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Integrating Curiosity and Uncertainty in Game Design

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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 adaptive-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...
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 \textit{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) adjusting-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.

\textbf{MODELS OF CURIOSITY APPLIED TO GAMES}

\textbf{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 \textit{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](image)

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.](image)

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. Adjective-Reactive Curiosity

Adjective-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, adjective-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 adjective-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 adjective-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.

Adjective-reactive curiosity is particularly important in games, because games teach players that the conventions of daily life do not necessarily apply (Caillous & 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 adjutivate-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 adjutivate-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 adjutivate-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 adjutivate-reactive curiosity are likely to already find identifying and enumerating objects in the game environment satisfying, but even players lower in adjutivate-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 *adjusactive-reactive curiosity* can help guide players toward puzzle solutions. Adjusactive-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 adjacent-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 *adjunctive-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 concept 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 Liang 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 possibility 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 adjustable-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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Tandem Transformational Game Design: A Game Design Process Case Study

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Abstract

In transformational game design, developing a clear, shared vision of how the player should change as a result of the game is a critical and ongoing process. However, multidisciplinary teams, particularly those comprised of both expert and novice designers and researchers, may experience barriers to a shared vision due to disparate vocabulary and theoretical frameworks. Adding a new contribution to the growing body of approaches that tackle this challenge, we present Tandem Transformational Game Design—a process that uses physical prototypes to continuously anchor a team’s shared alignment to their vision and goals. Drawing on HCI practices that emphasize prototyping to discover and reflect, the Tandem Design approach positions the articulation of game goals and the design of game prototypes as intrinsically intertwined, iterative cycles occurring in tandem with one another, supporting one another as the need arises. We outline the key elements of the Tandem Design approach and illustrate their implementation with our multidisciplinary team’s transformational game project, aimed at fostering greater scientific curiosity as an intervention for youth populations currently underrepresented in STEM. It is our hope that other teams working on similarly ill-defined transformational game design problem spaces can adapt our approach in order to solidify their vision and understanding of their own game’s goals, iterate on that vision together, and ultimately improve the efficacy and impact of their games.

*Keywords: transformational games; game design; playtesting; prototyping; multidisciplinarity*
Tandem Transformational Game Design:

A Game Design Process Case Study

Transformational games are designed with the specific intention of changing players’ behaviors, attitudes, or knowledge during and after play (Culyba, 2015). One of the biggest predictors of a game’s success is the team’s level of clarity and alignment on the vision (Tozour, 2015). However, transformational game design teams tend to be comprised of members from a broad range of disciplines, each bringing different perspectives, vocabularies, and areas of expertise to the table. This can make achieving such unification of vision quite challenging. Luckily, there are already several excellent resources, such as Sabrina Culyba’s *Transformational Game Field Guide* (2015), available for teams who want to ensure they are considering all of the factors that go into a vision of player transformation. With the present work, our team adds a new approach to existing best practices in transformational game design by integrating a growing body of research from human-computer interaction (HCI) about the benefits of physical prototyping in order to develop a deeper understanding of a game’s vision of player transformation, both individually and as a team. We present our approach, Tandem Transformational Game Design (hereafter referred to as Tandem Design), which positions making physical artifacts and articulating goals as intrinsically intertwined cycles occurring in tandem with one another, supporting one another as the need arises. With Tandem Design, the team relies on a deep grounding in relevant literatures to articulate a shared vision of the game’s design goals and outcomes and uses common game design processes to both create more fun and effective games and reevaluate the team’s understanding of their goals.
This paper presents an overview of Tandem Design and several illustrative game design case studies from our team’s ongoing research project, “Sensing Curiosity in Play and Responding” (SCIPR). Our project aims to design and study game-based interventions for fostering curiosity through play, thereby increasing young players’ comfort and engagement with science, technology, engineering, and math (STEM) topics. Our team used Tandem Design to develop a better shared understanding of our problem space - the conceptualization and operationalization of the construct of curiosity, intended audience - underrepresented groups in STEM: minority, women, and low socioeconomic status students, and transformational goals - increasing curiosity through play. The game case studies we present both elucidate the way that the Tandem Design approach directed our process and provide specific insights for designing games to foster curiosity. To quote designers Joep Frens and Bart Hengeveld (2013, p.1), “to make is to grasp.” We present this work in the hope that our Tandem Design approach of making, reflecting, and iterating upon games goals simultaneously will help other teams grasp their visions in a more concrete and ultimately more effective fashion.

