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■ *Research Paper*

Situating a Measure of Systems Thinking in a Landscape of Psychological Constructs

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Many of the greatest challenges in society have emerged as a result of humans acting within complex systems without fully understanding how they work. To address this problem, scholars from diverse fields have appealed to *systems thinking*. To date, a psychological perspective has been conspicuously absent from scholarship on this topic—a gap that the present paper seeks to fill by situating an individual difference measure of systems thinking in relation to well-studied constructs (e.g. holistic and relational thinking) and decision-making tasks in the psychological literature. Results indicate that the measure of systems thinking captures peoples' tendency to represent and reason about complex systems. The paper helps to validate a novel measure of an individual's tendency to engage in systems thinking and to provide a conceptual foundation for the thinking about the psychological underpinning of a systems thinking mindset.

Keywords systems thinking; reasoning; analogy; mindset; personality

INTRODUCTION

Many of the greatest challenges we face as a society have emerged as a result of humans acting within enormously complex systems without fully understanding how these systems work (Meadows and Wright, 2008). To address this fundamental problem, scholars from diverse fields have appealed to a *systems thinking* mindset for conceptualizing reality and, in turn, for making better decisions about the complex world in which we live (e.g. Buckle Henning and Chen, 2012; Checkland, 2012; Espejo, 1994; Meadows and Wright, 2008): People who engage in systems thinking attend to and process system-related information more broadly and recognize complex causal relationships and patterns of change; as a result, they are more likely to make decisions that enhance the well-being of the systems they interact within and depend on.

The primary aim of the current paper is to situate an instrument for measuring the degree to

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which people engage in systems thinking (the Systems Thinking Scale; Davis and Stroink, 2015) in relation to well-studied constructs (e.g. holistic and relational thinking) and decision-making tasks in the psychological literature. To date, a psychological perspective has been conspicuously absent from scholarship on systems thinking and there has been relatively little work to empirically validate a measure of a psychological tendency for an individual to engage in systems thinking or to test whether systems thinking affects decision making (refer to, e.g. Burnell, 2015). A psychological perspective on systems thinking, substantiated by empirical investigation, may facilitate an ongoing discussion about what it really means to engage in systems thinking (refer to, e.g. Buckle Henning and Chen, 2012).

We first describe the similarities and differences between systems thinking and holistic and relational thinking. We then present a series of empirical studies in which we (a) compare the Systems Thinking Scale to a set of existing personality instruments and (b) use these scales to predict behaviour in a set of tasks that have been used to measure variability in holistic and relational thinking.

We end the paper with a discussion of why we think it is important to promote systems thinking in the lay public (i.e. in order to facilitate decision making for complex issues) and point to some specific tools (e.g. linguistic and visual metaphor) that may be well suited to this goal (refer to, e.g. Flood and Jackson, 1991; Thibodeau *et al*., 2015). At the core of our approach is a belief that a systems thinking mindset is malleable and can be enhanced by a variety of kinds of interventions: both intensive educational training and more subtle framing manipulations.

RELATED CONSTRUCTS

Although the language used to describe systems thinking varies across the many disciplines that invoke the term (Buckle Henning and Chen, 2012), fundamental tenets of the mindset emphasize a consideration of a whole (in contrast to reductionist ways of thinking), an expanded understanding of causality (i.e. appreciating that outcomes are caused by a complex and nuanced array of interacting variables), and recognition that systems are in constant, but patterned, flux (i.e. recognizing the dynamic, often cyclical, nature of systems) (e.g. Checkland, 2012; Espejo, 1994; Meadows and Wright, 2008; Richmond, 1993; Sweeney and Sterman, 2007).

There are at least two well-established constructs from the psychological literature that share commonalities with a systems thinking mindset: holistic thinking, a focus of cross-cultural work in psychology (e.g. Choi *et al*., 2007; Nisbett *et al*., 2001), and relational thinking, which has been studied in the context of problem solving and analogical reasoning (e.g. Gick and Holyoak, 1980; Rottman *et al*., 2012).

