Integrating Curiosity and Uncertainty in Game Design

Alexandra To, Safinah Ali, Geoff Kaufman, Jessica Hammer
Carnegie Mellon University
5000 Forbes Ave.
Pittsburgh, PA, USA
aato@cs.cmu.edu, safinaha@cs.cmu.edu, gfk@cs.cmu.edu, hammerj@cs.cmu.edu

ABSTRACT
Curiosity as a psychological state or trait is characterized by a preference for uncertainty that motivates responses such as exploring, manipulating, and questioning. Given the established link between curiosity and player engagement levels, game designers can thus induce curiosity by creating or increasing the salience of information gaps. To this end, a thorough understanding of curiosity - its varieties, antecedents, and consequences - is an essential addition to the designer's toolbox. This paper reviews five key types of curiosity: perceptual curiosity, manipulatory curiosity, curiosity about the complex or ambiguous, conceptual curiosity, and adjustive-reactive curiosity. It further examines a variety of game examples to show how each form can manifest during play. In addition, the present analysis ties established understandings of curiosity to Costikyan's well-known theory of uncertainty in games, proposing that designers can employ uncertainty to motivate, manipulate, and accommodate players' curiosity levels.

Keywords
game design, games, curiosity, uncertainty

INTRODUCTION
In the past half century, researchers from several fields, including cognitive psychology and education, have been developing models of human curiosity. The model of curiosity we base this paper upon describes curiosity as a person's preference for uncertainty and tolerance of "information gaps" between the known and unknown (Loewenstein 1994). A preference for uncertainty means seeking out, rather than avoiding, situations that might provoke curiosity; the ability to tolerate information gaps predicts whether a person responds to such situations with curiosity rather than helplessness, frustration, or anger. While games are well-established motivators of curiosity in practice, we propose that a deeper understanding of curiosity theory can provide valuable new insights for designers of both digital and non-digital games. In this paper we explore the relationship between curiosity considered as a preference for uncertainty and uncertainty considered as a set of game design patterns (Costikyan 2013).

While the relationship between curiosity and uncertainty in games may on the surface seem obvious, there are actually multiple types of curiosity (Kreitler et al. 1975). Different game design decisions can support different types of curiosity in the player. Additionally, curiosity is affected both by a person's baseline preferences, known as *trait*

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curiosity, and by situational factors, known as *state curiosity*. Games are unlikely to change a person's baseline preference for uncertainty, but can be designed to include diverse mechanics and content that appeal to players of varying levels of trait curiosity. Additionally, games can create situations in which people are temporarily more curious than they otherwise might be, inducing state curiosity. Finally, even the concept of a preference for uncertainty is more complex than it seems; it depends on factors such as individuals' ability to tolerate emotional discomfort, confidence in their ability to resolve the uncertainty, and familiarity with the domain about which they are uncertain.

We propose a mapping of distinct types of uncertainty in games, as per Costikyan, to different types of curiosity that are evoked in players when they experience them. Using this mapping we propose two major design implications: (1) game designers can support different types of curiosity in players through the way they stage moments of uncertainty in games and (2) adaptive curiosity detection offers designers the potential to adjust curiosity-supportive game systems in real time. As a result, designers can be equipped with an array of techniques to trigger curiosity via uncertainty, and subsequently activate and sustain higher levels of player engagement and enjoyment.

LITERATURE ON CURIOSITY

Curiosity has long been understood as a human trait - Samuel Johnson called curiosity, "one of the permanent and certain characteristics of a vigorous intellect" (qtd. in Litman 2005). Historically, research on curiosity has emphasized three key issues: (1) What is the definition of curiosity? (2) What is the underlying cause of curiosity? (3) To what extent is curiosity a stable trait for a given person, and to what extent is it influenced by situation determinants (and which determinants)? To this list of empirical questions, modern researchers add another: (4) How can curiosity be observed and measured?

Formal psychological research into curiosity began in the early 1960s, with Berlyne's empirical study of curiosity (Berlyne 1960,1974) that used a range of different behaviors to categorize distinct types of curiosity. Curiosity philosophers eventually came to what Loewenstein (1994) referred to as the pre-modern consensus, synthesizing thinkers such as Aristotle, Cicero, St. Augustine, Hume, Bentham, and Kant, that curiosity is an intense appetite for information operationalized as the desire to fill an *information gap*. Loewenstein's (1994) own information gap theory, the model we focus upon in this paper, frames curiosity as a *state arising when attention becomes focused on a gap in one's knowledge and there is a perceived ability and desire to close that gap* - distinguished from other possible states such as anger, helplessness, apathy, or frustration.