Transformational Game Design:

Challenges and Opportunities of Multidisciplinary Teams

Game designers are proficient at creating fun and engaging games, but transformational games require designers to consider other factors, as well. In addition to acute attention to psychological and social factors that affect players willingness and ability to change (Culyba, 2015), effective transformation design also requires deep understanding of relevant content and subject matters. Meeting the “triple bottom line” of a viable, entertaining, and effective
transformational game means drawing on theories and methodologies from a range of fields in addition to game design, such as psychology, learning sciences, and HCI (Seidman et al., 2015).

Transformational game design teams often utilize diverse team members, bringing game designers together with experts in the design and research of psychological or educational interventions. It is imperative for these teams to achieve unity while merging their unique methods, tools, and perspectives. For example, psychologists have effectively deployed interventions in non-game contexts, such as in the design of in-school tutoring and mentoring sessions (Good et al., 2003; Stout et al., 2011; Martens et al., 2006). However, fun can never take a back seat; simply inserting an existing intervention into a game or gamifying a proven intervention almost ensures a transformational game’s failure. This is in part because games that are overt about their intentions have been shown to be less effective and, moreover, less fun (Kaufman & Flanagan, 2015). To this end, transformational game design approaches that aim to more fully integrate or embed known theories or interventions in the design process tend to produce better results and, from players’ perspective, better games.

Moreover, research has shown that teams that have a high shared sense of identification with the group tend to exhibit higher levels of learning and productivity, than teams that lack collective identification (Van Der Vegt & Bunderson, 2005). Thus, assembling the diverse team that a successful transformational game requires is not enough; teams must develop unification where none existed previously (Van Der Vegt & Bunderson, 2005). In order to draw strength from a team’s multitude of perspectives and domains of expertise and maximize the potential of each teammate, rather than being delayed or inhibited by differences of process and vocabulary, it is important to develop a shared expertise in the game’s vision for transformational change.
In order to accomplish this successful intermingling of disciplines, iterative, player-centric game design methods must be combined with psychological insights and iterative design methods (Seidman et al., 2015; Flanagan et al., 2013). To this end, psychologists (or other relevant domain experts) must join forces with game designers, who, domain experts in their own right, often have no established way to bring non-game designer members to the table, and vice versa. Non-designer content experts, meanwhile, may struggle with translating their knowledge of a literature to game design decisions. While transformational game design teams do, in practice, find ways to build on these multiple intellectual traditions, the integration is challenging.

Game design best practices are grounded in rapid prototyping to produce more engaging games (Schell, 2014). These include the rapid iterative testing and evaluation method (Medlock et al., 2002), play-centric design (Fullerton et al., 2006), playtesting with a purpose (Choi et al., 2016) and game jams (Preston et al., 2012). However, in multidisciplinary transformational game design teams, it is likely that some members may have little experience with rapid prototyping or game design, and well-defined processes for onboarding non-designers are still nascent (Culyba, 2015).

Many fields are beginning to incorporate the making of physical artifacts as a method for bringing in non-expert designers into the design conversation, as these artifacts serve as a sort of conversational grounding between groups who think about problems in different ways (Sanders & Stappers, 2013). Some fields have established a long-held tradition of using making as a method for anchoring reflection on both a problem space and proposed interventions. HCI researchers, for example, have developed formalized versions of this approach, including making
for validation and exploration and research-through-design (Frens & Hengeveld, 2013; Zimmerman & Forlizzi, 2014). These methods draw on the intellectual tradition of design as a reflective practice, in which artifacts are used to explore abstract constructs and to serve as litmus tests for evaluating theories (Schön, 1983). The intangible object is made, not as an end in and of itself, but as a means for deeper personal and shared understanding of an intangible idea.

Physical prototypes as discussion facilitators are also beginning to appear in game design, although the field’s bias toward making certainly isn’t new. There is a well-grounded tradition in game design of relying on both design goals and playtesting results to influence iterations of games (Fullerton et al., 2004; Aleven et al., 2010). However, there is less precedent for using multiple physical game prototypes to facilitate a game design team’s discussion of the shared mental model of their problem and goals. While many transformational games are often an end unto themselves, deployed in order to change attitudes or behaviors, there is also a burgeoning practice of using transformational games as a means toward understanding, as anchors for discussion and reflection within a team, with the expectation that the vast majority of these “means” will be eventually cut. Tiltfactor uses a process not unlike the Tandem Design approach; Seidman et al. (2015) illustrate how broad iterative prototyping can lead to a crystallization of design goals, abandoning game prototypes that are deemed unable to satisfy any of those goals through further design iteration.