Like systems thinking, holistic and relational thinking emphasize a consideration of the whole over individuated features or elements of a system (or scene or problem or object). For instance, holistic thinkers are more likely to identify relatively distal causes and consequences of a given outcome (e.g. to consider the global environmental and economic implications of protecting a specific area of land as national park and not just the local effects of such a decision) and to see how the effects of one action (e.g. laying off employees) can ripple into other areas of society (e.g. lead to an increase in crime; Maddux and Yuki, 2006).

Similarly, relational thinkers are more likely to consider the full complexity of causal systems and to downplay salient superficial features when making similarity judgments and approaching complex problems (Gick and Holyoak, 1980; Rottman *et al*., 2012; Vendetti *et al*., 2014). A real-world scientific breakthrough helps to illustrate the relational mindset (Gentner, 1983): Although the sun is superficially very different from the nucleus of an atom (they differ in almost every perceptible way—e.g. size, weight, temperature, colour), Rutherford (1911) speculated that they may serve similar functions in their respective environments (i.e. both are relatively high in mass and, as a result, may cause other objects—planets and electrons—to orbit around them). In other words, Rutherford engaged in relational reasoning to identify deep, structural similarities between two systems that are superficially very different, which led to a paradigm shift in physics.

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However, along with the similarities between systems, holistic, and relational thinking, these constructs also differ in nuanced but important ways. For instance, it is not hard to find examples of behaviour that would be characterized as low in systems thinking from 'holistic cultures'. For instance, China, a culture identified as high in holistic thinking (Nisbett *et al*., 2001), has increased per capita and gross carbon production faster than any other nation in recent years (Gregg *et al*., 2008)—suggesting a lack of systems thinking with respect to the natural world. This example highlights a difference in how the constructs are applied: Systems thinking is often paired with a normative claim, as in systems thinking *should* facilitate decision making with respect to complex systems like the natural world. Holistic thinking, on the other hand, is more descriptive: commonly employed to distinguish between patterns of attention, causal attribution, and self-construal between East Asian and Western societies (Choi *et al*., 2007).

In addition, a tendency to engage in holistic thinking is often contrasted against a tendency to engage in analytic thinking (Nisbett *et al*., 2001). People high in holistic thinking tend to pay attention to an entire field of a visual or conceptual scene whereas people low in holistic thinking tend to be more analytical: attending to focal objects and using 'rules' like formal logic to represent the information they take in. This distinction may be less relevant to a continuum of systems thinking: People high in systems thinking may show patterns of behaviour that suggest they attend to the full spectrum of a scene, but systems thinkers may nevertheless use analytical strategies to conceptualize and reason about this information.

There are also important differences between systems and relational thinking. Unlike systems thinking, relational thinking commonly refers to how people represent and make judgments about multiple systems, problems, or scenes (Rottman *et al*., 2012; Vendetti *et al*., 2014): How is system A (or an element in system A) similar to and different from system B (or an element in system B)? Although we expect systems thinkers to more readily engage in relational reasoning because they have a tendency to recognize relatively deep, structural factors rather than to focus on superficial features of systems, systems thinking is also well suited to describe how people reason about any given system (i.e. in non-relative terms). Further, to our knowledge, there is no individual difference measure of relational thinking (although recent work has linked relational thinking to math and science training; Rottman *et al*., 2012).

Given the conceptual similarities between systems thinking and holistic and relational thinking, the present work seeks to test the hypothesis that systems thinkers (as measured by the Systems Thinking Scale; Davis and Stroink, 2015) are more likely to engage in holistic and relational thinking. However, it is also important to keep in mind the fundamental differences that distinguish between the constructs, which motivate the current focus on systems thinking *per se*—rather than relying exclusively on the established psychological constructs of holistic and relational thinking. In other words, although there is overlap between systems thinking, holistic thinking, and relational thinking, there are also important differences that warrant the development of instruments specifically designed to measure systems thinking.

