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Rethinking serious games design in the age of COVID-19: Setting the focus on wicked problems

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Abstract. We live in a complex world, in which our existence is defined by forces that we cannot fully comprehend, predict, nor control. This is the world of wicked problems, of which the situation triggered by the COVID-19 pandemic is a notable example. Wicked problems are complex scenarios defined by the interplay of multiple environmental, social and economic factors. They are everchanging, and largely unpredictable and uncontrollable. As a consequence, wicked problems cannot be definitively solved through traditional problem-solving approaches. Instead, they should be iteratively managed, recognizing and valuing our connectedness with each other and the environment, and engaging in joint thinking and action to identify and pursue the common good. Serious games can be key to foster wicked problem management abilities. To this end, they should engage players in collective activities set in contexts simulating real-world wicked problem scenarios. These should require the continuous interpretation of changing circumstances to identify and pursue shared goals, promoting the development of knowledge, attitudes and skill sets relevant to tackle real-world situations. In this paper we outline the nature, implications and challenges of wicked problems, highlighting why games should be leveraged to foster wicked problem management abilities. Then, we propose a theory-based framework to support the design of games for this purpose.

Keywords: Serious Games, Wicked Problems, Complexity, Game Design.

1 Introduction: the wicked age of COVID-19

We live in the age of COVID-19, an epoch in which a pandemic is forcing us to acknowledge that the world is not what we believed and perhaps wished it was. In this epoch we are realizing that a virus can trigger and catalyze processes that are changing our world in uncertain, concerning, and somewhat irreversible ways. In the age of COVID-19 we are reminded on a daily basis that our world is shaped by forces that generate extraordinary problematic situations, which affect our society, economy and environment, while overcoming our ability to comprehend and control circumstances. These are labelled “wicked problems”, because they shape the future of our world and our future in it, and because they defy and defeat ordinary approaches to “solving” problems [30]. Wicked problems situations are to a large extent unpredictable and uncontrollable, which makes them seemingly chaotic and intractable [21,

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30]. However, wicked problems can be continuously managed to promote the adaptation of social systems to everchanging and threatening circumstances [11, 26]. If appropriately designed, serious games can represent an optimal platform to develop knowledge, attitudes and skills specifically required for wicked problem management.

In this paper, we present a framework to support the design of serious games to learn wicked problem management. First, we review the nature, relevance and challenges of wicked problems. We then explain why games should be leveraged to learn how to manage wicked problems. Finally, we propose a theory-based framework to support the design of wicked problem management serious games.

2 The ordeal: nature and implications of wicked problems

2.1 The heart of wickedness: complexity, conflicting actors, and problem systems

Wicked problems are extraordinary types of problems. Just like an ordinary problem, a wicked problem is determined by an undesirable state of affairs that needs to be changed. However, ordinary problems can be analyzed to define what conditions need to be changed (initial state), what new state of affairs should be attained in order to improve things (goal state), and what approach should be adopted to transition from the problematic to the desirable state of affairs (problem solution) [1]. It can then be definitively solved by implementing the planned approach. This is not the case for wicked problems, since they are ill-defined situations in which problematic conditions, possible goals and viable approaches are to some extent unclear and mutable, due to their complexity [21].

Wicked problems are defined by large numbers of factors that interact in multiple ways [30]. This makes them highly complicated. Their complexity, however, transcends sheer complicatedness. Interacting factors change over time, and so do the ways they interact, as factors evolve and reorganize to adapt to external changes [28]. Furthermore, interactions between factors generate emergent systemic effects that propagate across time and space, and cannot be fully understood nor predicted based on the examination of individual factors and their interactions [24, 28]. In this sense, wicked problems behave as wholes greater than the sum of their parts. Complicatedness, adaptive change and emergent effects ultimately determine the true complexity of wicked problem situations, and make them not fully knowable, uncertain, unpredictable, and therefore uncontrollable. To worsen things, wicked problems usually involve diverse actors, who have different and often conflicting interests and needs, and are therefore affected in different ways by the same circumstances [8, 25]. Finally, wicked problems never come alone, as one problematic situation usually indicates the existence of a whole system of interacting problem scenarios [30].

Altogether, complexity, multiplicity and heterogeneity of actors, and co-occurrence of interacting problem scenarios make it impossible to determine, for any given situation, what the “problem” is, and what a “solution” could be. This makes wicked problems intractable through classic problem-solving approaches [21, 25, 30].

