	"Error prevention" refers to saving the game, starting the game, helpful tips, and in-game tutorials.	(1) Provide consistent and intuitive save option, helpful tips, and in-game tutorials.	(1) Enable players to experience and understand the save option, helpful tips, and in-game tutorials.
	"Game Story Immersion" refers to the game story encouraging immersion.	(1) Provide a game story.	(1) Enable players to feel immersed.

Fig. A.5 Coding Schema 1

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Desurvire et al., 2004 [cite]	"Game Play" refers to the challenges that players have to overcome to win the game.	(1) Provide varying activities, ways of winning, new skills, and difficulty levels; (2) Provide game elements that are consistent with the story; (3) Provide clear goals, overriding goals, and short-term goals; (4) Provide obstacles that do not penalize players for the same failure; (5) Provide a game world that reacts with persistent changes to player actions; (6) Provide immersive rewards that increase player capabilities and customization.	(1) Enable players to not feel fatigued, to learn new skills, and to develop mastery; (2) Enable players to suspend their disbelief and discover the story through game play; (3) Enable players to pursue goals; (4) Enable players to not feel penalized for the same failure; (5) Enable players to feel a sense of control and impact over the game world; (6) Enable players to feel immersed and more capable.
	"Game Story" refers to the development of the story and character.	(1) Provide coherent, interesting, and relatable story, world, and characters.	(1) Enable players to understand and feel interested and related to the story, world, and characters.
	"Game Mechanics" refers to the code that produces interactions between game units.	(1) Provide consistent, challenging, and exciting game reactions to player actions; (2) Provide visible effects of AI agents that are consistent with player expectations; (3) Provide easily identifiable score, status, and goals of players; (4) Provide naturally-mapped, standardized, and customizable controllers.	(1) Enable players to feel challenged and excited by the game's reactions; (2) Enable players to predict AI agents; (3) Enable players to easily identify their score, status, and goals; (4) Enable players to intuitively and quickly learn the controls of the game.
	"Game Usability" refers to the game interface and the input and output devices.	(1) Provide immediate feedback and sounds to player actions; (2) Provide consistent and intuitive interface, save option, game menu, helpful tips, and in-game tutorials; (3) Provide recognizable art with afforded function.	(1) Enable players to feel emotions and the impact of their actions; (2) Enable players to experience and understand the interface, save option, game menu, helpful tips, and in-game tutorials; (3) Enable players to recognize art and its afforded function.
Dillon, 2011 [cite]	"Fear" refers to an emotion that is easily triggered with new technologies.	(1) Provide realistic environments and situations.	(1) Enable players to feel afraid.
	"Anger" refers to an emotion that is often used as a motivational factor in games.	(1) Provide opportunities to play again; (2) Provide stories with bad guys.	(1) Enable players to play the game again; (2) Enable players to progress the story by stopping bad guys.
	"Joy / Happiness" refers to an emotion that is relevant for having fun in games.	(1) Provide rewards for completing tasks.	(1) Enable players to feel rewarded for completing tasks.
	"Pride" refers to an emotion that is an important motivational factor in games.	(1) Provide rewards for achievements; (2) Provide more difficult challenges.	(1) Enable players to feel good for achievements; (2) Enable players to want to improve to face more difficult challenges.
	"Sadness" refers to an emotion that promotes complex and mature themes.	(1) Provide complex and mature themes.	(1) Enable players to feel sad.
	"Excitement" refers to an emotion that is worth achieving in most games.	(1) Provide opportunities for other emotions and/or instincts to be triggered.	(1) Enable players to experience other emotions and/or instincts.
	"Survival (Fight or Flight)" refers to an instinct that pushes players to decide if they should face or avoid a threat.	(1) Provide threats to players that can be fought or avoided.	(1) Enable players to make decisions about fighting or escaping threats.
	"Self Identification" refers to an instinct that pushes players to admire successful and smart characters.	(1) Provide relatable characters.	(1) Enable players to model themselves based on relatable characters.
	"Collecting" refers to an instinct that that is linked to a variety of different emotions in games.	(1) Provide things to collect.	(1) Enable players to feel different emotions.
	"Greed" refers to an instinct that pushes players to collect more than they need.	(1) Provide collectable goods and resources.	(1) Enable players to feel the need to collect for the sake of it.
	"Protection / Care / Nurture" refers to an instinct that pushes players to care and help others.	(1) Provide characters or other players in need.	(1) Enable players to feel the impulse for caring and helping others.
	"Aggressiveness" refers to an instinct that pushes players to be violent in games.	(1) Provide characters or other players that can receive violence.	(1) Enable players to feel the impulse for violence against others.
	"Revenge" refers to an instinct that is a motivational factor in games.	(1) Provide stories with bad guys.	(1) Enable players to feel justified for stopping bad guys.
	"Competition" refers to an instinct that is linked with the social aspects of player psychology.	(1) Provide opportunities for players to compete with each other.	(1) Enable players to compete with each other.
	"Communication" refers to an instinct that allows expressing ideas and thoughts.	(1) Provide NPCs to talk to; (2) Provide chatrooms and forums to talk to other players.	(1) Enable players to talk with NPCs and other players.
	"Exploration / Curiosity" refers to an instinct that pushes players towards the unknown.	(1) Provide opportunities for discoveries.	(1) Enable players to discover unknown things.
	"Color Appreciation" refers to an instinct that attracts players to vibrant colours.	(1) Provide colourful scenes and environments.	(1) Enable players to be attracted to detailed and colourful graphics.
