

Missing: A Serious Game for the Mitigation of Cognitive Biases

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ABSTRACT

The current study was designed to address the following research question: Can a computer game provide an effective mechanism for training adults to identify and mitigate their cognitive biases? Human decision making relies on a variety of simple heuristic decision rules that can be quick and effective mental shortcuts when making judgments. However, these heuristics can also lead to irrational thinking and problem-solving in ways that produce errors or illogicality, known as cognitive biases. Though knowledge of cognitive biases and bias mitigation strategies can help to reduce the potential impact of cognitive biases on human reasoning, such deeply ingrained cognitive strategies are difficult to alter. The current study was designed to leverage the virtual learning environment of a serious game to take on this training challenge. To that end, a training game – *Missing: The Pursuit of Terry Hughes (Missing)* – was developed. *Missing* was created for an audience of educated adults, and the described instructional design is based on current research on effective andragogical learning theory. The *Missing* game design immerses the user into bias-invoking situations which provide direct experience with cognitive bias identification and mitigation strategies. In this paper, details of the game instructional design are presented, including a cognitive framework based on dual-process systems of reasoning which relates multiple biases, their causes, and mitigation techniques. An external test campaign was conducted to determine whether the game had a positive transfer of in-game experiential learning about biases to real world skills and behavior change. Results are presented that suggest this novel serious game both engages and trains players, resulting in measurable reductions in cognitive biases.

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INTRODUCTION

The human mind is limited in its capacity to render judgments in a way that is perfectly rational and fully informed. For any given decision or judgment, it is next to impossible to have complete access to every piece of information relevant to making that decision. Even if such access were possible, our brains do not operate like computer algorithms, capable of complex calculations in order to reach logically sound conclusions – not to mention that we hardly have time to undergo such rigorous analysis for every judgment that we make. As a result, human decision making relies on a variety of simple heuristic decision rules that can be quick and effective mental shortcuts when making judgments. Much of the time, heuristics are effective, resulting in decisions that are “good enough” while functioning to reduce cognitive load. However, heuristics can also lead to irrational thinking and problem-solving in ways that produce errors or illogicality, known as cognitive biases. Cognitive biases are pervasive in human reasoning and have important practical implications. The efficacy of many social institutions is contingent upon humans making balanced, rational judgments – the legal system, the medical and behavioral health fields, the business world, political spheres – and biased, distorted reasoning processes can have dire consequences.

Though cognitive biases are deeply ingrained and difficult to alter, knowledge of cognitive biases and bias mitigation strategies can help reduce the impact of cognitive biases on human reasoning. With this in mind, the Sirius research program¹ was developed to investigate whether a video game could be an effective mechanism for training adults to identify and mitigate their cognitive biases. As one of the performers on the program, the research team was challenged to design and produce a video game for this purpose. Three cognitive biases were selected as targets for mitigation: confirmation bias, the fundamental attribution error, and bias blind spot.

Confirmation bias is defined as the tendency to seek out or focus on information that confirms a hypothesis while overlooking or discounting evidence that might disconfirm that hypothesis (Cherry, n.d.). This can be considered a bias in both searching and interpretation of evidence, as ambiguous evidence is often interpreted as supporting the hypothesis (Cherry, n.d.). The fundamental attribution error results from assuming that another person’s behavior must stem from personal characteristics while overlooking the potential impact of situational influences (Grinnell, n.d.). For example, having just met a waitress who seemed curt and impatient, you might assume that she is a rude person; however, this conclusion ignores the fact that there might be a situational explanation for her behavior – perhaps she is in pain due to a pinched nerve. Finally, the tendency to recognize bias in others but not in oneself is known as the bias blind spot (Pronin, Gilovich, & Ross, 2004; Pronin, Lin, & Ross, 2002). Perhaps unsurprisingly, people tend to be far more capable of identifying biased thought patterns in others than in themselves (Pronin, Gilovich, & Ross, 2004; Pronin, Lin, & Ross, 2002).

The idea of using a video game as a vehicle for training has been around for over a decade (Stapleton, 2004). Video games that are designed for purposes beyond pure entertainment, such as teaching or training, are called serious games (Stapleton, 2004). A number of serious games have been produced in recent years to address a wide variety of topics. Some serious games are designed to teach the player about a specific subject or concept. Several examples include *JDoc*, a medical simulator for doctors to help them gain experience with diagnostic and medical procedures