There are several other theories on the underlying causes of curiosity that can be viewed as compatible with this theory. For example, incongruity theories state that curiosity is generated by a desire to make sense of the environment and this desire is aroused when expectations are violated (Hunt 1963). In this situation, the information gap is triggered by the environment. The extremity of the violation relates to the intensity of curiosity experienced. Curiosity is therefore, also affected by a person's prior knowledge about a domain, since that knowledge provides a baseline for any gap they may detect. It is also affected by whether or not a person believes a particular action or piece of information can help close the gap in their knowledge; people are more intensely curious about things they believe will resolve their uncertainty. Loewenstein further described curiosity as *a preference for uncertainty*, where uncertainty is the result of an information gap. Jirout and Klahr (1992) used this theory to measure curiosity and uncertainty preference independently to establish a relationship between curiosity and uncertainty, while Litman and Jimerson (2004) suggest an interest (I) induction and deprivation (D) elimination model that reflects different relationships to uncertainty: the anticipated pleasure of new discoveries (I-type) versus the desire to reduce uncertainty and eliminate undesirable states of ignorance (D-type).

Empirical work on curiosity has further shown that curiosity is not unitary, but can in fact be conceived of in the following five key types: (1) perceptual curiosity, categorized by increased attention to novel stimuli, (2) manipulatory curiosity, categorized by the feeling experienced while encountering a manually explorable object, (3) curiosity about the complex or ambiguous, categorized by the preference for interacting with more intricate stimuli (4) conceptual curiosity, categorized by active information seeking about concepts behind things and (5) adjustive-reactive curiosity, that just describes how people explore novel environments. In the following section we will review empirical work on curiosity as well as situate these five key types of curiosity within the concept of preference for uncertainty. In addition, researchers define a difference between trait curiosity and state curiosity (Berlyne 1960; Robinson 1974; Naylor 1981). Trait curiosity refers to curiosity as a stable quality of an individual. A person with higher trait curiosity will experience curiosity under more conditions, more readily, more frequently, and for longer periods of time. State curiosity refers to how curious a person will be in a given situation. Understanding that curiosity is *both* state and trait gives us a deeper understanding of the concept. A person may have a natural level of trait curiosity, but the level of curiosity they actually display will depend strongly on the situation.

In an attempt to measure curiosity, Jirout & Klahr (2012) suggested a novel game-based approach that establishes a relationship between curiosity of the players and uncertainty in games. Inspired by Jirout & Klahr's chosen medium of measuring curiosity, we suggest that games are optimally situated to evoke curiosity in players. The following section elaborates ways in which the five key types of curiosity relate to design elements and player behaviors in existing games.

MODELS OF CURIOSITY APPLIED TO GAMES

Prior Work on Curiosity and Games

A casual look at games reveals many possible moments of curiosity. How does one defeat the boss? What's over the next hill? What reward will this action yield? Under Juul's (2010) definition of games as having "variable and quantifiable outcomes," the uncertainty of how a game will turn out is in fact a critical part of what makes a game a *game* in the first place. Curiosity, then, lies deep at the heart of play.

Curiosity has been included as a component in several models of player engagement. For example, Lazzaro's (2004) Four Keys of Fun model includes "easy fun," which she characterizes as the type of fun elicited by curiosity-heightening elements such as exploration, creativity, and fantasy. In the same vein, the Game Discourse Analysis (GDA) approach ties the flow and presentation of information within games (e.g., the use of foreshadowing to create information gaps) directly to the levels of curiosity and engagement exhibited by players (Wouters et al. 2011). However, both of these models - at least in their publicly available form - treat curiosity as a single construct and unitary experience. As we will see later in this section, curiosity is in fact not one single concept, but five different independent factors.

Curiosity can also be considered alongside other common player experience metrics, such as various aspects of enjoyment and flow. Enjoyment has been conceived of as a catch-all for positive reactions to game play such as fun, liking, and pleasure (Mekler 2014) but may also include aspects of challenge and (minimal) frustration (Gajadhar 2010). Fun is conceived of as a positive distraction, while pleasure denotes positive absorption with a game (Blythe & Hassenzahl 2005). Flow, on the other hand describes a state of immersive engagement in a challenging yet enjoyable activity (Nakamura & Csikszentmihalyi 2002). Many of these concepts overlap, creating tension between definitions of flow, enjoyment, and other related player experiences. Moreover, curiosity may relate to these experiences in several ways. For one, as Lazzarro (2004) suggests, curiosity may itself be one form of fun. In addition, curiosity may represent a specific antecedent of flow, elicited by an information gap that is experienced at the optimal level of challenge or uncertainty to be surmounted by exploration and discovery (Berlyne 1954; Garris et al. 2002; Jirout & Klahr 2012).

