A Framework for Conducting Research and Designing Games to Promote Problem Solving

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Statement of the Problem

Many have argued that games address critical thinking and problem-solving skills (e.g., Gee, 2007; Greenfield, 2010; Van Eck, 2006 & 2007). Unfortunately, what research exists on this tends toward the descriptive rather than the empirical. Descriptive analysis can illustrate how some kind of problem-solving *process* is occurring within a game (e.g., scientific method), but it cannot tell us about the *kind* of problems, how often they occur, for how long, and, most importantly, how effective a given game is at promoting problem solving skills. This distinction is critical to the advancement of claims about games and problem solving. While we may all agree that games are problems and that completing games means players are engaged in successful problem solving, we cannot say what kinds of problems players are able to solve, nor what kinds of games and game features may support (or inhibit) different kinds of problem solving. Problems vary by domain, cognitive requirements, and many other factors; if we want to design games for specific learning domains, we must understand these problem types and how they may relate to different kinds of game play. This will require rigorous, empirical testing and design of games for each kind of problem solving we are interested in.

Unfortunately, we are not prepared to conduct the kind of research that will answer these questions. Current game taxonomies are inconsistent and often contradictory, having their origins in film studies and relying on common parlance. Conducting empirical research on problem solving and games will require that we be able to manipulate and control for different types of games so that we can examine what *kinds* of games promote problem solving better than others. At the same time, we recognize that games that share the same genre can be very different experiences and that some games cross genre boundaries (e.g., action-adventure). Even were this not the case, any given game is likely to vary in terms of pace of play, amount of interactivity required, number of problems presented, and so forth. These are differences that must somehow be accounted for.

This challenge is compounded by a lack of awareness on the part of most serious games researchers regarding existing problem types and problem-solving research. We require the same level of precision in our treatment of problem solving as we do in our definition of game typologies. To design a game to promote problem solving, we must know what kind of problem we are interested in: creating a menu for guests who have different diet restrictions, troubleshooting a car that won't start, diagnosing a patient's back pain problem, or solving global warming? Each type of problem differs significantly in structuredness, requirements for prior knowledge, ability to embed other subproblems, and cognitive structure, and therefore require different means of instruction (or game design).

Fortunately, cognitive psychology and instructional design have been studying problem solving for many years, and a rich body of research exists which can help inform our studies and design of problem solving in games. In this chapter, we attempt to bridge theory and practice by examining the relationships between games, problems, their cognitive processes, and instructional design. It should be noted that this framework is only a start; we have no more empirical evidence for the problem typologies we reference and rely upon than game researchers do for the ability of games to promote those different types of problems. Yet theoretical research on problem solving exists which has been studied, evaluated, and conceptually validated through peer review. This seems a good place to begin the process of generating empirical evidence for problem solving and games.

Theoretical Framework

Problem Solving

It is generally accepted in cognitive psychology that a problem has an initial state and a goal state. The initial state is the set of information and resources present at the beginning of the problem. The goal state is the information and resources that will be present when the goal has been met. The problem solver uses a representation of that goal state when considering how to proceed, which usually takes the form of doing things to reduce the disparity between the initial state and the goal state. The strategies s/he uses and the process by which s/he thinks about moving toward the goal state within the constraints of the problem and his/her prior knowledge are collectively referred to as the problem space. Most recently, Jonassen (2000, 2002) and Jonassen and Hung (2006, 2008) have proposed a typology of problems and associated prescriptions for the design of problem-based learning and instruction to promote problem solving in general. If games themselves are examples of problem solving, they should share to the same kinds of characteristics as different problems have. A closer inspection of this literature to see if and how it can be mapped to the study and design of serious games may yield important findings.

Games and Problem Solving

Jim Gee (2007) has argued that all games are situated, complex problem solving, and others have made the same point (e.g., Kiili, 2007). The core of our argument is that problems are highly differentiated by context, purpose, and domain, that different types of gameplay have their own affordances, and that it is necessary to understand problem types and gameplay types in order to align them meaningfully in the design of games to promote problem solving, or to conduct research on the effects of gameplay on problem-solving skills. There are three dimensions upon which a problem itself may vary: structuredness, cognitive components, and domain knowledge. Space does not allow a full accounting these dimensions, and the reader is referred to our work on this elsewhere (Hung & Van Eck, 2010). Likewise, we rely on an in-depth analysis of gameplay types, which we are able only to touch upon here, and the reader is referred to the aforementioned chapter for full accounting of gameplay types and interactivity.