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(Slaney & Murphy, 2008); *Virtual Cell* and *Geology Explorer* to teach cell biology and geology, respectively (McClellan, Saini-Eidukat, Schwert, Slator, & White, 2001); and a Real Time Strategy game for teaching computer programming basics (Muratet, Torguet, Jessel, & Viallet, 2009). Others are geared toward more abstract learning outcomes. One such example is the *Tactical Language and Culture Training System (TLTS)*, which trains players in basic language and culture skills in Tactical Iraqi Arabic, Tactical Pashto, and Tactical French (Johnson, 2007; Johnson, Vilhjalmsson, & Marsella, 2005). Geared toward military users, the *TLTS* is composed of an interactive lesson component and two types of games for practicing and developing skills (Johnson, 2007; Johnson, Vilhjalmsson, & Marsella, 2005). Another example of a serious game that trains a more abstract skill set is *DREAD-ED*, a cooperative multi-player game to help teach emergency management personnel communication and decision-making skills (Haferkamp, Kraemer, Linehan, & Schembri, 2011).

In the current study, a serious game was developed to train the recognition and mitigation of the three previously specified cognitive biases (confirmation bias, the fundamental attribution error, and bias blind spot). This paper describes how the game – titled *Missing: The Pursuit of Terry Hughes* – was developed for an adult audience using principles of adult learning theory (i.e., andragogy) as well as principles of constructivist learning theory. Each bias was targeted based on a cognitive framework of dual-process systems of reasoning, which relates biases, their causes, and effective bias mitigation techniques. In addition, the results of an external test campaign that was conducted to evaluate the efficacy of the training game are presented.

GAME DESIGN

Missing: The Pursuit of Terry Hughes is a serious computer game developed by a Leidos-lead research team² in the style of an adventure game. The game has a noir feel and combines the rich, immersive qualities of entertainment software with a host of training activities on cognitive bias recognition and mitigation incorporated into game play. The story develops over the course of three episodes, during which the player completes a series of tasks and interactions with game characters, all in pursuit of resolving the mystery at the center of the story. Players in *Missing* can examine different objects, meet and question non-player characters (NPCs), use a smartphone to take pictures and communicate, and navigate in the scenario, among other choices. Along the way, the player is exposed to specific bias-invoking situations in the form of “bias vignettes,” where cognitive biases exhibited by the player are measured. After each episode is played, there is an After Action Review (AAR) that teaches about specific biases, offers feedback on game performance, and reinforces the point with a story. How the game teaches players to recognize and mitigate specific cognitive biases is determined by the content of the bias vignettes and the AARs.

The design of these bias vignettes and AARs was guided by a cognitive bias framework derived from the literature, as well as established learning theory. The cognitive bias framework and learning theory principles that were integral to the development of *Missing* are described below. The structure of *Missing* is then explicated in more detail with the theoretical underpinnings of each aspect of the game design being highlighted.

Missing and the Cognitive Bias Framework

In order to begin developing a serious game to teach the recognition and mitigation of cognitive biases, a cognitive bias framework of the three specific cognitive biases being targeted, their causes, and mitigation approaches was defined. Previous research, based on work on priming and dual-process systems of reasoning (Evans, 2007; Forster & Liberman, 2007), guided an understanding and perspective on these biases. As the term “dual-process system” implies, there are two systems of reasoning involved in this model: System 1 reasoning is characterized by automatic, intuitive, and reactive thinking, whereas System 2 reasoning is characterized by deliberate reasoning and rule-governed thinking (Evans, 2007; Kahneman, 2003; Morewedge & Kahneman, 2010; Strack & Deutsch, 2004). The literature base has indicated that judgmental biases commonly arise when the automatic and intuitive processes of System 1 reasoning generate faulty conclusions, which the logical, controlled processes of System 2 reasoning fail to identify and mitigate (Morewedge & Kahneman, 2010). With that in mind, we sought to distinguish the cognitive processes that underlie each of the three biases (i.e., automatic System 1 reasoning processes) and the most promising mitigation strategies (i.e., logical System 2 reasoning processes) for each bias as suggested by the literature.

² The team consisted of researchers from Leidos, Carnegie Mellon University (CMU), and Creative Technologies Incorporated (CTI).

Confirmation Bias

Theory-Based Cause: Confirmation bias is believed to occur as the result of a *confirmatory search* (Klayman & Ha, 1987), leading to an increase in the selective accessibility of hypothesis-consistent information. In other words, when people search for information to test a focal hypothesis, they tend to search for evidence that would confirm that hypothesis rather than search for evidence that would disconfirm the focal hypothesis or support its alternatives (Morewedge & Kahneman, 2010).

Theory-Based Mitigation: The most effective de-biasing strategy thus far has been to ask people to consider not only the focal hypothesis, but also consider the evidence supporting its alternatives or negative (Morewedge & Kahneman, 2010). This increases the accessibility of and deliberate attention toward hypothesis-inconsistent information (Koriat, Lichtenstein, & Fischhoff, 1980).