Ermi and Mäyrä, 2005 [cite]	"Sensory immersion" refers to the player's experience of perceiving the audiovisual execution of the game.	(1) Provide impressive three-dimensional and stereophonic worlds; (2) Provide devices that overpower the real-world sensory information.	(1) Enable players to become focused on the game world and its stimuli.
	"Challenge-based immersion" refers to the player's experience of achieving a satisfying balance of challenges and abilities.	(1) Provide challenges balanced with the motor and mental skills of players.	(1) Enable players to interact with challenges that match their abilities.
	"Imaginative immersion" refers to the player's experience of becoming absorbed with the stories, world and characters of the game.	(1) Provide absorbing stories and worlds; (2) Provide relatable characters.	(1) Enable players to use their imagination; (2) Enable players to empathise with characters; (3) Enable players to enjoy the fantasy of the game.
Fabricatore, 2007 [cite]	"Core gameplay" refers to the most frequent and required set of activities for players to undertake.	(1) Provide a set of core gameplay activities that build most of the gameplay experience for players.	(1) Enable players to feel challenged, to master the game, and to be rewarded for it by undertaking a set of core gameplay activities.
	"Core game mechanics" refers to the most important and most dealt with mechanics in the game that allow carrying out the core gameplay.	(1) Provide a minimal number of core game mechanics that are easy to learn and master, that do not functionally overlap with each other, and that are relevant throughout the game.	(1) Enable players to easily learn and master a minimal number of core game mechanics.
	"Core meta-gameplay" refers to core gameplay activities with new semantics that don't require new game mechanics to be carried out.	(1) Provide a set of core meta-gameplay activities that build most of the gameplay experience for players together with the core gameplay activities.	(1) Enable players to feel challenged, to master the game, and to be rewarded for it by undertaking a set of core meta-gameplay activities.
	"Satellite game mechanics" refers to enhancement, alternate, and opposition game mechanics that enhance existing activities.	(1) Provide enhancing mechanics that add new features (add-on) or modify existing features (power-up); (2) Provide alternate mechanics that allow learning new ways of tackling gameplay activities; (3) Provide opposition mechanics that hinder player progression.	(1) Enable players to undertake existing gameplay activities in new ways by using modified, new, alternate, or hindering mechanics.
	"Peripheral gameplay" refers to gameplay activities that require new mechanics that temporarily substitute the core gameplay.	(1) Provide peripheral gameplay activities that players rarely undertake.	(1) Enable players to undertake peripheral gameplay activities without disrupting the mastering of the core gameplay.

Fig. A.6 Coding Schema 2

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Fabricatore, 2018 [cite]	"Game play activity" refers to the multiple loop process in which a player defines or accepts a goal, evaluates environmental conditions, plans actions, executes plans, and evaluates results.	(1) Provide opportunities for a player to define or accept a goal, evaluate environmental conditions, plan actions, execute plans, and evaluate results; (2) Provide feedback loops for the re-formulation of goals and plans, or the re-evaluation of conditions and results.	(1) Enable players to define or accept a goal, evaluate environmental conditions, plan actions, execute plans, and evaluate results. (2) Enable players to re-formulate goals and plans, or to re-evaluate conditions and results.
	"Game task" refers to an interaction network consisting of a transformable target object, transformation enablers and hindrances, and contextual and act feedback.	(1) Provide player token, digital tool, aider, barrier, opponent, target object, goal state, contextual feedback, and act feedback.	(1) Enable players to iteratively interact, thanks to contextual and act feedback, through a player token with digital tools and aider, or with barriers and opponents that help or hinder the transformation of the target object towards the goal state.
	"Game context" refers to a system of interrelated conditions that define the environment of the game.	(1) Provide goals and schemas; (2) Provide the following background conditions: settings, storylines and overarching aims; (3) Provide defining events that are caused by contextual conditions and schemas and that may modify background conditions; (4) Provide micro-context, meso-context, macro-context, as levels of the hierarchy of game context.	(1) Enable players to understand what to do and how within the given context; (2) Enable players to understand the time and place of the game, and their goals and role in the game; (3) Enable players to understand the causes (contextual conditions and schemas) and effects (local and global) of defining events by interpreting background conditions. (4) Enable players to focus on local elements in the micro-context as part of their immediate task performance, to perceive elements in the meso-context that may be related to new target objects and goals, and to understand the history of the game world through the macro-context.
	"Core schemas" refers to patterns that govern interactions, conditions, and effects of game state changes.	(1) Provide causal-mechanistic schemas that govern player interactions and game events; (2) Provide socio-cultural schemas that govern the social interactions and cultural expectations in the game; (3) Provide workflow schemas that define the dependency between game goals; (4) Provide timely and reiterated feedback schemas.	(1) Enable players to understand their actions and game events; (2) Enable players to understand how to interact with other players and characters; (3) Enable players to understand and choose how to progress; (4) Enable players to accept goals, plan task performance, evaluate contextual conditions, and understand aspects of the local and global game context.