From a design perspective, the Mechanics, Dynamics, and Aesthetics (MDA) framework includes challenge, discovery, sensation, and fantasy among the aesthetic components that are believed to make a game fun or engaging (Hunicke 2004). Of these, discovery relates most closely to curiosity; it captures the desire for uncertainty and the pleasure of reducing information gaps through the exploratory actions a player takes in a game. Costikyan's (2013) work on uncertainty unpacks the concept of uncertainty into ten different concepts. His work focuses on how game designers can use uncertainty to create better games; as described later in this paper, we argue that curiosity can amplify and deepen our understanding of his work.

Rather than work from these partial models within the game literature, we return to the curiosity literature, which defines five types of curiosity that have been shown to be independent factors underlying various knowledge-seeking and exploratory behaviors. These various forms of curiosity have emerged through decades of research attempting to capture and assess curiosity behaviorally, using such barometers as individuals' preference for stimuli of differing levels of novelty and complexity, as well as the types of manipulations and perceptual explorations they exhibit when interacting with objects in their immediate environment. The following sections unpack how each of the five types of curiosity relates to specific mechanics and dynamics in games, with the goal of elucidating techniques for designing for curiosity in order to increase player engagement.

1. Perceptual Curiosity

Perceptual curiosity characterizes how a person perceives normal stimuli and gives attention to novel perceptual stimuli, cued through gaps in perceptual information about sensory experiences such as touch, sight, and sound (Berlyne 1954). Perceptual curiosity as a state leads to increased attention to surprising or interesting objects in the visual field (Vidler 1977). As a trait, persons with high perceptual curiosity react positively to discovering new places, hearing new or interesting music, discovering what a new smell is, and exploring their surroundings (Collins et al. 2004).

In the game context, perceptual curiosity may be instigated in the moment through music or other auditory warnings that cause suspense, unknown cards that other players hold in their hands, a new landscape that can be searched for clues, and so forth. Games can also provide opportunities for players high in trait curiosity to indulge their higher preference for uncertainty and proclivity to explore - for example, open-world video games such as *Dragon Age: Origins* (BioWare 2009) allow players to roam freely and discover objects, locations, and encounters within the game that are peripheral to its main goal.

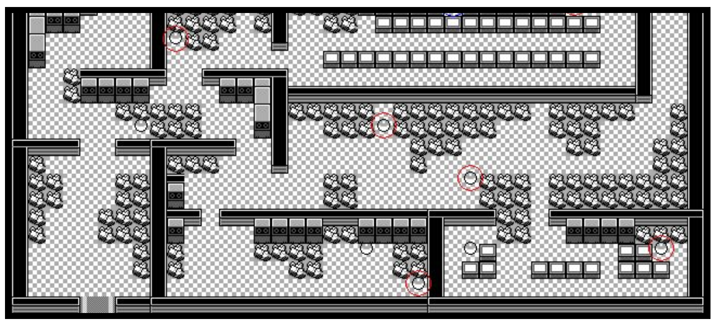

Figure 1: A partial map from *Pokémon Blue* with item icons circled in red

Creating a situation that provokes *state* perceptual curiosity means making players aware of a knowledge gap through the introduction of novel stimuli. For example, in *Pokémon Blue* (Nintendo 1996) when a player enters a new area, they can scan the map for novel prize item icons (Figure 1). The items are a novel visual stimulus against the backdrop of the map. While the item's relative location is displayed, the game designers have obfuscated the exact prize a player will win as a result of successfully retrieving the item. Sometimes the prize is a reward, such as a poké ball or potion, but in other instances the "prize" may be another Pokémon waiting to attack. A novel visual stimulus paired with a mystery to resolve - perceptual curiosity at its best. However, some extra reward items are not shown on the map. After discovering the first hidden item and thus discovering an information gap, players high in *trait* perceptual curiosity will explore all parts of the map, not just beelining for the visible items. Discovering the first item also heightens the player's *state* curiosity. This is concurrent with the information gap theory, which states that the player's curiosity is positively related to their knowledge in a particular domain.

Other actions that relate to perceptual curiosity are: observing, searching, exploring, matching, feeling (touching), and listening. Many of these verbs are motivated by an uncertainty about the source of a novel stimuli. For example, in first-person video games like the *Halo 3* (Bungie 2007), the sound of enemies arguing in the distance guides a player in the correct direction within a complex map by encouraging the player to find the source of the disturbance. Subtle lighting cues, graphical elements such as signs and arrows embedded into the game, the sounds of distant action, and even the haptic feedback of a controller increasingly vibrating as the player nears some in-game disaster are elements that game designers can use to signal a player's perceptual curiosity to guide them onward. Players familiar with a genre may begin to rely on these sensory clues.

2. Manipulatory Curiosity

Manipulatory curiosity describes the curiosity people feel when encountering a novel object that can be explored manually (Kreitler et. al 1975). As it is classically understood, manipulatory curiosity is driven by an instinctual urge to understand objects through touch, resolving information gaps about the physical nature of a thing. In games, manipulatory curiosity is most easily observed in the desire to touch and interact with physical game objects, including game controllers. It may also occur in digital games as players interact with novel in-game 'physical' experiences.