Confirmation Bias Game Vignettes: The bias is elicited during the game by urging the player to examine and investigate objects in the playfield in order to answer a question supporting the game narrative. For example, as the game begins, the title character of Terry Hughes is missing. The player is primed with a particular hypothesis (i.e., that foul play may be involved in Terry's disappearance), and is asked to search Terry's apartment for clues. The types of evidence that the player focuses on or ignores will help reveal confirmation bias; focusing on clues that confirm the primed hypothesis while overlooking other significant clues may be indicative of biased thought patterns and behavior. As a lesson for mitigation, the player is prompted to consider an alternative hypothesis after they have conducted an initial search, and potential evidence that they missed is highlighted in the AAR.

The Fundamental Attribution Error

Theory-Based Cause: When interpreting others' behavior – in other words, trying to understand why others do what they do – we tend to focus on their personal characteristics while overlooking the potential impact of environmental or situational factors (Gilbert, 2002). This perspective often leads us to over-emphasize or anchor on personality-based explanations for behaviors observed in others, while under-emphasizing the role and power of situational influences on the same behavior (Gilbert, 2002).

Theory-Based Mitigation: In one study, observers' biases were reduced by having them explicitly consider the degree to which a situation (rather than personality traits, such as an anxious disposition) might make one nervous (Krull, 1993). The primary mitigation strategy for this bias is to increase reflective, rule-governed thinking (i.e., System 2 reasoning) when making attributions by highlighting potential situational influences on behavior (Gilbert, 2002). Encouraging observers to consider the behavior of the majority under the same circumstances can help to reduce conscious anchoring on dispositional explanations for a person's behavior, as well (Gilbert, 2002). In addition, as with confirmation bias, explicit consideration of alternatives (in this case, considering alternative explanations for behavior) applies as a mitigation strategy for the fundamental attribution error (Gilbert, 2002).

Fundamental Attribution Error Game Vignettes: This bias is elicited during the game by presenting the player with an observation and a question regarding the motivation behind a game character's observed behavior. For example, after viewing a brief video clip of Terry fidgeting nervously in her apartment building's elevator, players are asked whether they think that Terry is a nervous person – a dispositional attribution for her behavior. The extent to which a player chooses personality-based explanations of a character's behavior while failing to take situational influences into account suggests the presence of the fundamental attribution error in his or her judgment.

Bias Blind Spot

Theory-Based Cause: Bias blind spot is theorized to derive from two factors: 1) naïve realism, a tendency to see one's own perceptions as directly reflecting reality and others' perceptions as biased if they differ, and 2) reliance on introspection in assessing bias for oneself paired with reliance on behavior in assessing bias in others (Pronin, Gilovich, & Ross, 2004). When considering whether oneself is biased, one considers the conscious thoughts that come to mind in the decision process (which rarely reflect bias), rather than the associated behavior (which often shows bias); thus, the tendency is for an individual to be unaware of his or her own cognitive biases, even when the individual can recognize cognitive biases in others (Pronin, Gilovich, & Ross, 2004).

Theory-Based Mitigation: Research suggests that the most effective mitigation strategy for bias blind spot is education-based. Teaching the importance of non-conscious processes in guiding judgment (as described above), the ubiquity of unintentional influences, and the resultant fallibility of introspection as a source of information has been demonstrated to reduce the impact of bias blind spot (Pronin & Kugler, 2007).

Bias Blind Spot Game Vignettes: During the AAR at the end of each game episode, players are asked to rate how biased they believe that they were with respect to their performance in the game. They are then asked to compare their performance to the performance of others who have also played the game. The extent to which players judge their performance as being unbiased, while judging the performance of others as being biased, suggests the presence of the bias blind spot.

Bias Framework Motivated Game Mechanics

Given our described bias framework, we identified the points at which the biases overlap with regard to common causes and potential sources for mitigation, illustrated in Figure 1. This enabled us to develop an efficient game that treats the origins of multiple biases at their common source, and allows players to generalize their learning across different problems and portions of the game to other biases.