Fabricatore et al., 2002 [cite]	"Entity" refers to the role, attitude, resources, and items, and behaviours of entities that the player interacts with.	(1) Provide coherent roles, abilities, and behaviours of entities; (2) Provide clear and changing friendly, hostile, or neutral attitudes of entities; (3) Provide contextual and explicit, audio and visual information related to the identification and customization of the role and attitude of entities; (4) Provide changing energy levels of entities that can be restored easily either immediately by picked items or on-demand by storing the items, and fully by progressing to a new scenario; (5) Provide contextual and explicit, clear and precise, audio and visual information related to the energy changes of entities; (6) Provide initially unlimited and quickly customizable equipment of entities; (7) Provide unique pieces of equipment that are available or unavailable for an appropriate amount of time and at appropriate gameplay situations; (8) Provide contextual and explicit, audio and visual information related to the type, function, aim, range, status, and availability of equipment; (9) Provide entities with non-disruptive logical behaviours, changing behaviours with evident causes, or unpredictable behaviours with identifiable causes and rules; (10) Provide appropriate, variable, useful, understandable, and customizable abilities of entities; (11) Provide contextual and explicit, audio and visual information related to the abilities of entities; (12) Provide minimal, expected, quick, automatic, non-disruptive, strategic, understandable, predictable, clear, and reversible interactions with the scenario; (13) Provide contextual and explicit, audio and visual information related to interactions with the scenario; (14) Provide relevant and understandable interactions among entities and between the player token and entities;	(1) Enable players to have realistic expectations and assumptions about or to choose an entity's roles, abilities, and behaviours; (2) Enable players to recognize the friendly, hostile, or neutral current or changing attitudes of entities; (3) Enable players to identify and customize the roles and attitudes of entities through audio and visual information; (4) Enable players to easily identify energy loses and their causes through precision-damage systems; (5) Enable players to identify, understand and customize the audio and visual information related to the energy of entities; (6) Enable players to customize and freely use initial equipment of entities; (7) Enable players to feel compelled by the different pieces of equipment and to feel appropriately challenged by the availability or unavailability of equipment; (8) Enable players to understand the audio and visual information related to the type, function, aim, range, status, and availability of equipment; (9) Enable players to identify and understand the causes and rules for the behaviour of entities; (10) Enable players to interact, understand, and customize appropriate, variable, and useful abilities of entities; (11) Enable players to perceive and understand the abilities of entities; (12) Enable players to have minimal, expected, quick, automatic, non-disruptive, strategic, understandable, predictable, clear, and reversible interactions with the scenario; (13) Enable players to perceive and understand the interactions with the scenario; (14) Enable players to perceive and understand interactions among entities and between the player token and entities.
	"Scenario" refers to the point of view of players, unexpected events, scenario transitions, and interactions with entities.	(1) Provide large visible area of the scenario and player token; (2) Provide customizable non-disruptive camera position; (3) Provide unexpected events that affect the interaction with the scenario; (4) Provide information about task progression before transitioning to a new scenario.	(1) Enable players to see a large area of the scenario and their player token; (2) Enable players to control or to not be disrupted by the changing camera position; (3) Enable players to feel challenged by unexpected events that affect their interaction with the scenario; (4) Enable players to understand the task progress before transitioning to a new scenario.
	"Hierarchy of goals" refers to the variety, the levels of linearity, and the information about goals and subgoals in games.	(1) Provide clear and nonrepetitive goals; (2) Provide clear links between different branches of the hierarchy of goals; (3) Provide quick exploration and backtracking opportunities in nonlinear hierarchy of goals; (4) Provide clear, precise, always accessible, and helpful information about the nature of goals, progress, and objectives in the game.	(1) Enable players to be entertained and engaged; (2) Enable players to understand the links between branches of the hierarchy of goals; (3) Enable players to explore nonlinear hierarchy of goals without permanent negative consequences; (4) Enable players to understand, remember, be immersed, and learn through provided information about the nature of goals, progress, and objectives in the game.
Harris et al., 2016 [cite]	"Asymmetry of Ability" refers to the different abilities that players have.	(1) Provide different abilities to different players.	(1) Enable players to use abilities that other players do not have.
	"Asymmetry of Challenge" refers to the different challenges that players have to face.	(1) Provide different challenges to different players.	(1) Enable players to complete different types of obstacles compared to other players.
	"Asymmetry of Interface" refers to the different input and output devices that players have.	(1) Provide different input and output devices to different players.	(1) Enable players to use different input and output devices compared to other players.
	"Asymmetry of Information" refers to the different information that players have.	(1) Provide different information to different players.	(1) Enable players to have access to information that other players do not have.
	"Asymmetry of Investment" refers to the different time duration that players dedicate to their roles.	(1) Provide different roles to different players.	(1) Enable players to spend more or less time in-game compared to other players.
	"Asymmetry of Goal/Responsibility" refers to the different outcomes that players want to achieve.	(1) Provide different objectives to different players.	(1) Enable players to achieve different objectives compared to other players.
	"Mirrored Dependence" refers to players identically relying on each other.	(1) Provide the same tasks and actions to different players.	(1) Enable players to perform the same tasks and actions to achieve the same objective together.
	"Unidirectional Dependence" refers to a player relying on another one.	(1) Provide different tasks and actions to one player that depend on the performance of tasks and actions of another player.	(1) Enable players to perform different tasks and actions, with one depending on the other, to achieve the same objective together.
	"Bidirectional Dependence (AKA Symbiosis)" refers to players relying on each other in different ways.	(1) Provide different tasks and actions to different players.	(1) Enable players to perform different tasks and actions to achieve the same objective together.
	"Asynchronous Timing" refers to players performing timing-independent actions.	(1) Provide actions that different players can perform independently.	(1) Enable players to perform timing-independent actions.
	"Sequential (Disjoint) Timing" refers to players performing sequential actions.	(1) Provide actions that different players have to perform sequentially.	(1) Enable players to perform sequential actions.
	"Expectant Timing" refers to players performing triggering or triggered actions.	(1) Provide actions that can trigger or be triggered by other players' actions.	(1) Enable players to perform triggering or triggered actions.
	"Concurrent Timing" refers to players performing continuous actions.	(1) Provide actions that different players should perform continuously.	(1) Enable players to perform continuous actions.