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2.2 How to tackle wicked problems: adaptive problem management

The ill-defined and seemingly chaotic nature of wicked problems should be continuously managed through iterative and adaptive processes [2, 26, 30]. These should rely on collaborative meaning-making, action and learning [3, 11, 25]. To this end, the management of a wicked problem should continuously integrate exploration and evaluation of circumstances, planning and action, and should be continuously informed by relevant environmental feedback (Fig. 1).

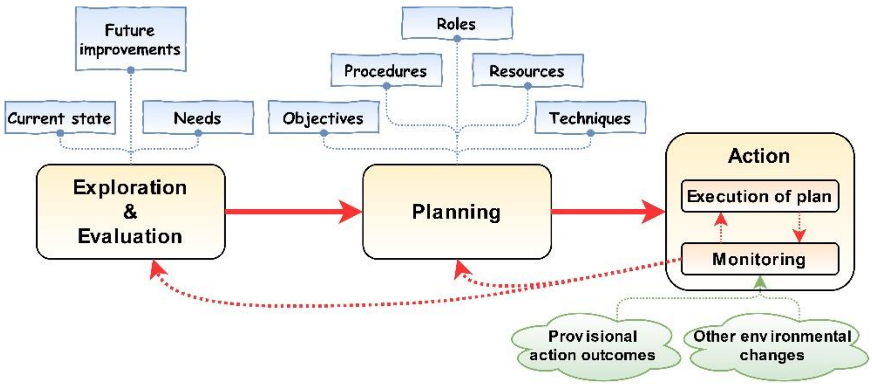

Fig. 1. Adaptive problem management process.

Exploration and evaluation are necessary to gain a systemic understanding of the current state of affairs, its implications for the involved actors, and possibilities for future improvements [2, 26]. These understandings should drive the planning of objectives to pursue and strategies to adopt. Objectives should reflect changes in the current state of affairs beneficial for all the involved actors, while strategies should define roles, procedures, techniques and resources required to achieve these changes [8, 11]. Planning should then drive action, acknowledging that in the arena of wicked problems there can be no "sticking to the plan". The execution of a plan should be underpinned by continuous monitoring and evaluation of provisional outcomes, and other environmental changes that might require adapting the problem management process, through a direct revision of ongoing plans, or a more substantial re-evaluation of the entire problem situation [3, 26].

Meaning-making is crucial in wicked problem management. Wicked problems require to continuously interpret things, relationships and events in order to infer how the world works, and define what should be done, why and how [17, 25]. Meaning-making ought to be collective and ensure the participation of all the actors affected by the problem situation. This is crucial to harmonize and integrate diverse and possibly conflicting worldviews and needs, identifying the common good and ensuring that objectives and plans reflect a shared vision of what should be done, why and how [11, 12, 25]. By extension, collective meaning-making should drive collaborative

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action. This is essential to enact plans requiring a diversity of competencies and resources that can only be provided through the joint effort of all actors [8, 11].

Finally, collective meaning-making entails collaborative learning. In order to identify mutually beneficial changes to pursue, formulate plans and adapt to changing circumstances, actors need to learn about one another and their environment [21]. The need to harmonize diverse and possibly conflicting interpretations of reality requires this learning to be an action-driven process of social construction of knowledge [11, 25]. This process benefits actors through enhancing their understanding of the world, developing their ability to devise and pursue better futures, and leading them to ponder and modify subjective beliefs and assumptions that might hamper the pursuit of the common good [3, 11].

3 The challenge: fostering wicked problem management abilities

Wicked problem management (WPM) requires knowledge representations suitable to identify and pursue the common good, and skill sets and attitudes required to form this knowledge and act accordingly [7, 21, 34]. Knowledge representations consist in conceptual models of problem scenarios, formed through meaning-making and suitable to drive decision-making and action. These models should be holistic, representing circumstances starting from global phenomena, and then modelling parts (human beings included) and interactions that might cause them, or be affected by them [11]. Models should also be pluralistic, acknowledging, reflecting and harmonizing diverse views and interpretations that actors involved in the problem situation might have [8, 25]. Attitudes consist in affective dispositions suitable to motivate purposeful engagement in wicked problem scenarios. Overall, these should promote a disposition to look after people, non-human beings and the broader environment, in the short and long term; and the confidence in the ability to act meaningfully to pursue the common good, even though this means constantly facing and adapting to circumstances that cannot be controlled [11, 21, 33]. Skill sets are cognitive and practical capabilities suitable to explore and transform problem scenarios, through engaging in purposeful interactions with relevant actors and environmental elements involved in them [7, 17, 34]. Altogether, the function of attitudes, skill sets and knowledge representations can be conceptualized as a form-inform-transform schema, whereby their interplay serves to (i) f*orm* new or revised knowledge representations, through continuous exploration of the problem situation and relevant environmental feedback; (ii) *inform* definition of goals and plans through these knowledge representations; and (iii) *transform* a problem situation based on set goals and plans.