Problem Structuredness

Jonassen (1997) argues that structuredness describes the *reliability* of the problem space in terms of the ratio of the information about the problem known and unknown, the number of variables, the number of possible solutions, and the degree of ambiguity involved in being able to assess one's success in solving the problem. Video games (or, more precisely, the gameplay that makes up different video games) also vary on a continuum from highly structured to poorly structured, so structuredness becomes one dimension upon which we can categorize both games and problems.

Cognitive Processes in Problem Solving

Solving different problems also relies on different kinds of cognition. There are six main cognitive processes relevant to problem solving as we discuss it: Logical thinking (the mental process that infers an expected event as a result of the occurrence of its preceding event or evaluates the validity of the conditional relations of these events), analytic thinking (identifying and separating an object, essay, substance, or system into its constituent components, examining their relationships as well as understanding the nature, behaviors, and specific functions of each component), strategic thinking (an integration process of synthesizing and evaluating the analytical results of a given situation and generating the most viable plan with intuition and creativity), analogical reasoning (the mental process by which an individual "reason[s] and learn[s] about a new situation (the target analogue) by relating it to a more familiar situation (the source analogy) that can be viewed as structurally parallel" (Holyoak & Thagard, 1997), systems thinking (the cognitive reasoning processes that consider complex, dynamic, contextual, and interdependent relationships among constituent parts, and the emerging properties of a system, (Capra, 2007; Ossimitz, 2000), and metacognitive thinking (the cognitive process that an individual is consciously aware of and which he or she articulates to various aspects of his or her own thinking processes). Different problems and different kinds of gameplay will support these types of thinking in different ways. Therefore, they become important for understanding how gameplay and problem solving can be aligned.

Domain Knowledge

In addition to structuredness and cognitive composition, problems will vary by the domain knowledge they require. There are many kinds of domain knowledge that may be required for problem solving including declarative knowledge, procedural knowledge, concepts, and principles. It is not necessary to be an expert in applying this terminology so much as it is critical that each type of knowledge be explicitly examined during the problem design stage to ensure that all domain-specific prerequisite knowledge be identified, classified, and pretested. We argue only that if the designer's goal is to promote problem solving and that problem requires prerequisite knowledge, one must include prerequisite knowledge as a design goal or the problem must be reconceptualized such that it does not require that prior domain knowledge.

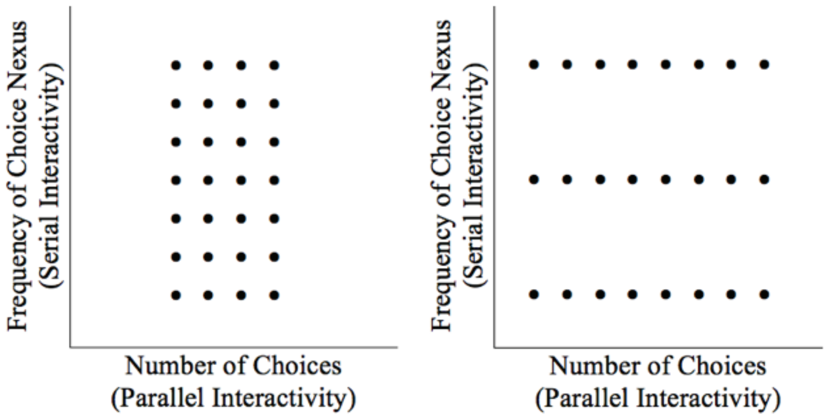
Classifying Gameplay Types using iGrids

The variance of problems along dimensions of structuredness and cognitive processes presents one challenge to the research and development of games for promoting problems solving. Yet games themselves vary greatly as well, as can be seen in classification systems (e.g., Apperley, 2006; Frasca, 2003). And because no one classification system is widely accepted nor completely compatible, our task is made even more difficult. Games often employ multiple gameplay strategies from different genres within the same game, leading to hybridized descriptions like action-adventure that work against meaningful classification. So how are we to distinguish among games (or types of gameplay) in a way that makes possible the empirical research and design of games to promote problem solving? While serious game researchers may not agree on different game genre classifications, most might agree that interactivity is one of the hallmarks of video games. This provides one means of classifying gameplay in a way that crosses all game types:

> The smallest unit of interactivity is the choice. . . . Choices are made in time, which gives us a two-dimensional grid of interactivity that can be drawn for any game. First, in the horizontal direction, we have the number of simultaneous (parallel) options that constitute the choice that a player is confronted with at any given moment. Second, in the vertical direction, we have the number of sequential (serial) choices made by a player over time until the end of the game (Wolf, 2006).