	"Coincident Timing" refers to players performing timing-dependent actions.	(1) Provide actions that different players should perform at the same time.	(1) Enable players to perform timing-dependent actions.

Fig. A.7 Coding Schema 3

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Hochleitner et al., 2015 [cite]	"Goals" refers to both overall game objectives and short term goals.	(1) Provide primary objectives early in the game, that are clear, understandable, identifiable or player-created; (2) Provide multiple short-term and long-term goals.	(1) Enable players to perceive primary objectives; (2) Enable players to create own primary objectives; (3) Enable players to create multiple winning strategies.
	"Motivation" refers to rewards, fairness and other aspects that sustain player engagement with the game.	(1) Provide meaningful rewards and skill acquisition; (2) Provide opportunities to progress; (3) Provide fair outcome; (4) Provide enjoyable replayability; (5) Provide interesting tasks; (6) Provide challenges sustaining player engagement; (7) Provide encouraging first-time experience.	(1) Enable players to feel rewarded; (2) Enable players to feel excitement to progress; (3) Enable players to perceive the game as fair; (4) Enable players to feel enjoyment of replaying the game; (5) Enable players to perceive tasks as interesting; (6) Enable players to continue playing; (7) Enable players to feel encouraged early.
	"Challenge" refers to aspects related to game pacing, game difficulty, and player skills.	(1) Provide an appropriate game pace that applies pressure but is not frustrating; (2) Provide a balance between challenge, strategy and pace; (3) Provide a reasonable, visible, consistent but unpredictable AI; (4) Provide different difficulty levels that adapt to the player's acquired skills; (5) Provide difficult tasks that need to be completed only once; (6) Provide challenges and concepts that are easy to learn but hard to master.	(1) Enable players to feel pressured but not frustrated; (2) Enable players to perceive the game challenges as balanced; (3) Enable players to feel challenged by AI; (4) Enable players to feel challenged to the appropriate levels of their acquired skills; (5) Enable players to feel satisfied after completing difficult tasks; (6) Enable players to perceive the game as easy to learn but hard to master.
	"Learning" refers to aspects related to help, tutorials and error conditions.	(1) Provide space for mistakes and understandable failure conditions; (2) Provide enough starting information and shorten the learning curve; (3) Provide the game's fundamentals as assistance before and during the game; (4) Provide tutorials and adjustable levels available throughout the game.	(1) Enable players to make mistakes and understand the failure conditions; (2) Enable players to start playing immediately; (3) Enable players to perceive useful general help; (4) Enable players to engage with the game quickly by learning.
	"Control" refers to the ability to change the game world by performing desired actions at any given time.	(1) Provide a controllable player character and an interactive game world; (2) Provide a transformable game world; (3) Provide skippable non-playable and repeated content; (4) Provide contextualized and instinctive game mechanics; (5) Provide easily accessible "save game", "turn off game" and "turn on game" options; (6) Provide accessible threats and opportunities.	(1) Enable players to feel a sense of control; (2) Enable players to feel a sense of impact on the game world; (3) Enable players to feel empowered to skip non-gameplay and repeated content; (4) Enable players to understand the properties and functions of game mechanics; (5) Enable players to feel empowered to save, turn off or turn on the game at any time; (6) Enable players to feel empowered to deal with threats and take advantage of opportunities.
	"Consistency" refers to the game's persistent changes and predictable responses.	(1) Provide persistence and noticeability to changes made by the player to the game world; (2) Provide consistency and predictability in the game's responses to player's actions; (3) Provide consistency between game elements, settings and story.	(1) Enable players to perceive changes made by them to the game world; (2) Enable players to reliably anticipate the game's responses to their actions; (3) Enable players to perceive contextually consistent game elements, settings and story.
	"Game story" refers to emotional engagement and narratives.	(1) Provide a meaningful game story that supports the gameplay; (2) Provide a coherent and immersive game story from start to end; (3) Provide game aspects that evoke emotions in players.	(1) Enable players to discover the game story through the gameplay; (2) Enable players to suspend their disbelief about the game story; (3) Enable players to feel personally involved in the game.
	"Feedback" refers to acoustic and visual information enabling the identification of game elements and the player's location in the game.	(1) Provide acoustic and visual effects that are meaningful and timely; (2) Provide feedback that creates challenging and exciting interaction; (3) Provide immediate feedback to player's action; (4) Provide information related to different game elements; (5) Provide information related to the player location on the mini-map; (6) Provide information related to different resources.	(1) Enable players to become interested in acoustic and visual effects; (2) Enable players to feel emotions from the provided feedback; (3) Enable players to immediately feel the effects of their actions; (4) Enable players to identify different game elements; (5) Enable players to identify their location on the mini-map; (6) Enable players to not be required to memorize different resources.
	"Visual appearance" refers to the ability to visually assess in-game objects and their purposes.	(1) Provide in-game objects that visually stand out; (2) Provide in-game objects that visually convey their affordances.	(1) Enable players to visually perceive the presence of in-game objects; (2) Enable players to visually perceive the affordances of in-game objects.
	"Interaction" refers to the quality of the game's input methods.	(1) Provide manageable and responsive input methods; (2) Provide alternative and intuitive interaction methods; (3) Provide an obvious first player action resulting in immediate positive feedback.	(1) Enable players to feel an appropriate level of sensitivity of input methods; (2) Enable players to intuitively discover available alternative interaction methods; (3) Enable players to quickly discover the first available action.
	"Customization" refers to the ability to change the game based on the player's needs and desires.	(1) Provide appropriate customization options for different game aspects; (2) Provide persistent customization options for input mappings.	(1) Enable players to change the settings of different game aspects; (2) Enable players to change the input mappings in the game.