Finally, an additional contribution of the present work is to propose that a feeling of embeddedness within a system feeling is an important component of systems thinking and may be a critical moderator in the relationship between systems thinking and decision making (note that this emphasis further distinguishes systems thinking from holistic and relational thinking; refer also to, e.g. Buckle *et al*., 2012). Seeing oneself as part of a given system (embeddedness) may be a necessary precondition for a systems thinking mindset to improve decision making. Research on self-construal (Markus and Kitayama, 1991) and connectedness to nature (Mayer and Frantz, 2004; Tam, 2013) demonstrate that there is variability in the degree to which people feel 'interdependent' with the social and physical systems in which they live. In the context of a social system, interdependence reflects the degree to which people perceive themselves as connected to others: People with an interdependent self-construal are more likely

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to empathize with those around them and try to maintain social harmony (Cross *et al.*, 2011). In the context of a physical system, interdependence (e.g. connectedness to nature) reflects the degree to which people perceive themselves as egalitarian members of the natural world: People who feel connected to the natural world express more value and concern for nature and, in turn, are more likely to engage in behaviours to protect it (Mayer and Frantz, 2004; Tam, 2013). Thus, while individuals from China may be high in holistic thinking and feel embedded in their social system, if they do not also feel connected to the natural world, the benefits of seeing holistically may not extend to decisions made in relation to environmental quality.

The present paper takes a two-pronged approach to situating systems thinking in the psychological literature by considering the relationship between a measure of systems thinking to a variety of related personality measures as well as to a variety of decision-making tasks that have been used to measure the breadth to which people represent information and recognize complex causes of, consequences of, and interrelationships between actions. We describe specific predictions related to systems thinking and both of these kinds of measures in the succeeding texts.

In line with a recent call for the study of demographic information predictive of systems thinking, we also consider how gender, age, education, and political ideology relate to systems thinking (Burnell, 2015). Burnell (2015) reported a positive correlation between education and systems thinking and speculated that older people (with more variable experience over time) and females (who tend to be associated with greater empathy and subjectivity) may exhibit more systems thinking. The conservative worldview (e.g. emphasis on personal accountability) leads us to predict that people who identify as ideologically moderate or liberal may tend to exhibit more systems thinking (Skitka and Tetlock, 1993).

THE SYSTEMS THINKING SCALE

In every study, we used the Systems Thinking Scale of Davis and Stroink (2015) to measure participants' 'tendency to perceive and understand relevant phenomena as emergent from complex, dynamic, and nested systems'. To our knowledge, this is the first instrument developed specifically to measure variability in an individual's tendency to engage in systems thinking. The scale includes 15 items, designed to reflect the core tenets of a systems thinking mindset, including the degree to which people represent complex problems holistically (e.g. 'ultimately, we can break all problems down into what is simply right or wrong'; reverse scored) and recognize the dynamic patterns of change (e.g. 'everything is constantly changing') and interwoven causal relationships that are hallmarks of complex systems (e.g. 'when I have to make a decision in my life, I tend to see all kinds of possible consequences to each choice').

Both prior and present work have found that the scale is reliable (e.g. in the present studies, we find that the scale exhibits high internal consistency—Cronbach's α is about 0.8 for each of the four samples—as well as high test–retest reliability—a correlation of about 0.8 across two time points). Prior work has also established the construct and predictive validity of the measure. For instance, prior work with the scale has revealed differences in how systems thinkers represent complex problems like environmental dilemmas (Davis and Stroink, 2015) and social issues (Thibodeau *et al.*, 2015) and approach problems that require creative thinking (Randle, 2014). Davis and Stroink (2015), for example, showed that systems thinkers were more likely to engage in pro-environmental behaviour when presented with a complex environmental dilemma (Davis and Stroink, 2015). The present work seeks to further validate this measure by comparing it to individual difference measures and decision-making tasks from the psychological literatures on holistic and relational reasoning.

PERSONALITY MEASURES

To test the concurrent validity of the Systems Thinking Scale, we identified eight scales that measured constructs related to systems thinking. The first two were the Analysis-Holism Scale

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(Choi *et al*., 2007) and the Attributional Complexity Scale (Fletcher *et al*., 1986), which have both been used to measure variability in holistic thinking. At a conceptual level, these two measures are closely related to systems thinking, especially in their shared emphasis on capturing peoples' holistic (non-reductionist) conceptions of complex causal relationships.

We identified three scales that relate to how people think about thinking: the Personal Epistemological Beliefs Scale (Hofer, 2000), which measures the degree to which individuals view knowledge as fixed or fluid and as being either an amalgam of discrete facts or a set of interrelated concepts, the Need for Cognition Scale (Cacioppo *et al.*, 1984), which measures the degree to which people like thinking about complex issues, and an adapted version of the Authoritarianism Scale (Adorno *et al*., 1950), which measures the extent to which people question established conventions. We expected to find positive relationships between the measure of systems thinking and the epistemological beliefs and need for cognition and a negative relationship with authoritarianism because we expected systems thinkers to question established conventions, enjoy and value thinking, and see knowledge as tentative and evolving.