Serious games represent optimal platforms to foster wicked problem management abilities, due to their potential to: (i) simulate complex dynamics and elicit problem management in conditions of complexity [16, 19, 22]; (ii) contextualize gameplay activities reproducing real-world settings and dynamics [35]; (iii) promote the integrative development of knowledge, attitudes and skill sets through engagement in meaningful activity [15, 20]; and (iv) function as collective learning environments exempt

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from spatiotemporal constraints that limit formal learning contexts [19, 35]. The nature of WPM suggests that these potentialities can be leveraged to foster WPM abilities by designing serious games based on the principles presented in Table 1.

Table 1. Principles to foster WPM abilities through serious games.

Gameplay contexts should mirror a wicked problem scenario of interest and promote iterative management abilities by reproducing:	
1	**Complexity conditions.** Gameplay scenario involving (i) game space articulated as a system of interrelated systems; (ii) events engendering change, unknowability, unpredictability, uncontrollability and uncertainty; (iii) ill-defined situations requiring players to make evaluations and decisions with incomplete and uncertain information; and (iv) collective tasks, involving social construction of knowledge, and collaborative evaluation of circumstances, decision-making and action.
2	**Contents.** Gameplay scenario (i) involving physical, social, economic and cultural settings characterizing a real-world scenario of interest; (ii) defined by multiple actors with conflicting needs and interests, emphasizing the significance of the scenario from different perspectives; (iii) promoting the development of knowledge representations, higher-order thinking and operational skill sets, and affective dispositions, relevant to tackle real-world scenarios.
3	**Process.** Iterative gameplay tasks (i) driven by and promoting meaning-making; (ii) requiring progressive construction of solutions, with ongoing revisions of plans and objectives; and (iii) fostering activity-based learning.

Addressing these principles requires rethinking: (i) what players should engage in and with; (ii) how learning processes involved in the gameplay experience unfold; and (iii) how these processes should be promoted "by design". To support the creation of wicked problem management serious games, we developed the WPM-SGD design framework. WPM-SGD comprises theory-based conceptual tools (models and guidelines) to facilitate the design of games suitable to promote wicked problem management abilities. The remainder of this article presents WPM-SGD components key to address the first of the three principles: complexity conditions. To this end, we outline the WPM- SGD tools relevant to incorporate key complexity conditions in WPM, dis- cussing their theoretical underpinnings, and presenting related examples where appropriate.

4 Rising up to the challenge: designing complexity in serious games to foster WPM

WPM-SGD was developed adopting a human factors design approach. The discipline of human factors and ergonomics (HFE) investigates the interaction between subjects and systems, to design systems to enhance human activity, psychophysical wellbeing, and overall systemic efficiency [27]. In terms of game design, adopting an HFE approach requires modelling the game space from a player perspective [18], accounting for (i) how players perceive and make sense of the game space, (ii) why and how they interact with it, (iii) how learning stems from their interactions with the game

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space, and (iv) which game elements are key to enable or hinder desirable interactions and their effects.

4.1 Modeling gameplay contexts as systems of systems: key requirements

In order to foster WPM, serious games should engage players with the conditions of complexity that make wicked problems intractable through ordinary problem-solving approaches. Managing wicked problems requires embracing a "system of systems" perspective. A wicked problem scenario should be treated as a part of a larger whole which comprises many other interdependent systems, so that what happens within a problem scenario may alter external systems, and vice versa [10, 30, 36]. Events local to a given problem scenario may generate effects that propagate globally, across time and space, affecting other systems. These effects may be somewhat indiscernible, unpredictable and uncontrollable. By the same token, the state of a problem scenario may be altered by external events. These events, their consequences and origins may also be somewhat indiscernible, unpredictable and uncontrollable. The degree of discernibility of all this depends on the information flows available to interpret what is happening or has happened, when, where, why and how. By extension, information flows allow anticipating future events and their effects, as knowledge of the past allows inferring patterns to predict future happenings [6]. Altogether, dynamics of propagation of event effects and information flows across systems generate change, unknowability, uncontrollability, unpredictability and uncertainty that define the complexity of wicked problems and make them extremely difficult to address [2, 30, 36]. In terms of game design, this implies that key complexity conditions characterizing real-world wicked problems can be reproduced through designing suitable (i) networks of interacting game elements, (ii) event generation and propagation schemas and (iii) mechanics of generation and propagation of game state information flows.