	"Menu and interface elements (HUD)" refers to aspects of the heads up display (HUD) and the game's menu.	(1) Provide a consistent and non-intrusive interface; (2) Provide an intuitive menu that is part of the game; (3) Provide a clear and unobstructed view of the game area; (4) Provide critical information that stands out; (5) Provide standard interface elements adhering to common interface design guidelines.	(1) Enable players to perceive clearly the information from the interface; (2) Enable players to perceive clearly the meanings of the menu; (3) Enable players to perceive all visual information in a game area; (4) Enable players to recognize their status and make appropriate decisions; (5) Enable players to understand the meaning and function of standard interface elements.
Hunicke et al., 2004 [cite]	"Mechanics" refers to the various actions, behaviours and control mechanisms of the game.	(1) Provide actions, behaviours and control mechanisms to players within a game context.	(1) Enable players to engage in gameplay dynamics.
	"Dynamics" refers to the behaviours of mechanics that respond to player input or to the output of other mechanics over time.	(1) Provide workflow and feedback systems to players.	(1) Enable players to have aesthetic experiences.
	"Aesthetics" refers to the desirable emotions evoked in players when they interact with the game.	(1) Provide sensation - game as sense-pleasure; (2) Provide fantasy - game as make-believe; (3) Provide narrative - game as drama; (4) Provide challenge - game as obstacle course; (5) Provide fellowship - game as social framework; (6) Provide discovery - game as uncharted territory; (7) Provide expression - game as self-discovery; (8) Provide submission - game as pastime.	(1) Enable players to have a gameplay experience defined by multiple aesthetic goals.
Khalifa et al., 2019 [cite]	"Guidance" refers to the use of non-verbal game elements to guide players in an intended direction.	(1) Provide a target direction based on the shape of levels, placement of collectibles, presence of enemies, and changes of environmental cues.	(1) Enable players to explore the environment, progress in the game, and avoid bad decisions.
	"Safe Zone" refers to game areas where players are protected from negative interactions.	(1) Provide undisturbed time in an identifiable protection area based on the patterns of nearby hazards and enemies.	(1) Enable players to analyze their surroundings and plan their next actions.
	"Foreshadowing" refers to introducing a game element in a controlled environment that later becomes more important.	(1) Provide a game mechanic that, once learned, will be used in a future challenge.	(1) Enable players to become curious and excited about future possibilities.
	"Layering" refers to combining multiple known objects and strategies to create new experiences.	(1) Provide new and harder challenges by combining familiar game elements in unfamiliar ways.	(1) Enable players to overcome fair challenges; (2) Enable players to create new strategies.
	"Branching" refers to using multiple pathways for achieving an objective.	(1) Provide unlimited access to all pathways, allowing levels to be beaten with starting tools; (2) Provide access to some pathways only after specific conditions have been reached through other pathways; (3) Provide safe pathways with small rewards and dangerous pathways with big rewards.	(1) Enable players to feel empowered and explore the environment; (2) Enable players to become curious; (3) Enable players to take risks for greater reward.
	"Pace Breaking" refers to increasing or decreasing the dramatic tension in the game from one scene to the next.	(1) Provide an unavoidable hazard of obvious difficulty with accompanying audio and visual cues; (2) Provide free time and space for interacting with different aspects of the game.	(1) Enable players to become more tense and focused; (2) Enable players to become more calm and relaxed.
Pereira and Roque, 2012 [cite]	"Playfulness" refers to free, informal, and unstructured participation in the game.	(1) Provide variety of interactive game elements.	(1) Enable players to explore and improvise.
	"Challenge" refers to targeted, formal, and structured participation in the game.	(1) Provide goal-relevant challenges, penalties and rewards.	(1) Enable players to overcome challenges and master skills.
	"Embodiment" refers to virtual and actual physical participation in the game.	(1) Provide physical representations and/or interpretations of the players within the game world.	(1) Enable players to be physically involved in the game.
	"Sociability" refers to social, relationship-building participation in the game.	(1) Provide hierarchical and/or team-based social structures.	(1) Enable players to compete, cooperate and communicate.
	"Sensemaking" refers to significant and meaningful participation in the game.	(1) Provide themes, narratives, roles, motives, actions.	(1) Enable players to role-play and self-express.
	"Sensoriality" refers to multisensory participation in the game.	(1) Provide visual and sonic stimuli with varied styles and natures.	(1) Enable players to perceive, filter, accept and reproduce stimuli.

Fig. A.8 Coding Schema 4

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Ralph and Monu, 2015 [cite]	"Game mechanics" refers to elements used to create challenges for players.	(1) Provide a variety of levels, turns, quests, puzzles, objects, rules, etc.	(1) Enable players to overcome challenges and develop skills.
	"Narrative mechanics" refers to elements used to progress the game narrative.	(1) Provide a variety of communication sources, dialogue options, quests, puzzles, cut scenes, etc.	(1) Enable players to experience the story of the game.
	"Technology" refers to Artifacts used to deliver mechanics and play the game.	(1) Provide appropriate virtual and physical, simple and complicated, new and old Artifacts.	(1) Enable players to play the game.
	"Embedded narratives" refers to stories told to players through the narrative mechanics of the game.	(1) Provide story elements through the variety of narrative mechanics.	(1) Enable players to experience the intended story of the game.
	"Dynamics" refers to the emergent behaviour of the game and the player during their interaction.	(1) Provide artifact behaviours, player behaviours, player-player interactions, and artifact-player interactions.	(1) Enable players to experience interactions with other players or game Artifacts.