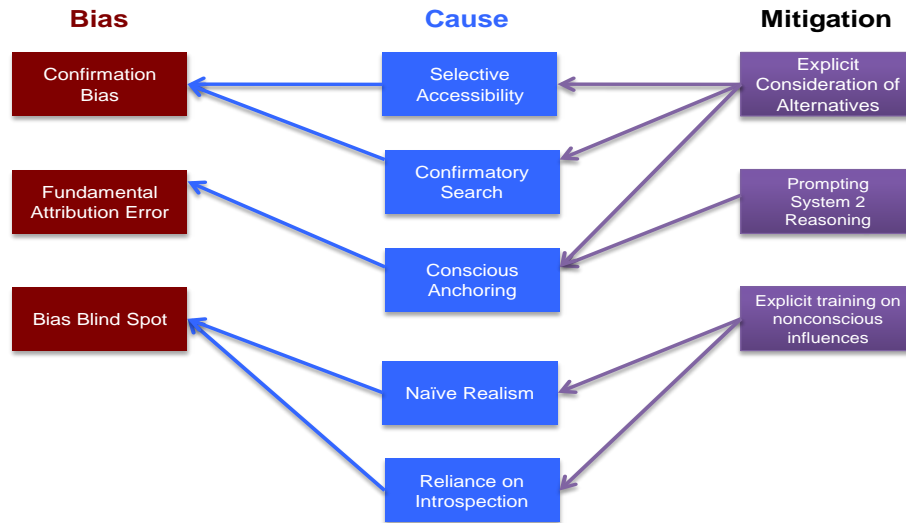


Figure 1. Cognitive Bias Framework

The game is structured to move the player through four major instructive phases. This incorporates the bias framework and theory-based mitigation techniques directly into the game play. These four phases are:

- 1) **Cognitive bias elicitation:** Present the player with a naturalistic scenario designed to elicit a target bias.
- 2) **Bias measurement:** Examine player actions (or query player) to determine if bias has occurred.
- 3) **Participant feedback:** Provide feedback to the player about the bias in the current scenario and whether the player demonstrated or avoided it.
- 4) **Cognitive reinforcement:** Reinforce the player's understanding of the bias by offering additional examples highlighting similar bias aspects and contexts.

These four steps are repeated multiple times in a given game episode such that all three biases are experienced one or more times. Additionally, the game is comprised of three episodes offering repeat learning experiences for the biases.

Missing and Learning Theory

Having established a strategy for training players to recognize and mitigate their cognitive biases, the development team relied on principles of learning theory to design the final prototype of *Missing*, which was then refined over numerous development cycles. The developers had to create a learning environment that would address the unique characteristics and needs of the adult learner while being conducive to critical exploration of the metacognitive process of thinking about how we think. To that end, *Missing* is well-steeped in two primary learning theories that complement one another: andragogy and constructivism. Each of these theories is briefly described below.

Andragogy

The theory of andragogy seeks to identify the critical phenomena for facilitating learning in adults, as differentiated from pedagogy, which focuses on teaching children. Throughout history, researchers and educational theorists have

worked to build an understanding of how adults learn; from the days of Plato and Socrates, it was been recognized that a central element of adult education is a focus on active inquiry and knowledge construction, as opposed to passive reception of information from a teacher. Educator Malcolm Knowles (1990) developed a theory of andragogy that identified several key phenomena for adult learning. Of these phenomena, the four that were most influential for the development of *Missing* are Need to Know, Self-concept, Readiness to Learn, and Orientation.

First is Knowles's (1990) concept of **Need to Know**, which refers to the adult learner's need to know *why* it is important to learn something. Second, adults learn best when treated as though they are capable of self-directed learning rather than being dependent on a teacher, which corresponds to the andragogical principle of **Self-concept** (Knowles, 1990). The third andragogical concept particularly relevant to the development of *Missing*, **Readiness to Learn**, recognizes that adult learners are most likely to engage in learning in order to acquire skills that have immediate relevance to their lives (Knowles, 1990). Finally, **Orientation** refers to the difference in orientation between education for children and for adults; while children's education is usually content-oriented, adult education is generally problem-centered or task-oriented (Knowles, 1990).

Constructivism

The other learning theory paradigm that was particularly influential in the development of *Missing* is constructivism. As serious games have increased in complexity, the learning theories utilized to support their use and design have focused on the principles of constructivist learning theory (Rooney, 2012) which, incidentally, compliments the phenomenon of andragogy (Blondy, 2007). According to constructivist theory, knowledge is a function of how a learner creates meaning from his or her own experiences. The learner is theorized to be in equilibrium until a novel experience is encountered. This experience is then tested against the learner's current understanding of the world (i.e., hypotheses). If the new knowledge fits the currently held hypothesis, the learner is in equilibrium and the experience serves to strengthen the learner's hypothesis about the world. If, however, the new experience does not fit the current hypothesis, the learner is said to be in chaos and then engages in social negotiation until he/she changes his/her world view or the perception of the new experience to again achieve equilibrium. Through this process, the learner is constantly constructing a better model of understanding.