4.2 Systemic design of game contexts

To support the systemic modeling of the game context, we formulated a systemic model of game context expanding on our previous work [18]. Based on leading HFE perspectives, we conceptualized the gameplay context as a hierarchical system composed of *interaction clusters* (sub-systems) involving volitional agents, objects and environmental conditions [6, 10, 36]. Volitional agents can act purposefully to satisfy their needs, alone or in groups, whereas objects are purely reactive entities that change their states in response to external stimuli [18]. Environmental conditions are factors that affect the state of agents and objects, as well as their ability to interact with the rest of the environment [10, 36]. As they unfold, interactions between these elements change the state of the game space generating *events*. Some events involve state changes that can directly or indirectly affect the player's activity. We denominate these *defining events*, and their potential consequences for the player *gameplay effects*. Events can be directly or indirectly originated by player actions (*player-triggered events*), or by other game elements (*non-player-triggered events*). To exemplify all this, consider a hypothetical

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geopolitical simulation game, in which the player is a policy maker in the Republic of Muchocalor. Assume that the player has to deal with a situation in which a prolonged drought required extensive groundwater pumping, which caused severe groundwater depletion. In this case, groundwater depletion would represent a non-player-triggered defining event. The source of this event would be an interaction cluster comprising the landowners that recur to groundwater pumping (volitional agents), groundwater basins (objects), and the draught (environmental condition). Assuming that the player would have to regulate this problematic situation, a gameplay effect of groundwater depletion would be an increased gameplay challenge.

This conceptualization also supports the design of *propagation of events*. An event generated by an interaction cluster C1 could involve game state changes that interact with another cluster C2, generating a new propagating event. For example, in the above scenario, the groundwater depletion event would also involve depleted underground water basins turning into pits. These could then interact with another interaction cluster such as a road system, causing a cascading event: land subsidence due to loss of support below ground. This new event could then affect ground transportation, etc. Propagations could unfold as far as the designer decides, generating expanding networks of interdependent phenomena increasingly harder for players to interpret and predict.

Fig. 2 presents a schema of interaction clusters, generation and propagation of events, and illustrates the examples discussed above. This model can be used to plan networks of interacting elements, and the related generation of events. Through planning amount and scope of interaction clusters, events, and interaction and propagation chains, designers can define the complexity that players should tackle.

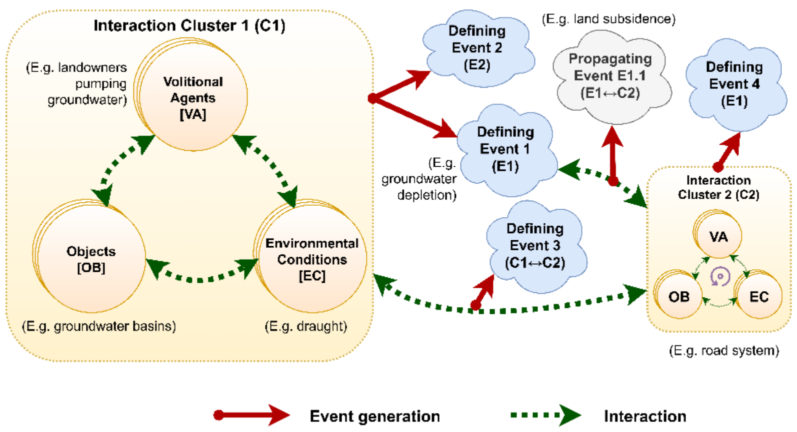

Fig. 2. CIEP model: prototypical **C**luster, **I**nteractions, and **E**vent **P**ropagation schema.

In real-world wicked problem scenarios not all events are equally discernible and influenceable by the involved actors [11, 26]. This is an important condition that should be reproduced in WPM serious games, as it is key to define unknowability,

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unpredictability, uncontrollability, and uncertainty of game situations. To support this, we propose a three-tiered hierarchical model of propagation of game events and information flows, based on our past research [18].