*Tandem Transformational Game Design*

Tandem Transformational Game Design (Tandem Design) is a process that encourages rapid and divergent iterations of both game prototypes and a team’s alignment on its transformational goals. Tandem Design functions in two interrelated cyclical sub-processes we
call *game-driven goal delineation* (goal cycle) (Figure 1.A) and *goal-driven game design* (game cycle) (Figure 1.B). A disparate vision can often unseat a team’s efforts at creating an effective game, often caused by a very different understanding of goals and lack of shared vocabulary. Tandem Design continuously aligns teammates’ mental models of the goals of the game using playtest discoveries and related literature as tools constantly deepening discussion and articulation of both games and delineated goals.

![Tandem Transformational Game Design](image)

**Figure 1.** The Tandem Design Process. **Delineate Goal:** Team rearticulating goals for player transformation. **Lit Review:** shared reading of research to develop a shared vocabulary. **Alignment:** The juncture between the two phases. See descriptive paragraph below. **Prototype:** All team members create rapid game prototypes with one or more delineated goals as the initial point of inspiration. **Playtest:** Early, often, within team as a goal reflection exercise. **Iterate:** the process of refinement when remaining inside one cycle. *Icons from (Harlow, n.d.; Luck, n.d.)*

In summary, Tandem Design (Figure 1) involves teams articulating their goals based on relevant literature (Figure 1.A), then using those goals as starting points for rapid divergent
prototyping and playtesting within the team (Figure 1.B), which then in return lead the team to re-articulate their goals with a better shared understanding of them (Figure 1.A).

When a team has completed a full goal cycle or full game cycle they move on to alignment (Figure 1.C) - often employing the use of collectively designed physical and digital artifacts (e.g., lists on a whiteboards, photos of design exercises, game prototypes) that could be remixed and used to illustrate in the moment, but later preserved to capture the team’s past iterations of their games or articulated goals. Whether to remain in one cycle after alignment or swing over to the other is a matter of context clarified further in the following two sections. It is critical to not spend too much time in one cycle alone, as game artifacts are needed to ground any discussion of goals, and aligned goals are needed to evaluate the effectiveness of the games.

**Game-Driven Goal Delineation**

Game-driven goal delineation articulates the team’s desired player transformation outcomes through shared game prototype playtesting and reading literature from relevant fields. It is not a substitute for in-person communication about vision, but rather provides a scaffold for *more effective* in-person communication or alignment by grounding all team members in a shared understanding of prior work and foundational theoretical frameworks. This goal cycle (Figure 1.A) ideally provides a highly malleable, working definition, rather than a fixed representation, of the player transformation (e.g., changes to behaviors, emotions, or cognitions) the team’s game aims to achieve. Some teams call this *player vision* or *game vision*, but “vision” occasionally is envisioned as something static and intangible, so we use *delineation* to connote a more ongoing, iterative process. Some teams may have a client directive or a single source of expertise that determines starting goals. Others, like our team, may be starting with a disparate
collection of research that touches one part or another of a problem space. Regardless, seasoned teams should anticipate that their understanding of their goals will inevitably shift over the course of a project as they develop a deeper understanding of them (Culyba, 2015). Tandem Design uses ideas of reflective practice and the process of alignment to help continuously ensure all team members’ deepening understanding of these goals over time.

In order to make the following sections as clear as possible, we will first define the terms we will be using throughout our discussion. For an example of how the terms relate to one another, see Table 1. Our problem space is the subject area of player transformation for which we’re creating our game. Elements are the vague transformational goals drawn from our research about the problem space that we use to create the more concrete, actionable behaviors, attitudes, and cognitions that make up our delineated goals. Sometimes, the team’s evaluation of its defined elements spurs additional passes through the cycle to uncover more specific information about an element in the literature before more clearly translating it into a delineated goal. These delineated goals will then be used to spark ideas about design decisions later in the process.

Table 1. From left to right, the table depicts an example progression from abstract problem space to concrete design decisions in the goal cycle.