Several components of constructivism were integral to the development of *Missing*. For one, constructivism dictates that the learner's current knowledge must be challenged before learning can occur (**challenge current knowledge**). Next, the principle of **active learning** asserts that meaningful understanding occurs when the learner develops effective skills to resolve problematic situations. Third, constructivism purports that traditional learning situations rely heavily on memorization and do not allow the learner to build the necessary associations between the concepts and the reflective metacognitive processes experts use to solve problems. Thus, an authentic context for the problem is important and serves as a crucial link between the concept and the construction and transfer of knowledge (**authentic learning**). Lastly, a rich learning environment provides the learner with **multiple and alternative perspectives**. This environment addresses the needs of learners with various experiences and learning styles.

The Game Design of *Missing* and Theoretical Underpinnings

In the following section, the structure of *Missing* will be outlined. For each element of the game design, relevant aspects of the cognitive bias framework and learning theory will be highlighted.

Opening Video

Missing opens with a short introductory video that provides exposition and draws the player into the game story. The player is granted a glimpse into the life of the protagonist, Terry Hughes, through a collage of social media postings that reveal Terry to be a gregarious, well-liked figure with an extravagant social life. Everyone knows Terry – and when she falls off the grid for a day, her absence is noticed. Her brother Chris, in particular, is worried; in his concern, he contacts you, the player – Terry's neighbor – and asks you to look around her apartment for clues as to her disappearance.

Incorporating an engaging storyline into serious games is one strategy for retaining player attention, promoting fun and entertainment, and encouraging immersion into the game content. All of these factors help to optimize player learning outcomes.

Episode One

In the first episode of the game, *Missing* offers the opportunity to explore an immersive environment that stages facilitated challenges to current thinking; in this particular case, cognitive bias. This interactive process allows the learner to work through realistic and authentic tasks to discover principles that aid in the construction of new concepts.

Having been primed by the opening video to believe that Terry's sudden disappearance may be the result of foul play (e.g., a kidnapping), the player enters the noir-styled 3D world of the game, where he/she is exposed to the aforementioned bias vignettes. These include two searches that act as naturalistic scenarios through which confirmation bias may be elicited via the theory-based causal mechanism of confirmatory searching; first, the player searches Terry's apartment for clues as to her disappearance, and second, the player searches Terry's home office for clues as to what sort of personal problems she might be having (i.e., financial problems or romantic problems). The game environment includes three types of clickable objects: confirming (i.e., objects that might confirm the hypothesis that Terry was abducted, such as a mysterious red smear on the refrigerator), disconfirming (i.e., objects that suggest that Terry's disappearance was planned, such as a missing suitcase in a row of suitcases by her closet), and neutral objects (i.e., objects that neither confirm nor disconfirm either hypothesis, such as an article of dry cleaning hanging on a door knob). The game then monitors which objects the player focuses on while searching and prioritizing pieces of evidence and uses that information to deliver feedback in the AAR for Episode One.

There are several fundamental attribution error bias vignettes in Episode One as well. In these vignettes, the player is, once again, placed in a situation that is designed to elicit the target bias. A scene in which another character in the game is exhibiting a particular behavior is presented (e.g., the player answers a phone call and speaks with the character Stephanie, who appears abrupt and vague). The player is then asked to make an attribution for the character's behavior (e.g., another character asks, "Do you think Stephanie is an evasive person?"), and must choose between making a dispositional attribution, assuming that the character's personality was driving his/her behavior in this instance, or considering that situational factors might be affecting the character's behavior.

The format of Episode One allows for the player to activate the andragogical phenomenon of Self-concept, or self-directed learning. Players are free to explore their environment, engaging with whichever objects they wish to investigate and answering the other characters' questions as they see fit. In Episode One, players have not yet been explicitly informed about the teaching purpose of the serious game; they are not yet aware that the game is designed to train the recognition and mitigation of cognitive biases. This allows the player to freely experience the play environment, behaving naturally while becoming immersed in the game story and entering a state of flow.

While most people do not spend time investigating the potential abduction of a neighbor on a regular basis, the bias vignettes in *Missing* in which players must evaluate conflicting evidence or make attributions for the motivation behind another's behavior are generalizable to the judgment and decision-making situations that most adults face on a regular basis. Constructivism purports that learning is more likely to occur when learners are presented with an authentic situation that enables, simulates, or reconstructs real-life complexities and events than from experiences that are irrelevant or meaningless to learning. An authentic learning context is important for the transfer or assimilation of knowledge into existing cognitive schemas, which *Missing* provides.

After Action Review (AAR) One: Defining the Biases

In the AAR for Episode One, the player is first introduced to the concept of cognitive biases. Before launching into feedback on game performance with respect to each bias, a brief video of a subject matter expert defining cognitive bias in general is played, followed by separate videos defining each of the biases (confirmation bias, the fundamental attribution error, and bias blind spot). These videos are approximately two to three minutes in length, intended to provide a fundamental, clearly-stated understanding of what cognitive biases are.