As subjects act, they perceive and interpret their surrounding environments acknowledging that there are dimensions that they cannot directly discern and/or influence with their actions [5]. Accordingly, we modelled the game context as a three-tiered system, to allow defining "by design" players' possibilities to perceive and interact with different elements of the game space. The three tiers consist in a *micro*, *meso* and *macro levels* (Fig. 3). The micro-context is players' primary focus of attention. It comprises: (i) entities that players can directly perceive, interact with, and are in fact involved in an ongoing gameplay task (e.g. helpers, enemies and tools involved in a current action plan); and (ii) environmental conditions that players could alter, and which influence the state of elements directly involved in ongoing gameplay tasks (e.g. ambient lighting affecting the visibility of enemies). The meso-context comprises elements that players can directly perceive and could interact with, even though these are not involved in any ongoing gameplay task. Players might need to deal with these elements, should their plans change (e.g. alternative or complementary tools that could be used; optional objects that could be collected; distant enemies that might be tackled; etc.).

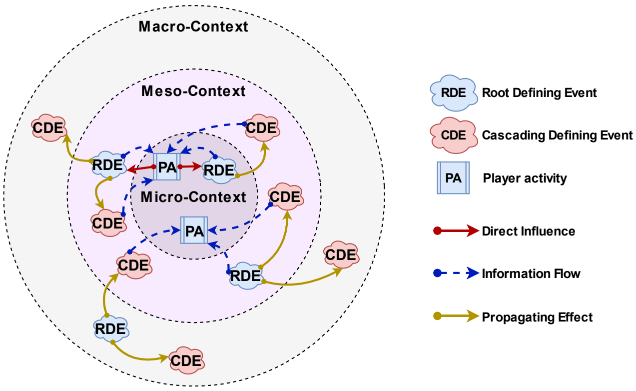

Fig. 3. 3T-Context: game context model to tierize clusters, events and information flows.

The meso-context thus represents a space of possibilities, which may allow or require players to modify their courses of actions by adapting current plans or formulating new ones. The macro-context reflects large-scale phenomena that originate from interplaying game events, and affect multiple aspects of the game space. It comprises elements that players cannot directly interact with, even though these define and explain many things and relationships in the game space (e.g. political systems; value systems; physical models; etc.). The macro-context reflects the history of past events leading to the present game state, and its understanding is crucial for players to forecast game states. Players can indirectly affect elements of the macro-context through cascading effects of gameplay tasks (e.g. a political

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system cannot be directly affected, and its existence can only be comprehended through manifestations such as trade regulations; however, actions boycotting trade can lead to a change in the political system). We propose in Fig. 4 key patterns of propagation of events and information flows, suitable to help designers plan the game context and anticipate possible effects on the player.

Fig. 4. ProPat model: key event and information flows propagation patterns.

Altogether, the models presented in Fig. 3 and Fig. 4 can help designers plan the distribution of interaction clusters, and map propagation of events and game state information flows. This can be useful to control what players should be able to discern and interact with, and consequently generate conditions of ill definition and uncontrollability that they should tackle. To further support this work, we propose in Table 2 a procedure to guide the design of game contexts.

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Table 2. Core procedure for the systemic modeling of gameplay contexts.

1	**Hierarchical systems modeling.** Define the gameplay context as a network of key interaction clusters, establishing for each cluster:
1.1	Components (volitional agents, objects and environmental conditions interacting in the cluster).
1.2	How components can interact.
1.3	Defining events generated by interactions within the cluster.
2	**Events description and propagation.** For each defining event, establish:
2.1	Game state changes generated.
2.2	Gameplay effects engendered by the game state changes.
2.3	Propagating events that can be generated, identifying additional clusters that contribute to their generation.
3	**Tierization of game elements and events in micro, meso and macro-context:**
3.1	Situate interaction clusters and events, in order to define possibilities/limitations for players to interact with them.
3.2	Define information flows propagation across tiers, in order to define possibilities/limitations for players to discern relevant aspects of the game context.