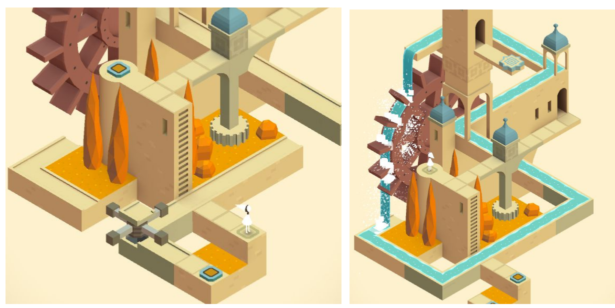

Figure 2: In *Monument Valley: FS* the platform triggers a wheel the player can turn to make the water flow.

Games like *Operation* (Hasbro 1965) involve careful physical exploration of the properties of strangely-shaped pieces. Tactile interaction with games can also include the manipulating of game controllers; a player might randomly press buttons and pull triggers on a novel video game controller to understand its capabilities. In the context of a digital game, the player's exploration can also include understanding the mapping of controller manipulations to resulting game actions. Manipulatory curiosity can also be enacted through interactions with input technology such as a computer mouse or a Kinect Sensor. Touch screens also provide opportunities for players' tactile exploration of game systems.

Consider the mobile game *Monument Valley* (Ustwo 2014), which presents novel M.C. Escher-inspired structures that are physically impossible in reality. The structures must be manipulated through a series of sliders, wheels, and push-down platforms for the main character to progress (Figure 2). The player manipulates objects in the game through the touch screen by tapping, sliding, and rotating their finger. Each physical manipulation is reflected by specific changes to the structure currently on the screen. Players may already understand how to interact with a touch screen based on prior interactions with other apps, but the way the in-game structure will be affected by their tactile manipulation is unknown. Players' desire to learn about how in-game objects such as *Monument Valley*'s buildings respond to their digitized physical manipulation can also be considered a form of manipulatory curiosity.

3. Curiosity about the Complex or Ambiguous

Curiosity about the complex or ambiguous is a person's preference for observing or interacting with stimuli that are more intricate, mysterious, and contradictory over stimuli that have features that are less simple, one-dimensional, or expected (Kreitler et al. 1975). This type of curiosity is measured by observing what type of stimulus the person prefers to engage with and how long they choose to engage with it, compared to alternatives.

In game context, complexity and ambiguity can characterize both game materials and game states. For example, in the game *NetHack* (1985), there are simple game elements such as the gems which can be sold for money, and there are complex game elements such as weapons, which have variable probabilities to hit and variable amounts of damage they do. These weapons can or cannot be enchanted which determine their effectiveness. This creates ambiguity. While complexity in *NetHack* come from game materials and states, in games such as *Poker*, complexity and ambiguity are often defined by other players' behavior in real-time. A player with an obvious tell may be simpler to read than an excellent bluffer, but their behavior is more ambiguous than that of a player who simply folds every time they have a bad hand. Additional ambiguity in the game is added by the cards other players might possess, which is a game state.

Over time, players' perception of ambiguity and complexity may change. For example, in *Don't Starve* (Klei Entertainment 2013), the player must survive by collecting survival tools, including edibles, and using them in an optimal way. When the player first encounters frogs in the game, it is unclear whether or not they are hostile and what the player can do to interact with them. If a frog is killed, the player can loot the frog's legs. Similarly, the frog legs that are looted are both complex - the frog legs show multiple pieces of information such as calories and components - and ambiguous - the player can take multiple actions with the frog legs, such as eating them or frying them, and these have a variety of outcomes for the player. At first, players prefer to engage with the frog and spend more time engaging with it than with other game elements. However, once players know how the frog interacts with the rest of the game system, and develop higher-level strategies to use it effectively, it is understood as less complex and ambiguous in context. Players' motivation to fill the information gap created by curiosity about the ambiguous or complex can be used by game designers for varying complexity of game elements to directly influence engagement.

4. Conceptual Curiosity

Conceptual curiosity refers to the desire to engage in deep conceptual exploration and active information seeking - the desire to find things out (Kreitler et al. 1975). In many ways it is the closest to popular understandings of curiosity, which focus on wanting to understand a particular topic or learn the answer to a specific question. Conceptual curiosity goes beyond the popular understanding, because it emphasizes the development of an explanatory mental model (Kreitler et al. 1975). For example, when people exhibit manipulatory curiosity about an object, the focus is on tactile experience; when people exhibit conceptual curiosity about the same object, what matters is developing a mental model that explains *why* the object behaves the way it does (Kreitler & Kreitler 1974).