These definitional videos serve to activate a number of components of both andragogy and constructivism in the adult learner. Explaining to an adult that pervasive patterns of bias, illogical thought patterns, and erroneous reasoning negatively affect our judgment and decision-making skills is a major impetus for Need to Know – what are cognitive biases? How might they be impacting decisions that I make in my career and personal life? How can they be mitigated? Having established that cognitive biases have an important, real life impact, a Readiness to Learn becomes activated; learning to mitigate cognitive biases has immediate relevance to the life of the adult learner. Having the relevant cognitive biases identified and defined may serve to challenge the player's current knowledge or understanding of his/her own thought patterns, which the player may not recognize to be affected by biases. In

addition, the basic lecture format in which the three biases are defined for the player is one of multiple learning perspectives, or ways of presenting this information.

AAR One: Feedback

Within the AAR, the player is also given feedback on his/her performance for each of the bias vignettes in the game. Before receiving feedback, however, players must specify the extent to which they believe that they exhibited either confirmation bias or the fundamental attribution error for the respective bias vignette, as well as their perceived bias relative to other players (i.e., “In your estimation, to what extent did you show confirmation bias relative to the average player?” with response options “much less,” “less,” “slightly less,” “just as much,” etc.). This information is used to evaluate bias blind spot at the end of the AAR.

The feedback to players first reminds them of the circumstances surrounding the bias vignette and how they responded, explains whether or not their response demonstrated bias, and suggests mitigation strategies specific to the target bias. This harkens back to the andragogical principle of Orientation, in which learning is task-oriented (i.e., how should I be handling these bias-invoking situations so that I am mitigating my biases?), rather than content-oriented alone. *Missing* seeks to change the way that the individual thinks, rather than just passing on facts and descriptions of cognitive biases. In terms of constructivism, several principles apply. *Missing* presents bias-invoking situations which challenge the player’s way of thinking – creating chaos when the learner is given feedback that he or she acted in a biased way; in other words, challenging current knowledge. This primes the learner to test his or her current way of thinking about a problem, reinforcing a Need to Know for the adult learner. Active learning is accomplished in that players are exposed to a game environment in which they face problematic situations, take some action, then process feedback on their performance. Feedback is another of the multiple perspectives that can be used as a teaching mechanism in the game.

AAR One: Narrative Stories

Finally, for each bias, a “narrative story” that reinforces the generalization of bias identification and mitigation skills across different situations is provided as a form of cognitive reinforcement. While these mitigation strategies will provide the learner with a set of tools to reduce cognitive bias, additional reinforcement may be needed to ensure that these strategies are spontaneously used in different contexts, and that their efficacy persists for a longer period. Learners often fail to apply strategies learned in one context to another, even when they are highly analogous (Gick & Holyoak, 1980). However, when learners encounter *multiple* analogous instances of a strategy, they may form a schema of the strategy that leads to higher transfer to other contexts (Gick & Holyoak, 1980). Thus, providing analogous cases may help learners to create schemas that will facilitate their use of bias mitigation strategies across contexts, because they will better recognize when these strategies apply. To provide these analogous cases within the game, we included a story-based teaching approach (Schank, 1982; Schank, 1990). The narrative stories augment game vignettes by presenting analogous cases to the player during the AAR. The introduction of the analogous case reinforces the learned strategy by allowing schematization across different contexts.

The narrative stories as a teaching mechanism reinforce a Need to Know, as they outline reality-based cases in which cognitive biases had large-scale consequences (e.g., in the case of the U.S. Government’s search for Weapons of Mass Destruction in Iraq), or even ways in which cognitive biases may have smaller-scale impacts on our everyday decision-making. They also encourage authentic learning by aiding the learner to build the necessary associations between the bias identification and mitigation strategies of the game and how those might be applied in the “real world.” Along with the bias definitions and feedback, the narrative stories provide an additional alternative perspective on the learning content for the player.

Episode Two, AAR Two; Episode Three, AAR Three

In the remainder of the game, two more episodes play out to guide the player through the complete game story, accompanied by their respective AARs. Throughout, andragogical and constructivist principles are woven into the game content to encourage optimal learning for adults. *Missing* promotes active learning by presenting the learner with an environment in which he or she is confronted with a problem. The learner is asked to actively collect data and develop hypotheses, engaging a self-directed learning style in support of Self-concept. The learner is challenged to perform higher level thinking and given metacognitive guidance on cognitive bias detection and mitigation in an authentic learning environment. The very nature of serious games such as *Missing* accommodates multiple learning styles by allowing the learner to move around, listen, and interact with the environment. The environment also exposes the learner to multiple types of learning opportunities (e.g., bias vignettes, lectures, narrative stories). This allows the learner a wide range of learning contexts and experiences that facilitate the transfer of knowledge to real

life situations. The Need to Know and Readiness to Learn come from the apparent advantage in both work and personal life of having an understanding of biases and how to minimize their impact on rational thought. The learning that comes from *Missing* is practical and task-oriented for everyday life.