Wolf (2006) calls this a Grid of Interactivity, and we refer to them as iGrids. Frequency of choice and number of choices make good initial measures of pace, complexity, and cognitive load, and we believe these constructs impact problem solving and problem typology differentially. Wolf points out that it is not possible to map an entire game space on a graph, nor do we mean to suggest they otherwise. Nonetheless, such plots remain a useful tool for conceptualizing the issue of interactivity and one which we can rely on as a first step to further defining the kinds of gameplay that differentially support different problem types.

Although genre-based taxonomies of games are problematic, for now we will refer to genre-based terminology for the purposes of illustration. To understand an iGrid, imagine Aristotelian archetypes of different game genres such as "action" and "simulation" (see Figure 1).



e.g., Left 4 Dead (Valve, 2008) e.g., Civilization Series Games

Figure 1: iGrids for two different gameplay types.

The x-axis represents parallel interactivity, which is the number of choice options a player has at a given point in time (called a choice nexus), while the y-axis represents how often the player is presented with a choice nexus. For example, the game represented by the iGrid on the left of Figure 1 forces the player to make choices frequently over the course of the game with little time *between* choices but presents *few options* to choose from at those points. In the iGrid on the right, we see a game that presents *many options* to choose from but which forces the player to make choices *fewer times* over the course of the game with long periods of time between choices. Of course, there are action games with more parallel choices (e.g., weapons, running vs. hiding, inventory, armor, etc.) and periods of gameplay with lower choice nexus frequency. Likewise, games like those in the Civilization series *allow* near-continuous serial opportunities for interaction, but they do not *require* it.

iGrids, as measures of gameplay, become useful tools for discussing the differences in games that are likely to impact learning. While not sufficient on their own to fully delineate different types of gameplay, they at least provide an additional point of reference for communicating what is meant by whatever labels we use to describe games (e.g., action or strategy). Further, and most importantly, they allow us to describe game*play*, which after all can vary dramatically over the course of a single game. It will be important to be able to describe the key characteristics of gameplay in our quest to measure the ability of different types of gameplay to promote different types of problem solving.

By combining iGrids with an analysis of game/gameplay types using the same dimensions and characteristics that are used to differentiate problem types, we are able to develop a framework for describing games/gameplay that makes further study possible. In our discussion, we rely on terminology regarding gameplay which we have fully articulated elsewhere (Hung & Van Eck, 2010). Rather than generate new terminology and labels for the resulting taxonomy, we rely on existing taxonomies (e.g., Apperley, 2006) with some modifications. The resulting classifications are in some cases significantly different than common parlance, however. For example, Frasca's (2003) classification would list *SimCity* and *Flight Simulator* as simulations, whereas our analysis of gameplay suggests that *SimCity* is a strategy game (optimizing a system by strategically balancing factors) and *Flight Simulator* is a simulation game (a test of coordination of perception, cognition, and muscular control). Likewise, Apperley's classification would put FIFA Soccer and SimCity together as simulations, whereas we maintain that gameplay and cognitive characteristics make FIFA Soccer an action game. Space does not allow a full accounting of game play types (Action, Strategy, Simulation, Adventure, Role-Playing, and Puzzles), but Figure 2 presents the iGrids for each type.