<table>
<thead>
<tr>
<th>Problem Space</th>
<th>Element</th>
<th>Empirical Finding (Literature) that More Deeply Explores This Element</th>
<th>Delineated Goals: Player will...</th>
<th>Design Decision Examples</th>
</tr>
</thead>
</table>
| How might we make a player feel more curious? | From first-pass lit review: Curious people frame failure as a challenge, not a threat | “Growth Mindset” as a way to make players more open to failure | • Experience failure as an invitation to retry  
• Welcome risk-taking  
• Avoid words that suggest that they are failing in an unchangeable way | • A game with many opportunities to fail  
• A game that requires a certain amount of failure to win  
• A game whose setup messages failure in growth mindset terms |
To begin developing a common shared vocabulary for discussing a problem space, game-driven goal delineation always involves a preliminary articulation of goals (Figure 2.1), a literature review involving part or all of the team to further develop shared knowledge and vocabulary (Figure 2.2), and a moment of alignment when the team decides whether they have amassed sufficient information and articulated satisfactorily delineated goals to begin prototyping (Figure 2.3). This bias leans toward making when at all possible.

Figure 2. Our team’s pathway through our first game-driven goal delineation cycle. Without game prototypes, this first pass is more of a way of getting a sense of all teammates’ starting understanding.

Our team began with one broad delineated goal: how might we make players feel more curious during and after gameplay? One teammate then curated an initial literature review, and whittled down a large body of research on curiosity into a number of papers deemed to be most relevant for the entire team to read. We then reviewed the literature and convened to articulate the elements we’d found and to create more specific delineated goals (Figure 2.4).
We articulated these elements—such as *curiosity is deeply intertwined with uncertainty* and *curious people investigate*, along with some delineated goals we thought might come from them, including *comfort asking questions* and *comfort with uncertainty*. At first, our elements were broad and general, but we still preserved these assumptions using concrete artifacts, such as whiteboard lists. We got as specific as possible, with the implicit knowledge that some of our elements could be disproved or abandoned later: assessing the team’s current understanding, rather than achieving perfect accuracy, was the goal here.

**Figure 3.** Elements of curiosity that we articulated during our first two passes through the Goal Cycle, which we found helpful to categorize by type of player transformation experienced into behaviors, emotions, and cognitions.
These elements were then used as conversation starters to spark discussion about when in our lives we ourselves had felt curious, which brought to light other delineated goals, such as *feels like failure is not a threat*. Did we feel like our delineated goals addressed everything we’d seen about curiosity in the literature? Were there gaps in our shared understanding that we saw based on our expertise? Were we ready to start prototyping games based on the information we had, even if it wasn’t perfect?

![Game-Driven Goal Delineation (Second Pass)](image)

**Figure 4.** After aligning at (3) in our first goal cycle, our team found a significant gap in our current understanding which would have impacted our ability to prototype our delineated goals, and therefore iterated again (4, 5, 6) before continuing on to prototyping.

Here after alignment (Figure 4.3) we could either move on to the game cycle or perform another iteration in the goal cycle. After alignment, teams then have a choice: they can remain within the same cycle and iterate or loop over to the opposite cycle. In the goal cycle, when consensus is reached about their delineated goals then it is time to move to the game cycle; when the team is drastically misaligned on goals or finds a gap, the team remains in the goal cycle.
Figure 5. Documentation photo (left); transcription (right) A low-fi but highly-used early elements list. After reviewing the curiosity literature, the team extracted the elements (right, then labeled outcomes), brainstormed related moments in their own lives out loud, and extracted related theories from those stories and goals.

We remained in the goal cycle a second time because of a gap in our goals we uncovered when attempting to articulate them as a team. The team’s psychology expert identified that we were missing delineated goals about barriers to bringing about the transformation we wanted that might keep the game prototypes from working as intended. We delineated our goals one more time (Figure 4.5), reviewed literature about player experience and curiosity barriers (Figure 4.6), and added several important elements, including avoiding stereotype threat and fostering a growth mindset. The second cycle took less than one week and drastically broadened the space in which we could ideate game concepts and encouraged even more emphasis on player-centered considerations in both our goal delineation and, later, our game design processes. Other teams may experience something similar as they pass through their first game-driven goal delineation.
cycle: often trying to align a team of experts will uncover gaps in understanding that may be solved more quickly by having the team run through the cycle once more with the goal of finding additional empirical or theoretical papers to deepen or broaden the team’s discussion.

After a second round of literature review, goal articulation, and alignment, we had the first draft of our delineated goals (Figure 5). This list of goals also gave us a starting point to begin thinking about game mechanics that might encourage these emotions, behaviors, and cognitions, described more in goal-driven game design. While this list of goals is far beyond what any one game could address alone, we encouraged this breadth of ideas within the team and used rapidly designed game prototypes in the game cycle to test the efficacy of incorporating various goals into context of a transformational game.