Games can spur conceptual curiosity by creating an information gap within the game. For example, strategy games such as the *Civilization III* (Firaxis 2001) series often conceal the details of game mechanics from the player. Terrain may affect the outcome of a battle between units, but players must investigate the game's manual or a walkthrough to understand exactly how. Part of the pleasure of the game is discovering the complexity of the game's underlying model, and developing a corresponding mental model that allows the player to better achieve their desired outcomes in the game. Knowing the effect of terrain on in-game battles may be satisfying on its own, because it reduces the information gap, but players also work to verify that their understanding is correct by using it to improve their battle skills.

Civilization III also provides an example of conceptual information gaps that are at least partly external to the game. The game incorporates real-world historical elements, such as famous world leaders or wonders of the world. These historical elements have in-game impact - for example, building the Great Wall of China in *Civilization III* doubles the effectiveness of a city's walls. The game incorporates factual information about the Great Wall, both within the game and on game-related websites, but far more information about the Great Wall is available outside the bounds of the game. For some players, this information gap provokes them to seek out better information on the Great Wall using other sources (Squire 2004). For players like this to feel that they truly understand the Great Wall as a concept, it is not enough to know how to manipulate it within the game. They connect the in-game concept to the concept as it is understood in other contexts, such as Chinese history or the history of architecture.

5. Adjustive-Reactive Curiosity

Adjustive-reactive curiosity describes how people explore ordinary environments (Kreitler et al. 1975). When driven by this type of curiosity, they do not necessarily seek out experiences that are novel, ambiguous, or complicated. Instead, they work to connect their expectations about how things should behave in general to the specifics of a given situation. For example, adjustive-reactive curiosity includes exploring objects in ways that are common for that object - writing with a pencil or opening and closing a box. Writing with a pencil is neither novel, ambiguous, nor complicated for a typical adult. However, verifying that *this* pencil writes in *this* situation is still an act of curiosity, which does not take the basic function of the object for granted. Another manifestation of adjustive-reactive curiosity is the desire to identify and acknowledge all objects in a given environment, so that the person has a good sense of the space around them.

Applying this to games, we can see that adjustive-reactive curiosity depends heavily on two things: a player's expectations about the possibilities of their environment, and the player's ability to perceive the environment they are in. Players work to verify that their expectations are accurate and perception is complete - closing the information gap between their understanding of the game environment and how it actually behaves.

Adjustive-reactive curiosity is particularly important in games, because games teach players that the conventions of daily life do not necessarily apply (Caillois & Barash 1961) Instead, the player must probe their environment to understand how apparently familiar objects work in the context of the game. As players develop expectations about how game objects work, they can satisfy their adjustive-reactive curiosity by verifying that those expectations are met. For example, objects in *Katamari Damacy* (Namco 2004) exist to be rolled up into giant balls, even if their ordinary function is rather different. Once players understand the expectation of "objects can be rolled up," they can satisfy adjustive-reactive curiosity by checking that this interaction applies to a particular object, even if they could theoretically understand the interaction through reason alone.

Game design techniques can change how satisfying a player finds adjustive-reactive curiosity in a given situation. For example, many games such as *World of Warcraft* (Blizzard 2003) encourage environmental awareness by generating either threats (e.g., beasts) or rewards (e.g., herbs) in the game space inhabited by the player. Players high in adjustive-reactive curiosity are likely to already find identifying and enumerating objects in the game environment satisfying, but even players lower in adjustive-reactive curiosity are likely to respond to these temporary incentives. These games motivate players towards environmental awareness, not by increasing the knowledge gap, but by making that gap riskier and less tolerable for the player.

IMPLICATION 1: SUPPORT FOR DESIGNING FOR UNCERTAINTY

We propose that a deeper understanding of curiosity can help game designers better use uncertainty techniques in games, thus improving the play experience. Studies show that the level of exploration is affected by the amount of uncertainty (Litman & Spielberger, 2003). Within the context of a game a player can feel curious about a puzzle, a narrative, optimal strategies to win the game, the actions of other players in the game, the ways to use a controller for a digital game, or the probability of a die roll in a tabletop game. In each of these examples, uncertainty is a key motivator for the player's curiosity.