4.3 Detailed planning of information flows

As they play, players engage in meaning-making to continuously interpret the state of agents and objects, their interactions, the resulting events and the corresponding effects [5, 18]. Providing players with information adequate to feed meaning-making is essential to promote gameplay motivation and progression [18], support desirable game-based learning [20], and elicit the development of desirable knowledge representations, skill sets and attitudes [17, 21]. Information should also be limited, to reproduce ill definition characterizing real-world wicked problem scenarios [8, 17]. Planning game information flows is therefore challenging, and requires accounting for how information can affect meaning-making, learning, motivation and decisions-making. Fabricatore and Lopez [20] proposed a human factors model of the gameplay activity suitable to address all this (Fig. 5.). The authors conceptualized game-based learning as the outcome of continuous meaning-making processes unfolding through interaction with the gameplay context. Meaning-making is intended as a process of formation and update of mental representations of the game context [6]. Through this process, players perceive and interpret things, events and relationships as they interact with the game space, forming and updating mental representations based on their thoughts and feelings [6, 20]. Players then use mental representations to define further interactions with the game space, in a cyclical process that engenders the integrative development of knowledge representations (i.e. mental representations), affective dispositions, and skill sets required to think, feel and act meaningfully upon the game space [20, 23]. Learning can then be the product of social exchanges and negotiation [14], when players are required to interact with other game actors (both human and synthetic).

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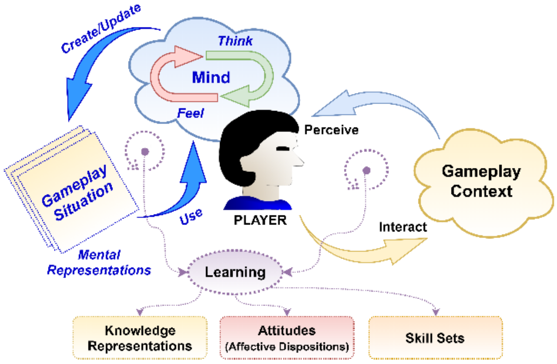

Fig. 5. InAcLE model: process integrating Interpretation, Action and Learning through meaning-making.

Based on these conceptualizations, we argue that in WPM serious games information flows should be planned accounting for:

1. What information fully describes a relevant interaction cluster, an event, its source, and its designed gameplay implications.
2. How players could interpret this information.
3. What knowledge representations they could form based on the provided information.
4. Which decisions they could take, based on their interpretations.

To support this, we created TFLD (Fig. 6), a tool for the design of information flows suitable to promote the formation of mental representations driving desirable player thinking, feeling, learning and decision-making. TFLD comprises a method for the analysis of gameplay situations, and the consequent planning of information flows suitable to:

1. **Support gameplay progression**, by promoting the formation of mental representations suitable to motivate and define gameplay goals and tasks.
2. **Promote the development of desirable knowledge representations**, by providing information suitable to focus the player attention on relevant matters.
3. **Encourage desirable player decisions**, by promoting the formation of mental images that emphasize the relevance and adequacy of specific decisions.
4. **Stimulate desirable attitudes and interpretation skill sets**, by providing information that stimulates desirable affective dispositions, and elicit required skills.

The method is complemented by a model to support the analysis of gameplay situations in order to identify key information that defines the situation, possible interpretations that players could give to this information, and key decisions that they could make based on these interpretations. The TFLD tool is available online at: https:/bit.ly/2DDqN2P

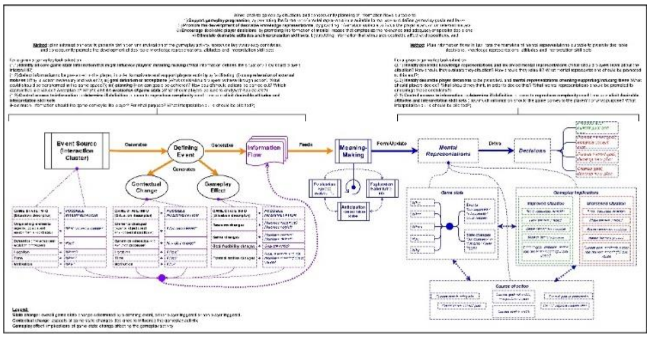

Fig. 6. TFLD tool: conceptual instrument to support the design of information flows to promote desirable **T**hinking, **F**eeling, **L**earning and **D**ecision-making.

4.4 Collective engagement

Player engagement in collective processes is a further condition that WPM games should reproduce. This is important for two reasons. Firstly, the complexity of wicked problem scenarios is largely due to the involvement of social communities and actors with diverse and often conflicting needs and worldviews [8, 26]. Hence, WPM usually requires engaging in shared and oftentimes conflictive evaluation, decision-making and action processes [11, 12]. Secondly, fostering learning in complexity scenarios requires engaging learners in collective processes of knowledge construction [14, 21].