Table 1 identifies specific game features and mechanics implemented in the game directly in support of the bias mitigation strategies.

Table 1. Game Mechanics/Features that Implement Bias Mitigation Strategies

Game Mechanics/Features	Confirmation Bias	Fundamental Attribution Error	Bias Blind Spot
Game Vignettes	Search challenges that include confirming, disconfirming, and neutral evidence	Judgment challenge given conflicting evidence	Player rates how biased they are compared to other players of the game
Priming for the bias	Prime player with confirming evidence	Player primed with personality-based evidence	None
Formal bias definition	Provided in the AAR	Provided in the AAR	Provided in the AAR
Hints during game play and AAR	To prompt explicit consideration of alternatives	To prompt explicit consideration of alternatives and System 2 reasoning	Provide explicit training on non-conscious influences
Practice Examples	During AAR interactive additional examples provided for practice	None	Player is tested during each AAR
Explicit Feedback on Performance	Game and practice example feedback	Game performance feedback	Game performance feedback
Cognitive Reinforcement	Narrative Stories	Narrative Stories	Narrative Stories

METHOD AND RESULTS OF GAME EFFICACY EVALUATION

In order to assess whether or not *Missing* was effective at training the recognition and mitigation of cognitive biases, an external test campaign was conducted by an independent verification and validation team³ not affiliated with the authors. Participants were assigned to either the game condition (experimental group) or an educational video condition (control group) in order to compare the knowledge transfer from the game relative to a more traditional method of teaching about cognitive biases. All participants took a pretest to assess prior knowledge about cognitive biases, either played the game or watched the video, then took a posttest to assess the training effect. A sub-set of participants also completed a follow-up test eight weeks after the testing session to assess knowledge retention over time. The following is an overview of the method and results of this evaluation.

Method

Participants

Two separate groups of participants were recruited: a college student group and an intelligence analyst group. This study design was intended to assess the efficacy of *Missing* as a teaching tool for different demographic populations. For this study, college students are representative of the young adult population that is preparing to enter the workforce and take on positions where biased reasoning can have practical, real world consequences. A sample of intelligence analysts was recruited as well, a prime example of workers in a field where biased interpretation of information can have disastrous outcomes.

Students were recruited from two large universities in the Washington DC/Baltimore region. A total of 54 students participated in the game/experimental condition and 58 participated in the video/control condition. Of these

³ The Government-led Independent Verification and Validation team consisted of researchers from the Applied Physics Laboratory at Johns Hopkins and MITRE.

students, 38 of the game condition participants (70.4% retention) and 42 of the video condition participants (72.4% retention) completed the follow-up test eight weeks later. The analyst population was recruited from the Washington DC/Baltimore region as well. A total of 29 analysts were in the game condition, of which 11 completed the follow-up test (37.9% retention). Thirty (30) analysts participated in the video condition, with 10 completing the follow-up test (33.3% retention).

Materials and Procedure

A standardized measure of cognitive bias knowledge and mitigation was developed jointly by the Educational Testing Service (ETS), developers of widely used standardized tests such as the SAT and the GRE (“Tests and Products,” 2014), and MITRE. The bias assessment instrument was composed of two sections, one on the recognition and discrimination of the three target biases and one on bias mitigation. Three different forms were developed to be administered as pre-, post-, or follow-up tests in counterbalanced order.

Along with the bias assessment instrument, materials for the experiment included copies of *Missing*, loaded onto computers that met the minimum specification to run the game (Intel® Core™ i7 processor; Windows 7 operating system; 4 GB Dual Channel DDR3 SDRAM 1333 MHz or greater memory; 1 GB on board DDR3 RAM video card), and the control video. The control video was a professionally produced, engaging video that taught recognition and mitigation of confirmation bias, the fundamental attribution error, and bias blind spot; thus, the video might be considered an active control (i.e., the current standard of practice for providing education about cognitive biases).

During testing, participants would arrive at one of several designated lab sites. They would then be randomly assigned to the game or video condition and a pretest form. After taking the pretest, the participant would either play the game or watch the video, which was followed by completion of the posttest. Those who were willing received an email with a personalized link to the follow-up test eight weeks after the study date and given a week to complete it.