**Goal-Driven Game Design**

In this section, we detail the specific process of goal-driven game design (Figure 1.B) and highlight generalizable pieces of this game cycle that future teams may make use of. Goal-driven game design utilizes existing design practices such as reflective practice, rapid prototyping, and iterative design (Zimmerman et al., 2014; Frens et al., 2013; Nielsen 1993;) while expanding on existing game design practices such as playtests that view the player experience holistically (e.g., what is fun, difficult, confusing, etc.). Goal-driven game design especially emphasizes 1) rapid prototyping for both better gameplay and understanding, and 2) better gathering of information for when teams swing back into the goal cycle. Typical playtesting practice in game design allows a game designer to understand how a player experiences a game. Our game cycle’s emphasis on rapid, broad prototyping grounded in one or more delineated goals allows each team
member, with little to no prior related experience, to create games in parallel by focusing on one or more delineated goals and developing a deeper understanding of it over time.

Our first cycle of goal-driven game design began after we had passed through the game-driven goal delineation cycle twice. Other teams may only need to do this once before beginning to prototype and only return to the goal cycle later. With a shared body of working knowledge and vocabulary at our disposal from this phase of the process, all teammates individually developed 15 one-sentence game proposals that were flagged with the related delineated goal(s). These ideas, 65 in total, were then shared with the team and grouped in a team clustering exercise during alignment (Figure 6.3) according to theme (e.g., role play, question-games). Then, based on interest, each teammate chose 3 concept clusters to flesh out into 1-page proposals. The team as a whole reviewed all 1-page proposals and voted on what seemed most promising and interesting to them based on both the delineated goals and personal interest. Then, just before the prototyping phase the most expert designers went through and identified what they deemed to be the most promising game concepts and vetoed any ideas that seemed least related to the goals or problematic in any way.

In prototyping phase (Figure 6.1) each designer chose one or more concepts to make either individually or in a pair into a playable game for a total of five prototype plans. The games were messaged as tools for understanding our goals, rather than end games in their own right (concepts would be cut or drastically altered). To ensure the games’ alignment with the goals in the prototyping phase, we first used the game’s initial description to draft a proposal for which goals related most highly to each game. We translated the goals to specific game mechanics, dynamics, and interaction styles for each game as demonstrated in Table 1.
Figure 6. The Goal-Driven Game Design Cycle. Now with delineated goals, team members divergently prototype (1), playtest within the team (2), align with the team on what’s working (3), then either move on to game iteration (4) or revisit the goal cycle.

Playtest turnarounds (Figure 6.2) were quick (two weeks or less) and emphasized prototype playability over polish or completeness. While some versions of games were playtested with multiple outside groups (such as participants within our target demographic in the lab as well as participants outside our target population include colleagues and friends), others were iterated after just one playtest within the team itself depending on whether the game was enjoyable and expressed the selected goals. Describing these playtests in-depth is beyond the scope of this paper. In playtesting, we collected varying data including: gameplay behavior in the form of observations, think-aloud protocols, post-play focus group interviews, and self-reported emotional experiences in the form of a emotion “heatmap.” These data were analyzed by the team using the following criteria: 1) Did the game appear to encourage the delineated goals you wanted? 2) What other (unexpected) delineated goals did your game design also support? 3) Did
your game instantiate goals in a way that aligns with the rest of the team’s vision for what success looks like? 4) What other (unexpected) delineated goals did team members notice in your game? 5) Are any of these working against each other? We also asked about and observed for engagement and usability. While this last point is beyond the scope of the paper, it is important to call out as an indispensable component of developing a smoothly functioning game.

Following playtesting, the team re-enters the alignment phase (Figure 6.3). Following prior recommendations from other projects, we designed games for “fun first”; that is, prioritized getting an enjoyable game completed. After alignment, teams may choose to stay in the game cycle or move over to the goal cycle. In the game cycle, when a game is not fun, not balanced well, theme is off, content or design works needs iteration, the team remains in the game cycle (Figure 6.4). When questions, tensions, or clear misunderstandings arise out of playtesting results as to whether a game is meeting the goals, then it is time to revisit the goal cycle.