Exploring how to promote collaboration in serious games is beyond the scope of this paper. A large body of literature has already investigated the benefits and implementation of collaborative learning in serious games [9, 29]. The field of computer-supported collaborative learning represents another valuable source of information concerning why and how to promote collaborative learning through simulations and games [13]. We will however highlight that, in order to promote WPM, collective gameplay activities should be designed accounting for three key principles:

1. Players/learners should engage in social construction of knowledge, and collaborative evaluation of circumstances, decision-making and action [8, 11, 14, 19, 21].
2. Players should interact and negotiate with other agents, who should have different and conflicting roles, needs, interests and worldviews [16, 19, 20].
3. Collective activity does not require engagement with other human players. Agents driven by artificial intelligence can also be leveraged to create single-player games suitable to promote collective activities in complex scenarios [4].

4.5 Target skill sets and attitudes

The tool presented in section 4.3 emphasizes the importance of designing situations and related information flows suitable to promote desirable skill sets and attitudes [20].

Fabricatore and Lopez [21] proposed an integrative framework of skill sets and attitudes relevant to engage in WPM (Table 3 and Table 4), extrapolated from an extensive review of the literature on wicked problems [e.g. 8, 17, 26, 30]. In order to support the design of WPM serious games, we expanded this framework by formulating transferable design approaches to promoting WPM skill sets and attitudes in new games based on the commercial games *Sky: Children of the Light* (thatskygame.com) (Table 3) and *Minecraft* (www.minecraft.net) (Table 4).

Table 3. Attitudes required to manage wicked problems

Attitude	Example from *Sky*	Design approach
Global belongingness. Sense of belonging to a global community which forms an organic whole with the environment. Fosters sense of responsibility for life and diversity, present and future.	Always present shadows of other players who are striving towards restoring the light in the universe together with the player.	Highlight to players real-time state of other players engaged in pursuit of shared goals and/or affected by shared circumstances.
Emotional commitment to sustainable development. Sense of responsibility to safeguard the future of our global community and its environment.	Player reliving the tragic memories of Ancestor Spirits and meeting other players who are struggling against the darkness.	Highlight to players the emotional influence that game characters have on each other and the player.
Compassionate altruism. Concern for the well-being of human and non-human others, and disposition to support others. Fosters sense of responsibility for life and diversity.	Ability of players to gift each other hearts and candles as a form of communication towards building friendships to defeat the darkness.	Highlight to players alternative ways of communicating with and helping each other by giving up personal resources for shared goals.
Confidence action capacity. Reliance on individual and collective capacity to act. Fosters overcoming feelings of powerlessness originated by the scale, uncertainty and uncontrollability of wicked problem situations.	Support and guidance that players receive from others who have walked the challenging path in front of them to reunite the stars in the sky.	Highlight to players the guidance and success of others who have encountered similar challenges in the game.
Hope in action effects. Confidence that individual and collective action can have meaningful impacts. Fosters overcoming powerlessness originated by wicked problem situations.	Ability of players to leave light behind for others in the hope of helping them the same way they were helped with light left behind from past spirits.	Highlight to players ways of guiding and supporting each other after overcoming challenging obstacles in the game.
Adaptivity. Acceptance that change, uncertainty and uncontrollability drive our world, and that we can as well change, adapt and develop. Fosters resilience to external changes, and iterative processes of co-evolution with the environment.	Need to re-explore the continuously updating realms of Heaven in order to achieve their aim of defeating darkness.	Highlight to players the changing state of the game's world and the progression requirement for them to re-explore newly developed scenarios.

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Table 4. Skill sets required to manage wicked problems