The sixth instrument included was the Connectedness to Nature Scale (Mayer and Frantz, 2004), which is one of the most widely used measures of the degree to which individuals sense that they are egalitarian members of the natural world. This scale was included because of our hypothesis that the degree to which systems thinking facilitates decision making may be moderated by a feeling of embeddedness and because we are particularly interested in studying systems thinking in the context of natural systems. The seventh instrument measured participants' tendency to feel embedded in a social system with the Self-Construal Scale (Singelis, 1994).

Finally, we included a measure of the big five personality traits (Gosling *et al.*, 2003). We predicted that openness to experience, but not the other four (conscientiousness, extraversion, agreeableness, neuroticism), would relate to systems thinking, as this personality trait has been linked to attributional complexity (Fast *et al.*, 2008).

DECISION-MAKING TASKS

Because personality measures rely on participant introspection, which may not accurately track underlying psychological processes, we also tested for relationships between the Systems Thinking Scale and two kinds of decision-making tasks: six that have been used to measure holistic thinking and three that have been used to measure relational reasoning. Two concerns guided our choice of decision-making tasks: The first was based on the task's conceptual relationship between systems thinking. However, we also recognized the possibility that specific features of certain tasks might influence how people responded to them. For instance, one of the tasks described a chief executive officer CEO who was forced to lay off employees, which may elicit a more emotional response from people with relevant prior experience (e.g. if, by chance, one of our participants had been laid off, they might engage in the task differently than another participant who had not had such an experience). For this reason, the second concern that guided our choice of decision-making tasks was breadth: We included a variety of tasks that were situated in a variety of domains so as to minimize the possibility that idiosyncratic features of any given task would overshadow the broader and more relevant issues we sought to explore.

The measures of holistic thinking were taken from prior work by Maddux and Yuki (2006), Choi *et al*. (2007), and Chiu *et al*. (2000). Most were designed to measure the breadth and complexity with which people represent social information. For instance, in one task, participants were presented with a description of a CEO of a company who was forced to cut his salary and the salaries of his employees as well as to lay off employees; participants were asked to attribute responsibility to the CEO a variety of outcomes, some of which were directly related to his decision (e.g. cutting salaries and laying off employees) and some which were more distally related to his decision (e.g. to consider the impact of the layoffs on the employees' families and to imagine that there was an increase in crime in the city a year after the decision). Results indicated that people attributed similar levels of

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responsibility to the CEO for proximal outcomes but that holistic thinkers were more likely to attribute responsibility to the CEO for more distal outcomes (Maddux and Yuki, 2006). We predicted that we would find similar patterns of results from systems thinkers.

Three measures of relational reasoning were taken or adapted from prior work on analogy and relational reasoning: An object mapping task was taken from Vendetti *et al*. (2014); a match-to-sample task and a plot identification task were adapted from Rottman *et al*. (2012). Measures of relational reasoning are designed to gauge the degree to which people focus on relationships between causal elements (relations) of systems, scenes, or problems, rather than superficial features. For instance, in the object mapping task, two pictures are shown, which contain some objects that are superficially similar to each other but play different relational roles (e.g. one trial includes two pictures that both include a man, a dog, and a cat; however, in one picture, the dog is chasing the cat, whereas in the other, the dog is chasing the man). Participants are asked to identify the object in the 'second' picture that 'goes with' a specific object in the first (e.g. the *cat*, who is being chased by the dog in the first picture). Identifying the *cat* in the second picture would be indicative of a more superficial form of reasoning, whereas identifying the *man* in the second picture would be indicative of a more relational mode of reasoning. We predicted that systems thinkers would be more likely to engage in a relational mode of reasoning.

In other words, we predicted that the measure of systems thinking would capture variability related to the core tenets of systems thinking that are measured, to varying degrees, by existing personality instruments and decision-making tasks. If our predictions are supported by the results, a major contribution of the work will be to provide a single instrument for measuring systems thinking, rather than the battery of tasks, which is relatively brief and well suited to measure a broad set of behavioural tendencies (e.g. to engage in relational reasoning, for which no personality measure exists) (Table 1).