	"Emergent narrative" refers to stories emerging through the dynamics of the game.	(1) Provide story elements through the player-player and artifact-player interactions.	(1) Enable players to create and experience their own stories.
	"Aesthetics" refers to the emotions evoked by the game.	(1) Provide a variety of aesthetics related to different player types and game genres.	(1) Enable players to internally interpret the game experience.
	"Interpreted narrative" refers to the player's mental interpretations of embedded and emergent narratives.	(1) Provide a variety of mental representations and interpretations of story elements.	(1) Enable players to internally interpret the intended and player-created stories.
Ryan et al., 2006 [cite]	"Autonomy" refers to the player's need for choice, control and freedom of their actions.	(1) Provide flexibility over movement and strategies; (2) Provide choice over tasks and goals; (3) Provide informative rather than controlling rewards; (4) Provide dynamic responses to players' actions; (5) Provide intuitive and user-friendly controls.	(1) Enable players to feel free and in control over performing actions; (2) Enable players to feel a sense of choice over pursuing goals.
	"Competence" refers to the player's need for challenge and feelings of capability.	(1) Provide intuitive and user-friendly controls; (2) Provide tasks with appropriate challenges to players; (3) Provide tasks with positive feedback.	(1) Enable players to feel appropriately challenged; (2) Enable players to acquire new skills; (3) Enable players to feel capable.
	"Relatedness" refers to the player's need for social connection with other players and artificial intelligence.	(1) Provide player-player and player-AI interactions.	(1) Enable players to feel connected with other players and artificial intelligence.
	"Presence" refers to the player's need for real and authentic experience within the game world.	(1) Provide interesting stories and visual environments; (2) Provide intuitive and user-friendly controls.	(1) Enable players to feel within and part of the game world.
Sweetser and Wyeth, 2005 [cite]	"Concentration" refers to the ability to concentrate on the game.	(1) Provide a variety of meaningful stimuli and relevant tasks that trigger and sustain player engagement and their concentration; (2) Provide high demands that are appropriate for the players' cognitive limits.	(1) Enable players to engage with a variety of meaningful stimuli and relevant tasks that trigger and sustain their engagement and concentration; (2) Enable players to feel that they are given appropriate demands for their cognitive limits.
	"Challenge" refers to sufficient and appropriate challenges for the player's skill level.	(1) Provide a variety of appropriate and increasingly more difficult challenges based on the skill levels of different players.	(1) Enable players to face a variety of appropriate and increasingly more difficult challenges based on their skill levels.
	"Player Skills" refers to the game supporting skill development and mastery.	(1) Provide online help, in-game tutorials, and easy/fun to learn/use mechanics and interface; (2) Provide appropriate increase in player skill and rewards.	(1) Enable players to engage with online help, in-game tutorials, and easy/fun to learn/use mechanics and interface; (2) Enable players to feel appropriately challenged and rewarded.
	"Control" refers to players feeling in control over their actions in the game.	(1) Provide game characters, units, interface, input devices, and shell that players interact with and feel in control of their actions; (2) Provide game world that can be impacted by player actions; (3) Provide opportunities for players to feel free to plan and perform their chosen actions.	(1) Enable players to feel in control of their actions when interacting with game characters, units, interface, input devices, and shell; (2) Enable players to feel their actions have an impact on the game world; (3) Enable players to feel free to plan and perform their chosen actions.
	"Clear Goals" refers to the game having clear and appropriately timed goals.	(1) Provide clear overriding goals early; (2) Provide clear intermediate goals at appropriate times.	(1) Enable players to understand game goals.
	"Feedback" refers to the game providing relevant feedback at appropriate times.	(1) Provide relevant feedback at appropriate times.	(1) Enable players to perceive relevant feedback at appropriate times.
	"Immersion" refers to deep but effortless engagement with the game.	(1) Provide opportunities for players to suspend their disbelief and to connect emotionally and viscerally with the game.	(1) Enable players to suspend their disbelief and to connect emotionally and viscerally with the game.
	"Social Interaction" refers to interactions between players in the game.	(1) Provide opportunities for competition, cooperation, and communication between players; (2) Provide in-game and out-of-game community spaces.	(1) Enable players to compete, cooperate and communicate; (2) Enable players to engage with in-game and out-of-game communities.
Tondello et al., 2017 [cite]	"Strategic resource management" refers to the game element that includes dynamics of strategic gameplay and resource management.	(1) Provide resources to manage; (2) Provide opportunities to strategize.	(1) Enable players to manage resources; (2) Enable players to strategize.
	"Puzzle" refers to the game element that includes a variety of puzzles.	(1) Provide different types of puzzles.	(1) Enable players to engage with different types of puzzles.
	"Artistic movement" refers to the game element that includes a variety of artistic expressions or body movements.	(1) Provide opportunities for artistic expression; (2) Provide opportunities for body movement.	(1) Enable players to artistically express themselves; (2) Enable players to move their bodies.
	"Sports and cards" refers to the game element that includes dynamics related to sports, cards, and gambling.	(1) Provide dynamics related to sports, cards, and gambling.	(1) Enable players to engage with dynamics of sports, cards, and gambling.
	"Role-playing" refers to the game element that includes dynamics related to role-playing.	(1) Provide fantasy or science fiction setting, avatars, and exploration.	(1) Enable players to explore fantasy or science fiction settings using avatars.
	"Virtual goods" refers to the game element that include dynamics of buying and collecting goods and resources.	(1) Provide the opportunity to buy and collect goods and resources.	(1) Enable players to buy and collect goods and resources.