During the game design process, we used the delineated goals to create as many artifacts as possible to continuously test team alignment to the goals. These artifacts were used alongside game prototypes to discuss and critique one another's’ understanding of our vision for player transformation. In iterating and staying within the game cycle (Figure 6.4), we rely on concepts from the EDGE framework (Aleven et al., 2010), re-designing both the game and the transformational learning goal. In order to re-design we utilize the MDA (i.e., mechanics, dynamics, and aesthetics) framework (Aleven et al., 2010) to break down the games and redesign using the focus our playtesting analysis prescribes. This iterative process also sometimes included rapid swapping of game concepts from one teammate to another. Because of the mutually agreed upon goals, there was very little overhead or explanation needed when handing
off a prototype and any disparity in approach could be discussed using the delineated goals, rather than personal preference alone. This lack of singular ownership and shared priorities led to more frank, open, and impartial discussions of what appeared to be “working” and what did not.

In goal-driven game design, we continuously utilized parallel ideation to create a large list of viable game ideas, which is shown to generate better ideas (Dow et al., 2012). We repeated this process, diverging to ideate and converging to check each other’s ideas. This process, in which we intentionally spliced games together, diced them apart, and traded ownership, was to avoid a “functional fixedness” of ideas (Adamson, 1952). That is, the inability to see the breadth of possibility space for one concept due to time spent thinking about it deeply. This, too, has been shown to generate better and more innovative ideas (Dow et al., 2012). In goal-driven game design, the game is a tool to explore transformational learning goals; iterations to both delineated goals and game are conducted in the interest of advancing an understanding of those goals.

Goal-driven game designs take the best of many different design processes and uses them in cohesion, creating a method that involves a breadth, depth, and rapidity of concrete artifacts. Our team faced the specific challenge of working as a large, interdisciplinary group of designers. While we had a shared goal, our various disciplines often had completely different vocabulary and approaches to problems; our process grounded us in the reality of physical artifacts and allowed us a starting point for productive shared discourse. Earlier in this paper we described our process for delineating goals.

The following section illustrates this cycle using the four remaining games that have emerged from our use of Tandem Design out of the original sixty-plus concepts. Our games are
widely divergent and intentionally so. Our delineated goals cover wide ground in the literature of curiosity and we could not, from the literature alone, determine which interventions would be the most successful. With this in mind, in sync with the HCI practice we are pulling from, we wanted to explore a breadth of ideas. The consistent through line of our delineated goals that make their way into our games is the concept of uncertainty, which is already well situated to be a binding tie between curiosity and games (To et al., 2016).

Case Studies

The SCIPR project’s goal is to increase curiosity as a STEM educational intervention for middle school students from marginalized science identity groups (e.g., underrepresented racial minorities and women) during a critical period (Berryman, 1983; AAUW, 2010). Our team used Tandem Transformational Game Design to create four games toward this end. Prior work in this area has shown that games can be effective tools to deliver such interventions for marginalized populations at this age (Hughes, 2007; Kaufman et al., 2015). We chose curiosity as a focus because it directly ties to students’ desire and eagerness to learn and to fill gaps in knowledge (Loewenstein, 1994); moreover, games themselves are similarly well-situated both to trigger curiosity and to allow for the observation or measurement of curiosity (To et al., 2016).

We worked in a multi-disciplinary team over the course of nine months. We began developing our goals for the first four months, and in the latter five months began prototyping playable games. Due to the long nature of this project, team members cycled in and out of the project at various phases; the entire team ultimately had two undergraduates, three Masters students, one research assistant, and persisting throughout the entire project were one PhD student and two university faculty. The backgrounds of all team members included HCI
Research, HCI Practice, Psychology, Game Design, Learning Sciences, and Education. Such diversity provided the challenges mentioned earlier, but ultimately helped us gain multiple perspectives in the game design process and create more integrative products.

At this stage of our research we have narrowed down to four playable games that aimed to encourage curiosity and target specific curiosity elements, as defined by our delineated goals: Alter Egos, Outbreak, Combinations, and First to Launch. In this section we present a deep dive on the game Outbreak with additional brief descriptions of the other three games as case studies for Tandem Design.

**Outbreak: A Deep Dive on Tandem Transformational Game Design**

*Outbreak* is a collaborative question-asking game for two to five players. The game positions players as remote radio dispatchers who must carefully pose questions to a robot while it explores an unknown laboratory in search of a cure for a deadly virus. Players collectively decide how to pick a team of game characters equipped with tools to address each room’s unique threats, including: zombies, monsters, angry people, hidden objects, or ghosts, which call for different characters’ skills.