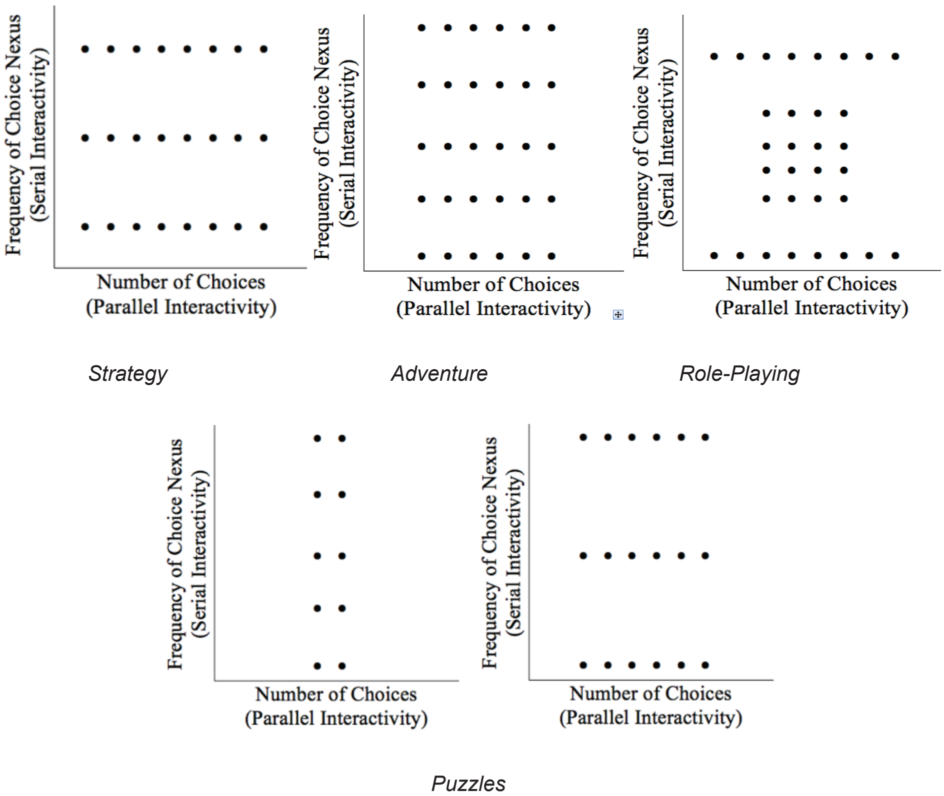


Figure 2: iGrids for five other gameplay types.

It should be noted that our categories are not intended to represent entire games as products; any given game will embed a variety of these gameplay types. But by focusing on the essential characteristics of gameplay *at any given moment*, we can make better determinations about what kinds of learning activities may or may not be best supported at a given time.

Problem Typology

Now that we have outlined our gameplay typology, we turn out attention to problems themselves. Jonassen (2000) has constructed a comprehensive typology consisting of 11 types of problems:

- Logical problem
- Algorithm problem
- Story problem

- Rule-use problem
- Decision-making problem
- Troubleshooting problem
- Diagnosis-solution problem
- Strategic performance problem
- Case analysis problem
- Design problem
- Dilemma problem

Space does not allow for a full accounting of all these problem types and examples. The reader is referred to Jonassen's text referenced above, as well as our previous work (Hung & Van Eck, 2010). Suffice it to say that each problem type varies along key dimensions of cognitive composition (e.g., types of reasoning), structuredness, and requirements for domain-specific knowledge.

Blending these dimensions with iGrids and our analysis of gameplay types, including game-specific dimensions like psychomotor skills and the affective domain, it becomes possible to align problem-types and gameplay types along the dimensions that both share, and thus propose a framework for which kinds of gameplay types will support which kinds of problems, best (see Figure 3).

Knowledge and Cognitive Process														
	Domain–specific knowledge[1]				*Higher–order thinking*						*Psychomotor skills*[2]		*Attitude change*[2]	
Problem type	Declarative	Procedural	Concepts	Principles	Logical	Analytic	Analogical	Strategic	Systemic	Metacognitive	Muscular movement	Muscular–cognitive coordination	Shift of belief system	**Game type**
Logical					+	+								Adventure; Puzzle
Algorithmic		+	+	+	+									Adventure; Puzzle; Action
Story	+	+	+	+	+	+	+							Adventure; Puzzle
Rule-use	+	~	~	+	+	+								Action; Strategy; Roleplaying; Adventure; Puzzle
Decision–making		~	+	+	+	+		+	~	~				Action; Strategy; Role-playing; Simulations; Adventure
Troubleshooting		+	+	~	+	+	+	+	~	~				Simulations
Diagnosis–solution		+	+	+	+	+	+	+	+	+				Simulations; Strategy
Strategic Performance		+	+	+	+	+	+	+	+	+	+	+		Action; Roleplaying; Simulations; Adventure
Case Analysis			+	+	~	+	+		~	+			~	Strategy
Design			+	+	+	+	+	+	+	+				Strategy
Dilemma				+	+	+	~	+	+	+			+	Strategy; Roleplaying

1 For Psychomotor Skills and Attitude Change: domain-specific procedural and principle knowledge and metacognitive thinking are assumed.

2 For the learning type under Domain Knowledge, application of the knowledge is also assumed in this chart.

+ signifies "always required."

~ signifies "sometimes required."