Results

Analysis of the data included evaluations of the following: A) whether the game was effective in teaching the recognition of and discrimination between the three cognitive biases, B) whether the training effect on recognition and discrimination of biases was retained over time, C) whether the game was effective in training the mitigation of cognitive biases, D) whether the training effect on bias mitigation was retained over time, and E) whether the game was a more effective training tool than an educational video.

To evaluate whether the game was effective in teaching the recognition and discrimination of the three biases, pre- and posttest scores were compared to obtain a percentage improvement. In this case, the percentage improvement represents an increase in the participants’ ability to accurately match the selected biases to their definitions and to differentiate the biases from one another when given a scenario and asked which bias the scenario represented. *Missing* achieved a 37% improvement in recognition and discrimination of biases for the student sample ($N = 54$) and a 44% improvement for the analyst sample ($N = 29$). In both cases, this improvement was statistically significant ($p < .01$). As might be expected, there was some fade in knowledge retention over the eight week gap period. Of the student group that completed follow-up testing ($N = 38$), knowledge retention decreased from 37% improvement to 25% improvement. This 25% improvement remains a statistically significant improvement over pretest scores ($p < .01$). Of the analyst group that completed follow-up testing ($N = 11$), the percentage improvement decreased from 39% at posttest to 26% at follow-up, which also remains a statistically significant improvement ($p < .01$). However, all follow-up results from the analyst group should be interpreted with caution, as the sample size is very small.

Next, the bias mitigation capability of the game was assessed, with percentage improvements indicating the reduction in errors associated with the biases. Overall bias mitigation was 25% and 27% for the student and analyst groups, respectively ($p < .01$ for both groups). For overall bias mitigation, effect sizes in the form of Cohen’s d were calculated as well. For both the student and analyst groups, the effect sizes ($d = 1.12$, $p < .01$ for the student group; $d = 1.13$, $p < .01$ for the analyst group) exceeded Cohen’s (1992) threshold for a large effect size ($d = .80$). Interestingly, for bias mitigation, there was very little fade in retention after the eight weeks. Even after a two month period, the student sample who completed the follow-up test ($N = 38$) had fairly comparable bias mitigation percentages: 29% ($p < .01$) at immediate posttest and 28% ($p < .01$) at follow-up testing. The analyst sample that completed the follow-up test ($N = 11$) showed a somewhat greater decline in performance after the eight weeks,

from 27% ($p < .01$) to 20% ($p < .05$). As before, however, the results for the analyst group should be interpreted with caution due to the small sample size.

Finally, the results of the *Missing* game were compared to those of an educational video. The game was significantly more effective for teaching recognition and mitigation of cognitive biases in both the student ($p < .01$) and analyst ($p < .05$) groups at immediate posttest than the educational control video. Of the sub-sets of the student and analyst samples that completed the follow-up test, this effect was maintained for the student group ($p < .01$), though not for the analyst group.

In total, these results are highly encouraging and suggest that *Missing* is an effective teaching tool for the recognition and mitigation of confirmation bias, the fundamental attribution error, and bias blind spot in aggregate. Notably, *Missing* outperformed the educational control video at a statistically significant level, which lends support to the idea that serious games may be more effective for training than standard approaches such as educational videos or lectures.

CONCLUSIONS

The serious game *Missing* was developed to investigate whether a video game could be an effective mechanism for training adults to identify and mitigate their cognitive biases. Three cognitive biases were selected as targets for mitigation: confirmation bias, the fundamental attribution error, and bias blind spot. Game design was guided by current literature on cognitive biases, which provided theoretical bias causes and mitigation strategies. The game design was also informed by literature on andragogical learning theory as applied to adult learners, our target population, as well as constructivist learning theory. These concepts were incorporated into specific game mechanics and story narrative and the effects of *Missing* on bias recognition/discrimination and mitigation were measured.

Though cognitive biases are deeply ingrained and difficult to alter, knowledge of cognitive biases and bias mitigation strategies can help to reduce the potential impact of cognitive biases on human reasoning. The immediate effect of *Missing* on bias **knowledge** in both student and analyst samples was encouraging at 37% and 44%, respectively. The immediate effect of *Missing* on bias **mitigation** in student and analyst samples was positive as well at 25% and 27%, respectively.

It was expected that there would be some decay in the effects of *Missing* on both bias knowledge and bias mitigation when measured eight weeks after game play. It was observed, however, that the learning results were robust after this longitudinal period. For the student sample, analyses showed only a one percent drop in bias mitigation measures. For the analyst sample, analyses showed a drop of only a few percentage points over the same time period. These results suggest that the knowledge gained by playing the game *Missing* is internalized and retained.

Through future work, we hope to replicate these results with three different biases: anchoring bias, projection bias, and the representativeness heuristic. A new version of the *Missing* game specifically designed for these biases will be developed and the effects of the new game will be measured.

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