*Outbreak*, like all of our games, began as a brief mash-up of prompts contributed and then discussed by all teammates. From the original 65 concepts, ideas such as a game with a “tome” and a “choose your own adventure” or “escape” style game were flagged by team experts as having potential to promote our delineated goals. In particular, we anticipated that specific types of curiosity, including narrative curiosity and curiosity about exploring a space (To et al., 2016), would be particularly likely to emerge from these genres of game. These dovetailed well, we hypothesized, with how a game about exploration might set up one of our delineated goals
(comfort with uncertainty), particularly in a science-themed narrative space. Later, as the game iterations presented opportunities, we added other possible goals, such as comfort asking questions and the use of psychological distancing (Table 3). Allowing for many different goal considerations within a single game was an intentional part of our iterative design process: we often worked in a style in which we allowed games to get “big and messy” before exploring what was or wasn’t working toward our goals and what elements to cut or revise.

At the end of an alignment stage (Figure 6.3) the team handed a 1-paragraph concept description of a storytelling escape game to a single teammate to move onto to prototype a playable game (Figure 6.1). During an internal team playtest (Figure 6.2), we discovered something important: only about two minutes of gameplay had been completed, because one of the largest challenges of creating a storytelling game was developing written content alongside mechanics. The mechanics were going to influence the story, and vice versa. And so, in the second iteration (Figure 6.4), we agreed as a team on a pathway forward that minimized the immediate need to generate content before testing mechanics, with the promise of later drawing on everyone’s contributions to generate written content.

As the game design process progressed, the team would utilize the alignment stages (Figure 6.3) to co-design or hold content-creation sessions in order to overcome such roadblocks. These sessions consisted largely of a prompt followed by a 5-minute individual “writing session,” coming back together to share ideas, and a final 5-minute session in which to build on individual ideas after hearing others’. The teammate leading the prototype also spent a portion of time brainstorming related, already-existing games with the team and then playing them while taking notes about what was working.
Like our other games, a commitment to playtesting early and often was at the fore, with a team playthrough and critique every two weeks (Figure 6.2). Like our other storytelling game, and because we wanted to allow our games to get “big and messy” before paring down, early versions of Outbreak contained many mechanics and ideas that ultimately were cut. Prototypes often alternately became either about “going wide” with ideas, materials, designs, and mechanisms grounded in one or more goals or “going narrow” and cutting or compressing features using the MDA framework. Playtests were visited with a position of open-mindedness and rigorous honesty about what was working most and least well, with every teammate contributing their personal opinions about this, grounded in their understanding of the shared vision of what we were trying to achieve. Each game cycle provided us vital information to our goal cycle, including the fact that some of our delineated goals, such as feels curious about a narrative and comfort with uncertainty, might be at odds.

**More Games**

*Combinations* is a team-based asymmetric card matching game. In the game, one player acts as the “mastermind” who secretly assigns scores to the different ingredients. For example, in the ice cream cone themed version, a cherry might be worth 10 points, chocolate syrup 100, and vanilla ice cream 1000. Other unmarked ingredients might be a wafer, strawberry ice cream, and raspberry syrup. On a turn, other players choose cards made up of the various ingredients and receive score tokens based on the composite total of the ingredients’ scores. They must use this information to figure out the hidden ingredient scores at the end of the game to first beat the mastermind and whichever team has the highest total score wins the game. *Combinations* forces
players to deal with initial uncertainty, but encourages them to rely on team members to seek answers and assess knowledge collectively (Table 3).

Table 3. A subset of the top five most common elements and top five most common related theories from our delineated goals as they are integrated within our current games. (Forconi, n.d.)

<table>
<thead>
<tr>
<th></th>
<th>Alter Egos</th>
<th>Outbreak</th>
<th>Combinations</th>
<th>First to Launch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure is not a threat</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increased Tolerance for Uncertainty</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Collective Knowledge Assessment</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Norms about Questions</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Search for Unanswered Q’s</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Misattribution of Arousal</td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Collective Identity/Shared Goal</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growth Mindset</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psychological Distancing</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Imagining Future/Possible Selves</td>
<td>✓</td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

First to Launch is a competitive hidden information and card-swapping game. Two teams race to solve a problem with their spaceship by gathering the correct tools for the job in order to launch first. Teams receive a puzzle with hints for tools they need, tiles with different tools and descriptions for what the tools can do (e.g., “oil can - this can grease rusty things”) and must
gather the right tools for the job by stealing from the other team, trading with hidden or exposed tiles on the board, and then calling the end of the game when they are ready to guess if they beat the challenge. First to Launch has goals similar to those of Combinations but additionally encourages question-asking to find information (Table 3) and utilizes a more explicitly STEM-related theme.