	"Simulation" refers to the game element that includes the ability to simulate real-life scenarios.	(1) Provide opportunities to simulate real-life scenarios.	(1) Enable players to simulate real-life scenarios.
	"Action" refers to the game element that includes dynamics related to action and excitement.	(1) Provide opportunities to perform exciting actions in fast-paced scenarios.	(1) Enable players to perform exciting actions in fast-paced scenarios.
	"Progression" refers to the game element that includes the ability to progress towards power or learning.	(1) Provide opportunities to progress towards power or learning.	(1) Enable players to progress towards power or learning.
	"Multiplayer" refers to the game playing style that includes a variety of multiplayer interactions.	(1) Provide collaborative and competitive interactions between players.	(1) Enable players to collaborate and compete against others.
	"Abstract interaction" refers to the game playing style that does not directly immerse the player in the game.	(1) Provide isometric or top-down view.	(1) Enable players to play from an isometric or top-down view.
	"Solo play" refers to the game playing style that directly immerses the player in the game.	(1) Provide third-person view; (2) Provide free movement in the game world.	(1) Enable players to play from a third-person view; (2) Enable players to freely move in the game world.
	"Competitive community" refers to the game playing style that includes a variety of community interactions.	(1) Provide streaming, e-sports, or co-located interactions between players.	(1) Enable players to interact with others in a community.

Fig. A.9 Coding Schema 5

Framework	Reported engagement features		
	Reported definition of gameplay feature *# What is the definition of the gameplay feature according to the study?* # "Gameplay Feature X refers to"	**Reported engagement configuration of gameplay feature** *# How should the gameplay feature be configured (system state and system state change) to promote engagement according to the study?* # "Gameplay Feature X (game system element) should be configured to" # "Gameplay Feature X (gameplay experience aspect) should emerge from game system elements that"	**Reported engagement function of gameplay feature** *# How may the configuration of the gameplay feature promote engagement according to the study?* # "The configuration of Gameplay Feature X may"
Walk et al., 2017 [cite]	"Blueprint" refers to the concepts related to the setting, rules, and style of the game.	(1) Provide settings related to societies, cultures, religions, physics, characters, flora and fauna; (2) Provide rules related to the game, the world, the interface; (3) Provide styles related to the graphics, sound, narrative.	(1) Enable players to engage with settings related to societies, cultures, religions, physics, characters, flora and fauna; (2) Enable players to interact with rules related to the game, the world, the interface; (3) Enable players to experience styles related to the graphics, sound, narrative.
	"Mechanics" refers to the code of the game.	(1) Provide the code architecture, the input/output handling, and the implementation of the game rules and object interactions.	(1) Enable players to experience the effects of the code architecture, the input/output handling, and the implementation of the game rules and object interaction.
	"Interface" refers to game elements that communicate the game world to the player.	(1) Provide diegetic or non-diegetic, spatial or meta report system; (2) Provide graphic assets, sound assets, cut scenes or text on display.	(1) Enable players to perceive and interact with diegetic or non-diegetic, spatial or meta report system; (2) Enable players to perceive and interact with graphic assets, sound assets, cut scenes or text on display.
	"Dynamics" refers to emergent and unpredictable interactions between players, between player and game, and between game elements.	(1) Provide opportunities for interactions to emerge between players, between player and game, and between game elements.	(1) Enable players to interact with the game and other players, and to perceive the interactions between game elements.
	"Senses" refers to the sensory experiences that the player has in the game.	(1) Provide output devices and surroundings.	(1) Enable players to see, hear and sense things in the game.
	"Cerebellum" refers to the emotions that the player experiences in the game.	(1) Provide opportunities for the player to feel emotions.	(1) Enable players to feel emotions in the game.
	"Cerebrum" refers to the intellectual challenges that the player experiences in the game.	(1) Provide intellectual challenges.	(1) Enable players to face intellectual challenges.
	"Player-Subject" refers to a mental persona who interprets, filters and processes the game experience to the player.	(1) Provide game dynamics; (2) Provide antagonist.	(1) Enable players to experience game dynamics through the player-subject; (2) Enable players to face a worthy antagonist through the player-subject.
	"Perception" refers to the player's perception of the player-subject's interpretations and decisions.	(1) Provide game elements and dynamics.	(1) Enable players to perceive the interpretations of game elements and dynamics from the player-subject.
Xu et al., 2011 [cite]	"Device metaphors" refers to suggesting in-game functions based on familiar real-life objects.	(1) Provide appropriate visual, auditory, and haptic cues suggesting in-game functions.	(1) Enable players to perform actions by inferring an in-game function based on appropriate visual, auditory, and haptic cues.
	"Control mapping" refers to intuitive mapping between physical and in-game actions.	(1) Provide mechanisms for projection from screen to space; (2) Provide mechanisms for synchronous interaction with real-life objects and their mapped in-game objects; (3) Provide mechanisms for affecting the game state by manipulating the device.	(1) Enable players to point at, aim at, and select in-game objects; (2) Enable players to affect in-game objects by interacting with the real-life objects they are mapped to; (3) Enable players to affect the game state by manipulating the device.
	"Seamful design" refers to integrating the technological seams inherent to handheld augmented reality interfaces.	(1) Provide natural limitations to player actions; (2) Provide support or continue the game when tracking is lost.	(1) Enable players to perform actions within the technological limitations; (2) Enable players to continue their gameplay experience by ignoring or finding the lost tracking.
	"World consistency" refers to replicating or defying the laws and rules of the physical world in the digital world.	(1) Provide replicated properties of the physical reality in the game; (2) Provide subverted properties of the physical reality in the game.	(1) Enable players to transfer their real-life knowledge in the game and intuitively interact with the digital world; (2) Enable players to feel surprised and challenged.