Figure 3: Framework for aligning problem and gameplay types.

This allows for both the design of games to promote specific kinds of problem solving and for the design of research to test the effects of varying specific kinds of gameplay on different kinds of problem solving. We can then also examine things like varying pace of play, frequency of problem solving, length of play over days, and other variables to establish heuristic design models and an empirical research base on problem solving and games. Knowing about different problem types allows us to see existing games in a new light. For example, dilemma problems can be seen in persuasive games such as *Darfur is Dying* (mtvU, 2009). But more importantly, knowing how those problem types themselves vary along the dimensions of domain-specific knowledge and required cognitive processes shows us that what superficially may appear to be similar games are in fact quite different in terms of their ability to support problem solving. For example, many might say that *September 12* (Newsgaming.com, 2003) and *Darfur is Dying* are both dilemma games, when in fact *September 12* is too well structured and stripped of context to fully support dilemma problems.

Relying on iGrid typologies of gameplay rather than on genre classifications similarly promotes more precise analyses of games and problem solving. By focusing on archetypal gameplay styles, we can see how strategy and role-playing games seem best suited for dilemma problems, for example. Further, we are able to apply this reasoning to hybridized games that might at first glance appear to not support different kinds of problem solving. Space does not allow a full accounting of every problem type and every gameplay type (iGrid), nor how they each are aligned, but this general description and the following example may suffice to illustrate the logic behind blending them.

Extending our example of the dilemma problem, the game *Bioshock* (2K, 2007), which many might categorize as adventure-action hybrid, is in fact a hybridization of action, adventure, and strategy. The game *Bioshock* pits the player against a variety of challenges in an underwater city named "Rapture." As with *Left 4 Dead* (Valve, 2008), the player must make their way through the city without being killed by Big Daddies (giant modified humans in diving suits) and demented humans while collecting weapons and resources. Among these resources are plasmids, which grant special powers by virtue of genetic modifications, and which are injected via syringes. They key to unlocking the powers of plasmids lies in the collection of ADAM, which can only be obtained in the game from Little Sisters, who appear to be preadolescent girls. Little Sisters are always accompanied by Big Daddies, who must be killed before the player can collect ADAM. The dilemma problem in the game occurs with the decision on how to harvest the ADAM. One way results in the death of the Little Sister but results in a large amount of ADAM. The other way saves the Little Sister but results in less ADAM. While this choice seems to be pretty simple (two choices) the choices have a significant impact on the difficulty of the game and the way it proceeds. Additionally, whereas the binary choice in *September 12* (Newsgaming.com, 2003) is limited to the same instances and has the same results easily seen in a short period of time, in *Bioshock* these choices are distributed over the course of up to 50 hours of gameplay with relatively high frequency (medium serial interactivity), and the effects of these choices are not fully realized until near the end of the game. Thus, it is possible to support dilemma problem solving across the full arc of a game which itself is interspersed with other gameplay types, which in their own right may support other kinds of problem solving.

Finally, while our purpose is to outline a mechanism by which problem types with their associated cognitive requirements can be matched to different styles of gameplay, the end result also provides significant guidance for design and development of the games themselves. Because the study of problem solving within education and instructional design has been going on for decades, a rich body of research and best practices exists for supporting problem solving. Knowing, for example, that a problem is highly structured implies that less support should be provided for its solution, while ill-structured problems will require addition scaffolding and strategies to avoid cognitive overload. On the other hand, well-structured problems that occur during games with hybridized gameplay styles may indicate the need for more support than otherwise. When the problem solving itself is driving the game design, we may deliberately modify the form and frequency of a different gameplay styles in order to better support the problem (once we have conducted the empirical research to know how to promote different problem types, that is!). Knowing the kinds of cognitive processes involved also may help guide our selection of in-game tools, story structure, and objectives as well.

If we are to build games that promote problem solving, we must build on existing problem solving research. If we are to make claims about problem solving and games, we must generate new research and design heuristics based on the alignment of problem solving and different gameplay types, and test those empirically. In this paper, we have outlined a way to begin to meet both of these challenges. We used Jonassen's typology of problem types to help analyze the cognitive processes involved in different types of gameplay and, in turn, dissected gameplay that brought the essential characteristics (for problem solving, at any rate) to light. With an understanding of the cognitive, physical, and domain knowledge requirements of each type of gameplay, instructional designers and game developers will have a better idea of what types of gameplay will most appropriately afford given problem-solving learning goals and objectives.

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