Costikyan (2013) analyzes sources of uncertainty in games, from uncertainty about how to correctly solve a puzzle to uncertainty about what other players will do. His formulation focuses on game mechanics and the designers' role in creating uncertainty - that is, in triggering temporarily heightened *state* levels of curiosity in players. Players, however, are not alike in their preference for uncertainty due to the varying level of *trait* curiosity they bring with them when entering the world of the game. Ideally designers would consider *both* levels of curiosity by setting up opportunities to pique state curiosity in all players and, at the same time, providing additional avenues (perhaps ones tangential to the game's focal narrative or action) to appease players with higher baseline levels of trait curiosity. It is important to note that uncertain experiences in games may not always provoke curiosity. Players set their own goals in games, such as socializing with other players or exploring the game world (Yee & Bailensen 2007). If curiosity is a gap between current and desired states of knowledge, player goals will mediate which states are desired. For example, a player focused on exploring a game world may not desire information about combat systems, and vice versa. However, moments of uncertainty within the game offer *opportunities* for curiosity when consonant with pre-existing or emergent player goals; they may also sometimes provoke players to rethink their goals. It is this relationship between curiosity and uncertainty which we now explore. While examining all ten of Costikyan's types of uncertainty is beyond the scope of this paper, we choose three types of uncertainty to illustrate the analytic value of connecting uncertainty to curiosity. By applying what we know about curiosity theory to Costikyan's concepts, we can uncover new possibilities in his existing work.

Solver's Uncertainty

Costikyan describes *solver's uncertainty* as the challenge of figuring out how to solve a highly constrained problem with a limited set of resources. For example, graphic adventures ask the player to overcome obstacles using a combination of objects in their character's inventory; *Portal* (Valve 2007) asks the player to reach the level's exit using portals to move through space and avoid obstacles. Costikyan characterizes these types of puzzles as lacking "creative" solutions. There may be a single possible solution, as in a well-formed *Sudoku* puzzle, and the player simply needs to find it. There may also be equifinal approaches where the player can explore several different methods for coming up with the single correct solution. To succeed in solving a puzzle is to reconstruct the solution the designer foresaw - though some puzzles allow multiple solutions, where time- or resource-efficiency distinguishes the best solutions from the rest. What, then, is uncertain about solver's uncertainty? The uncertainty arises in the gap between the player's attempted solution and the correct solution. As the player experiments or develops strategies, the uncertainty gap closes.

Parallel to Costikyan's work, curiosity theory suggests an explanation for why players become frustrated when experimentation in the solution space does not provide meaningful guidance toward a possible solution. The player loses confidence in their ability to close the uncertainty gap. This loss of confidence is critical, because players' ability to tolerate an information gap is directly related to their confidence in their ability to close it - not necessarily to the size of the gap itself (Loewenstein 1994). When players lose confidence in their ability to close the uncertainty gap, a previously pleasant level of uncertainty can become unpleasant or even intolerable. On the other hand, the game can support players in feeling confident about their ability to close the gap, even if the gap itself is large. For example, games that provide feedback on how "warm" a solution was can help players feel comfortable with uncertainty.

There are two other ways that curiosity theory can support designing for solver's uncertainty. First, *perceptual curiosity* can make exploring the solution space a satisfying experience in its own right. For example, *The Room Three* (Fireproof 2015) uses beautiful and mysterious environments to make probing the visual environment satisfying in its own right, though many probes provide little feedback about how to correctly solve the current problem. The pleasure produced by satisfying perceptual curiosity via exploration can help offset the frustration of solver's uncertainty, creating a higher tolerance bar before players simply give up. Second, understanding *adjustive-reactive curiosity* can help guide players toward puzzle solutions. Adjustive-reactive curiosity drives players to interact at least once with all available objects, and to try common types of interaction with them. Knowing these likely play patterns can help designers create puzzles where players' adaptive-reactive interactions gives them information about how to proceed. For example, when objects in the environment are hidden or obscured, making the player aware that they *are* hidden or obscured can trigger adjustive-reactive curiosity.

Hidden Information

In Costikyan's theory, *hidden information* is, quite literally, information that is hidden from the player. For example, in the tabletop game *Clue* (Hasbro 2002) the details of the murder are hidden in an envelope. While the details are drawn from a finite set of cards (e.g., Miss Scarlet, the candlestick, the library), which cards have been chosen in a particular game is a secret that players must discover. This is an example of *algorithmically-generated* hidden information, in which the solution to the mystery is different in each game. Alternately, the information that is hidden may be *designed*, in which case it can only be uncovered once before it is no longer a surprise. For example, the map in *Dragon Age: Origins* is revealed as players explore the game world, but does not change from game to game. Hidden information may also involve hiding *player activity*, as in *StarCraft* (Blizzard 1998), where the information being hidden is precisely what other players are doing.

The uncertainty in hidden information is quite literal: information can be hidden either physically in the environment or in the parameters of the game system. As the player uncovers the hidden information, the knowledge gap decreases. One thing to think about, therefore, is units of uncertainty decrease. For example, in *Clue*, the envelope is only opened once to reveal who committed the murder and how - but the game has a finite solution space, so players can eliminate options by identifying ways the murder was not committed. Every time a player learns something about who did not commit the murder, the uncertainty of the hidden information diminishes. In the game *NetHack*, on the other hand, potions are assigned colors at random. Each potion mapping must be discovered separately, and reduces the uncertainty of that potion's behavior to zero; at the same time, it has only a minimal effect on the uncertainty related to other potions.