	"Landmarks" refers to physical-digital landmarks that are used to navigate the hybrid space.	(1) Provide readily identifiable objects in the physical and digital world.	(1) Enable players to orient themselves and navigate the hybrid space; (2) Enable players to understand the relationships between the physical and digital worlds; (3) Enable players to experience the gameplay of other players from the spectator perspective.
	"Living creatures" refers to game characters that react to physical events, sound, and player movements.	(1) Provide game characters that mimic the behaviours of living creatures.	(1) Enable players to socially engage in the game and have genuine emotions.
	"Personal presence" refers to the players' sense of being in the digital game.	(1) Provide in-game reactions to player movement through the interface and camera point of view; (2) Provide intuitively controlled avatar; (3) Provide a digital world that can be changed by the physical actions of players.	(1) Enable players to feel that the game reacts to their physical movements; (2) Enable players to feel intuitive control over their avatar; (3) Enable players to feel the impact of their physical actions in the digital world.
	"Body constraints" refers to one player's movements constraining another player's actions.	(1) Provide competitive and cooperative opportunities for a player to constrain the actions of another player.	(1) Enable players to constrain each others actions by moving.
	"Hidden information" refers to a player having hidden information that can be revealed through movement or communication.	(1) Provide opportunities for players to hide or reveal information through movement and communication.	(1) Enable players to hide or reveal information through movement and communication.
Yee, 2006 [cite]	"Advancement" refers to the motivational component of gaining power, progress, status and wealth.	(1) Provide opportunities to gain power, progress, status and wealth.	(1) Enable players to gain power, progress, status and wealth.
	"Mechanics" refers to the motivational component of analyzing the rules to optimize character performance.	(1) Provide opportunities to analyze game rules; (2) Provide opportunities to optimize character performance.	(1) Enable players to analyze game rules; (2) Enable players to optimize character performance.
	"Competition" refers to the motivational component of challenging others.	(1) Provide opportunities to challenge and compete with others.	(1) Enable players to challenge and compete with others.
	"Socializing" refers to the motivational component of communicating with and helping others.	(1) Provide opportunities to chat with and help others.	(1) Enable players to talk with others, help them, and make friends.
	"Relationship" refers to the motivational component of forming long-term relationships with others.	(1) Provide opportunities to form meaningful relationships with others.	(1) Enable players to for long-term meaningful relationships with others.
	"Teamwork" refers to the motivational component of participating in a group.	(1) Provide opportunities to collaborate; (2) Provide group achievements.	(1) Enable players to feel satisfied for collaborating with others.
	"Discovery" refers to the motivational component of finding things that others don't know about.	(1) Provide hidden but discoverable things and lore.	(1) Enable players to discover hidden things and lore.
	"Role-playing" refers to the motivational component of creating a background story of the player character and improvising a story with other players.	(1) Provide opportunities to create a character history; (2) Provide opportunities to improvise story lines with other players.	(1) Enable players to create a character history; (2) Enable players to improvise story lines with other players.
	"Customization" refers to the motivational component of customizing the appearance of the player character.	(1) Provide customizable player character.	(1) Enable players to change appearances, accessories, style, and color schemes of character.
	"Escapism" refers to the motivational component of using online games to avoid real life problems.	(1) Provide relaxing online environment.	(1) Enable players to escape from real life.
Zagal et al., 2000 [cite]	"Rules and Goals" refers to game elements that define what can or can't be done in a game and game elements that provide objectives for players to pursue.	(1) Provide game elements that regulate the direction of and interactions in the game. (2) Provide game objectives.	(1) Enable players to interact in the game; (2) Enable players to pursue objectives.
	"Props and Tools" refers to game elements that define with what the game is played.	(1) Provide props that have decorative purposes; (2) Provide tools that have functionality.	(1) Enable players to look at props; (2) Enable players to interact with tools.
	"Player" refers to the person who starts a game in progress or "game instance".	(1) Provide opportunities for players to participate in the game.	(1) Enable players to participate in the game.
	"Social Interaction" refers to the characteristic that defines communication between players.	(1) Provide preferable player composition; (2) Provide appropriate game spaces; (3) Provide stimuli or natural opportunities for social interaction.	(1) Enable players to communicate with each other.
	"Competition and Cooperation" refers to the characteristic that defines differences between winners and losers or the pursuit of common goals.	(1) Provide participants to cooperate with; (2) Provide participants to compete against; (3) Provide non-exclusive goals.	(1) Enable players to cooperate; (2) Enable players to compete.
	"Synchronicity" refers to characteristic that defines simultaneous participation of players and the performance of independent but synchronized actions.	(1) Provide opportunities for synchronous play through rules, goals, props, tools and other players.	(1) Enable players to synchronously play with others.
	"Coordination" refers to the characteristic that defines the way the game process is controlled.	(1) Provide opportunities for solo or distributed coordination through rules, goals, props, tools and other players.	(1) Enable players to coordinate the game alone or together with others.
	"Prop and Tool Dependence" refers to the characteristic that defines the way games may or may not depend on the props and tools.	(1) Provide props and tools that are essential or non-essential to the game's rules and goals.	(1) Enable players to interact with props and tools that are either essential or non-essential for the game.
	"Existence of Meta-Gaming" refers to characteristic that defines the access to more information that some players may have.	(1) Provide opportunities for information asymmetry between players through game rules.	(1) Enable players to have access to information that others don't have.

Fig. A.10 Coding Schema 6