Alter Egos is a competitive, identity-building, storytelling card game for up to five players. To win, players must build a character with the most numerous and diverse set of personal identities, ranging from values-based ("good friend," “family oriented,” “independent") to interests-based (“music lover,” “comedian,” “inventor”). Alter Egos has changed significantly from the original concept (a collaborative identity-building roleplaying game) and now focuses on encouraging a growth mindset (Table 3).

Challenges

Throughout the process, our team encountered numerous challenges. One of the primary concerns we encountered was how to know which games were the “right ones” to keep or cut during our alignment evaluations. Relatedly, how would we know what was working for us would ultimately work for our target demographic? And finally, how would we know if the game outcomes were truly making players feel and express more curiosity?

Likewise, we could not be sure in the initial phases that what worked as a game for us would transfer directly to our audience of middle school students. However, early and rapid playtesting, even without the target demographic, is infinitely better than no playtesting at all (Schell, 2014). Because project constraints meant it would be months before we got a game in front of our target demographic, we needed to be realistic about what was good for the games.
Though we did encounter some changes that needed to be made when introducing the games to middle school students, they were far fewer than if we had attempted to design a game for middle schoolers that was “fun for them” but never tested to see if it was fun for us.

The uncertainty around whether a particular game would successfully allow players to feel and express more curiosity mirrors concerns that many transformational game design teams face, especially when working in an ill-defined space. We’re developing measures alongside the game prototypes, so how do we know which measures to move forward with in the early development phases? This is, again, why testing four low-fidelity prototypes internally and testing multiple concepts with the target demographic before narrowing to one concept was such a central part of our process. This is also why we addressed different goals with different games; we wanted to explore broadly to find points of impact. It can be tempting to, early on, decide which measures will produce the “right” answer before more information can be discovered through making the actual game cycle.

**Limitations & Future Work**

A key limitation of this work is that the transformative goals of the games we have designed have not yet been formally evaluated. That is, to corroborate the informal evidence we have been gathering of our games’ impact during playtesting (e.g., through observational and brief self-report measures), it is imperative to conduct more systematic, controlled investigations once the games’ designs have undergone further iterations. Another key component not represented in the Tandem Design model, but nonetheless vital for most transformational design teams, is the ultimate deployment or dissemination of their games among target populations and real-life settings. In our case, we will ultimately seek to deploy our games in local schools and
afterschool programs to test both whether the games might feasibly exist in those target locations (paying special attention to fun, run time, and degree of fit with pre-existing ecosystem, among other things) and whether they suit the needs and preferences of the target demographic. The knowledge and insights gained from both formal assessment and deployment activities could (and often should) bring teams back to either cycle of the Tandem Design model, in order to re-assess the game’s alignment with its goals and the potential need for further design iterations.

Conclusion

Although transformational games often have a multidisciplinary team of experts working in spaces that are not well-traversed or well-defined, there is no less of a need to have a shared vocabulary and vision than a standard team of designers or researchers. We describe the SCIPR project’s games for curiosity as a working example of developing a shared vision and process that enhances the output of rather than suffering from the variety of disciplines many transformational game teams contain. We present a model of how to define and talk about player transformation goals by starting with a unanimously agreed-upon but expert-curated set of literature that draws from all disciplines that relate to the game’s problem space. Our goals were (and continue to be) fed through theories and prior empirical work from HCI, game design, and developmental/social psychology, as well as game prototypes. Together, these disciplines provided a diverse but complementary set of lenses through which we devised a goals centering on a mutually agreed-upon set of “curiosity outcomes,” behaviors, emotions, and cognitions that pertain to curiosity, as well as their potential catalysts and inhibitors, prioritized in order of the team’s estimation of their relative promise or likelihood for a particular game design.
From there, we describe how a team might use such goals to get the entire team immersed in related literature and games, creating a wide variety of game prototypes, and productively critiquing each other's work with little overhead. These working critiques of game prototypes will, in turn, influence the original goals, changing how the team thinks and talks about player transformation and how to better make it happen. We prioritize creating a vast breadth of prototypes and narrowing based on a dual bottom line of fun and impact while designing for fun first, and a flexibility of approach that might include mash-ups and dissections of any number of concepts, as well as trading off on design “leads” for any given game. It is our hope that this flexible process will help teams facing similar problems come together and better utilize each and every team member’s expertise while allowing them to contribute directly to the game design and prototyping process.

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