Curiosity theory suggests two different relationships between players and hidden information, with different implications for designers. First, when players are driven by *perceptual curiosity*, they will be attracted to hidden information that is sensorily stimulating, where they can see that there is visible strangeness or are cued by other stimulation like a strange noise. Second, when players are driven by *adjustive-reactive curiosity*, they will want to establish and test predictable mappings. These two types of curiosity balance one another out, and designers can take advantage of that fact. By providing opportunities both to experience novelty through perception, and to establish relationships through experimental verification, players can self-regulate their arousal levels around curiosity in the game. For example, *World of Warcraft* provides players the opportunity to explore many different zones, which have novel and enticing visual designs. At the same time as they are experiencing novel perceptual stimuli, players can use their existing abilities within those zones to verify that they still work as expected.

Narrative Anticipation

Costikyan frames narrative anticipation as uncertainty about what happens next in a story. "Story" exists at several levels in games; it can mean the strong central narrative of a game such as *Dragon Age: Origins*, in-game quests with story snippets attached, such as those found in *World of Warcraft*, or platform games with narrative framing such as *Portal*. Costikyan also includes the "narrative arc" of games, in which a player's trajectory through the game begins slow, ramps up tension, and sustains the possibility of meaningful action throughout. For example, games like *Mario Kart* (Nintendo 1992) allow players to dramatically come from behind by adjusting the speed of NPC vehicles and giving disproportionately powerful bonuses to lagging players. The concept of the "play arc" is, in Costikyan's reading, a narrative experience.

Understanding narrative anticipation through the lens of *conceptual curiosity* suggests that players want to understand the story's internal logic, both narrative and interactive. Violating players' expectations can cause players to experience conceptual curiosity until they are able to develop a new model for how the story might work. For example, early in *Dragon Age: Origins*, players are asked to help defend Redcliffe Village from an undead assault. The game then reveals that a young boy, now possessed by a demon, is the source of the undead attacks. What seemed to be a story about zombie survival is in fact one about moral decisions - what to do with a very dangerous child. That change is both narrative (what story is being told) and interactive (what kind of decisions matter), and players must make a conceptual shift to move from one to the other. That shift, we argue, provokes conceptual curiosity until the player has mastered the new set of expectations; that curiosity can be expressed by testing options for interaction until the new narrative model is understood and mastered.

Narrative anticipation can also be understood as *curiosity about the complex or ambiguous*. For example, the motives of an NPC can be unclear, encouraging players to investigate to reduce ambiguity. This approach also encompasses narrative when understood as a game arc. Costikyan's examples of game arc narrative emphasize ways for players to affect the outcome of the game even if they cannot win, such as by throwing their support to stronger players in *Diplomacy* (Avalon Hill). These choices are often framed as giving the player agency, but they can also be seen as retaining ambiguity about the future state of the game. Players cannot foresee all future game states, but instead must continue to make decisions about how to participate in the game.

IMPLICATION 2: ADAPTIVE CURIOSITY DETECTION

As discussed earlier, curiosity levels can vary at both a situational level (i.e., as fluctuating *states* determined by contextual factors, such as the appearance of novel stimuli or the revelation of expectation-violating information) as well as at a dispositional level (i.e., as stable *traits* expressed by individuals across a variety of situations). With this distinction in mind, games designed to evoke curiosity via uncertainty deployment would ideally be equipped to assess and respond to players' trait as well as state levels of curiosity during play – that is, to detect and adapt to those levels and adjust the game play experience accordingly. Such "adaptive curiosity detection" would help ensure that players are presented with game scenarios that include information gaps whose size is optimally calibrated to players' current state of knowledge as well as their trait-level preference for uncertainty. In other words, if it is indeed the case that much of the motivational pull of games is derived from their ability to create and sustain curiosity-piquing elements of uncertainty, it stands to reason that being able to measure and accommodate the levels of curiosity that players bring with them to the game world (as well as the varying levels they experience as the game unfolds) would ensure a more prolonged satisfying game experience for a wider array of players.

Given the transient nature of curiosity and its lack of amenability to accurate self-report, researchers have prioritized the use of behavioral measures to capture both trait and state levels in individuals. As mentioned earlier, one of the most widely used, validated means of detecting curiosity behaviorally, at least among children, relies on a game-based measurement approach. In the game *Underwater Exploration!* (Jirout & Klahr 2012) children are presented with a submarine with two windows, given information about the types of fish that are present outside the window, and asked to select which window they wish to open. The game is set up such that each choice presents options varying in their level of uncertainty about the nature of the fish outside the window (from no uncertainty, in which case the exact type of fish is revealed, to medium, in which case children know one of several types of fish are outside, to maximum, in which case no information about the fish is provided). The task itself is adaptive, in that the two options presented to players are determined by their previous choices, thus allowing for the determination of both the level and stability of individuals' uncertainty preference and curiosity levels.