Skill set	Example from *Minecraft*	Design approach
Creative thinking. Ability to purposefully generate novel ideas to model and act on a situation of concern, possibly dissociated from previously-acquired frames of reference. Fosters adaptation to environmental changes, devising feasible goals, and evaluating implications of action.	Players explore new paths in the world, building new structures for survival and crafting new tools for progression through the interaction with the grid of blocks which makes up the game's world.	Highlight to players the alternative states and functions of game objects and agents which players can interact with for unique purposes.
Systems thinking. Ability to interpret real-world entities through conceptualizing them as systems, presenting emergent properties and behaviors that cannot be explained considering parts in isolation. Fosters managing mutability and unknowability of wicked problem situations.	Complex relationships between the game's day and night cycle, biomes' features, block types, extracted resources and mobs' behaviors (animals and creatures).	Highlight to players their influence on game states after interacting with objects and agents, and the relationships between these game elements.
Ill-defined problem solving. Ability to continuously manage problem situations through an iterative process of design and implementation of strategies, pivoting around emergent results of action. Fosters dealing with complex environments.	Unpredictable and uncontrollable behaviors of passive and hostile mobs who players have to deal with.	Highlight to players the unpredictable nature of game states, objects and agents that they have to interact with.
Analogical reasoning. Ability to identify similarities between two situations, and use these to hypothesize other similarities. Fosters identifying systemic recurrences, establishing patterns and predicting future situations accordingly.	Similar response to players interacting with or creating new and different types of blocks in the game such as wood, crops, ore, enemies, buildings, etc.	Highlight to players the similar response to interacting with different but related game objects and agents.
Deductive reasoning. Ability to formulate logical conclusions based on generally accepted statements or facts. It allows to safely predict results, informing "justification".	Day and night cycle which affects enemy behavior and player's vital signs in the game.	Provide information regarding simple causal relationships and then require players to use it to deduce new causal relationships.
Inductive reasoning. Ability to form a generalized conclusion based on what is particularly known or observed. It allows to form hypothesis, informing "discovery".	Predictable generation of valuable ore blocks or lava blocks promoting meaningful decision-making.	Highlight to players the probable state of game objects and agents based on previously revealed information.
Abductive reasoning. Ability to form a probable conclusion based on the information that is known. It allows to create value, informing "design".	Players choosing locations for their shelter, mine, farmland and craft area based on real-world information and the grid of blocks.	Highlight to players the functional similarities between states, objects and agents in the game and their respective real-world analogues.

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Social skill sets (pluralism, negotiation, dialogue, communication, sharing). Abilities that enable and drive social negotiation processes key to understand others' perspective, formulate shared worldviews and purposes, and plan joint action. Foster adequate involvement of all key stakeholders.	In-game chat allowing players to communicate while sharing limited resources and tools and negotiating preferences and responsibilities for mining ore, gathering food or building shelter.	Highlight to players the ways they can communicate with each other in order to manage shared resources and achieve common goals.
Operational skill sets. Abilities required to interact with reality by operating objects which, depending on the context, may serve to achieve set purposes. They are essential to implement planned actions.	Similarity and simplicity of operations such as collecting grass, mining ore and attacking enemies which allow for complex and meaningful actions.	Highlight to players the similar ways in which they can interact with different objects in the game for unique purposes.

5 Conclusions

The future of our world is shaped by forces that we cannot fully comprehend, predict nor control. These originate wicked problems that define our environments, challenge our ways of life, and even threaten our very existence. In this paper we explored what wicked problems are, and why they defeat ordinary problem-solving approaches. We emphasized that wicked problems cannot be definitively solved. However, they can be iteratively managed through collective processes aimed at identifying and pursuing the common good, in order to continuously adapt to changing circumstances.

Managing wicked problems requires specific attitudes, skill sets and knowledge representations that cannot be easily fostered through formal education. Serious games can be leveraged to overcome this limitation. To this end, they should be designed to engage players in gameplay contexts mirroring wicked problem scenarios. Unfortunately, the literature on serious games and wicked problems is scarce. To our knowledge, there are very few contributions aimed at supporting the design of serious games focused on wicked problems [e.g. 31, 32], and none of them focuses on what wicked problems are, how and why they should be tackled through iterative problem management processes, and how games should be designed to foster WPM abilities. We developed the WPM-SGD framework to address this gap.

In this paper we presented WPM-SGD conceptual tools aimed at supporting the replication of key complexity conditions that characterize wicked problem scenarios, and the design of information flows suitable to motivate and support gameplay progression, and foster the development of WPM skills sets and attitudes. These tools represent a portion of what is needed, as WPM-SGD is a work in progress. In line with the principles presented in Table 1, we plan to complete the WPM- SGD framework by developing conceptual tools focused on supporting the reproduction of key types of contents commonly found in wicked problem scenarios (e.g. sociocultural and physical settings), and the articulation of gameplay tasks to mimic the structure of WPM processes. Furthermore, we plan to develop instruments for the evaluation of serious games focused on wicked problems (e.g. sustainability games).

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In conclusion, we believe that significant efforts should be made to advance research into the design and use of serious games to promote wicked problem management abilities. We consider WPM-SGD a contribution to this endeavor, and we hope that it can serve to support designers, and orient future research.

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