Game designers could strategically employ this same basic strategy of providing players with successive choices with differing levels of uncertainty early in the game to determine their baseline levels of curiosity – and then adjusting the level of uncertainty present in the game's presented information, stimuli, and encounters to "match" players' apparent preferences. This could also be done less systematically (and more organically) by purposefully making the early stages of a game rife with opportunities for exploration and the ability for players to choose uncertainty-seeking versus -avoidance alternatives to get a general impression of players' curiosity levels.

For example, in *Waking Mars* (Tiger Style 2012), players are put into a deliberately uncertain and ambiguous scenario as their character, a jetpack-wearing astronaut named Liang, traverses a cavernous space full of mysterious life forms, exploring and experimenting with the planet's ecosystem by planting various types of seeds and learning their effects. This puzzle game, with its reliance on deliberate information gaps (e.g., the main character himself has little background knowledge about the subterranean landscape into which he's been thrust, and his fellow scientist and radio contact, Amani, provides occasional but unreliable help as the game unfolds) and vastly explorable and manipulable environment, would lend itself well to the integration of curiosity-detecting mechanisms throughout the game. For example, the game could take advantage of having the conceit of a semi-reliable companion in radio contact Amani by having her give some level of guidance (and, thus, provide varying levels of uncertainty) about the lifeforms Jiang encounters during the game.

Implementing such adaptive design techniques, particularly in an organic and unobtrusive way, would allow game designers to avoid the trap of a "one size fits all" approach and build into their games opportunities to accommodate a variety of player proclivities and preferences when it comes to curiosity and uncertainty.

DISCUSSION & FUTURE WORK

This paper has focused on the theoretical contribution of linking curiosity and uncertainty in game design, and our hope is that discussion will open the door to the formulation and exploration of new types of questions about curiosity and uncertainty in games. For example, we can now apply this analysis to systematically categorize mechanics that relate curiosity and uncertainty, and empirically investigate the effects of those mechanics to better understand how these concepts can be combined. We can also explore the question of player goals and curiosity, which in turn may be affected by factors such as prior experience, interest, and motivations for play, and we can work to understand how uncertainty can in turn shape player knowledge goals.

Additionally, we can take on the challenge of studying the nuances of how curiosity and uncertainty interact in different types, genres, or platforms of games. For example, in a digital game, the rules are similar to laws of nature and players are constrained in what they can do. In a non-digital game the laws are more similar to laws of society, where players are aware that they can break the rules if they are willing to face the consequences. How does this ability to break the rules interact with curiosity? In what ways do non-digital game's possibilitiy of shortcutting the rules vs. digital game's expectation that a puzzle is solvable increase tolerance for uncertainty differently? These are some of the questions we will address in our future work.

CONCLUSION

As this paper demonstrates, curiosity theory provides a meaningful analytic lens for game designers, whether they are understanding existing games as curiosity-producing engines or making decisions about uncertainty in their own games. One key insight is that players have differing tolerance for uncertainty and that situational factors can affect that tolerance. For example, players' confidence in their ability to close a knowledge gap makes them more tolerant of uncertainty. Another insight is that there are five key types of curiosity that can apply to games: perceptual, manipulatory, complex/ambiguous, conceptual, and adjustive-reactive. Designers can balance opportunities to satisfy different types of curiosity to help players tolerate information gaps that are critical parts of the game. A third insight is that games can be designed to both detect and adapt to player levels of curiosity.

While this paper provides a proof of concept, there is a need for additional analytic and empirical work in this area. Analytically, there is good reason to suspect that digital and non-digital games provide different possibilities for employing curiosity. Digital games, for example, can procedurally generate complex situations with information that is hidden from the players, while non-digital games are limited by players' ability to generate novelty manually. On the other hand, research suggests that players may express more curiosity in considering and exploring system design in non-digital games (Kaufman & Flanagan 2013). These differences suggest that the interaction between curiosity and game platforms is worth exploring more deeply.

Empirically, we believe it is important to collect and catalog existing techniques for curiosity management in games, even if those techniques are not intended by the designers to address curiosity as such. This paper has pointed toward an array of examples, but there is a need for systematic work that can reveal both patterns and gaps in game design techniques. The formulations and analyses offered here are intended to be a starting point for game scholars, game designers, and curiosity researchers to further explore, explicate, and exploit the interplay between curiosity, uncertainty, and engagement in games - that is, to use the information gaps on these topics we have made salient here to explore new understandings and applications of curiosity to advance game design and theory.

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