Table 1 Summary of measures (sources for the measures) and predicted relationships to systems thinking

Personality, demographic, and decision-making measures and tasks	
Personality instruments	
Holistic thinking	Analysis-Holism Scale (Choi *et al*., 2007)
	Attributional Complexity Scale (Fletcher *et al*., 1986)
Complex thinking	Epistemological Belief Scale (Hofer, 2000)
	Need for Cognition (Cacioppo *et al*., 1984)
	Authoritarianism (Adorno *et al*., 1950)
Embeddedness	Connectedness to Nature (Mayer and Frantz, 2004)
	Self-Construal Scale (Singelis, 1994)
Big five traits	Openness, conscientiousness, extraversion, agreeableness, neuroticism (Gosling *et al*., 2003)
Prediction: Systems thinking will be positively related to the measures of holistic and complex thinking, embeddedness, and openness to experience	
Demographics	
Variables	Age, education, gender, political ideology
Prediction: Older, more educated, more liberal, and female participants will engage in more systems thinking	
Decision-making tasks	
Measures of holistic thinking	Company layoff, student accident, wildlife preserve, pool game (Maddux and Yuki, 2006)
	Murder (Choi *et al*., 2007)
	Pharmacy mix-up (Chiu *et al*., 2000)
Measures of relational reasoning	Object-matching (Vendetti *et al*., 2014)
	Match-to-sample, plot identification (Rottman *et al*., 2012)
Prediction: Systems thinkers will be more likely to engage in holistic and relational reasoning	

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THE PRESENT STUDY

There are two main sections of methods and results: one in which we describe the relationship between the Systems Thinking Scale and related individual difference measures and one in which we describe the relationship between the measure of systems thinking and a set of decision-making tasks that have been used to study holistic and relational thinking.

METHODS

Participants

Four samples of participants contributed data to these studies: one of college students ($n = 240$) and three from an internet-based platform (Mechanical Turk) that has been shown to be more representative than typical convenience samples (Berinsky *et al.*, 2012). Demographics of the three internet-based samples are shown in Table 2. Data were excluded from analysis if the participant did not complete the study or if they had participated in a related study (e.g. from sample 3 if they had been a member of sample 2).

The size of the college student sample was determined by the size of the introductory psychology course in which the participants were enrolled: Nearly every student in the class completed the study as part of the course. The sample sizes for the online studies were set to be fairly large because of the novelty of the work (a slightly larger number of participants were recruited for samples 3 and 4 because we expected that some of these people would have completed a related study).

Materials and Design

The college sample completed a set of personality instruments but not the decision-making tasks. The first internet-based sample (sample 2) completed the full set of personality instruments and decision-making tasks; the final two internet-based samples completed the Systems Thinking Scale (no other personality instruments) and a subset (or slightly altered versions) of the decision-making tasks. For brevity and conceptual clarity, we describe the methods and results from the four samples concurrently, noting differences when appropriate.

Personality Measures

For the college sample (sample 1), the personality measures were administered as part of a 'pre-screen' at the beginning of the semester. For the first internet sample (sample 2), the personality and demographic questions were administered after the decision-making tasks. The order in which participants from sample 2 completed the personality measures was pseudo-random: Everyone completed the measure of the big five personality traits first; the order of the remaining eight personality instruments was randomized. For samples 3 and 4, the Systems Thinking Scale was administered before the decision-making tasks.

Table 2 Participant demographics for the internet-based samples

	Sample 2	Sample 3	Sample 4
N sampled	400	450	500
N analysed	398	408	469
Gender (females)	59%	62%	63%
Age: *M* (*SD*)	36.0 (12.7)	24.1 (12.4)	34.2 (12.0)
Education (some college)	83%	86%	85%
Political Democrat	41%	38%	36%
Political Republican	19%	19%	16%

Sample 1 included 240 college students (from an introductory course, which tends to enroll mostly first-year students who are between 18 and 20; roughly two thirds of whom were female, at a college that tends to be ideologically liberal).

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Samples 1 and 2 (college students and the first group of participants recruited from the web) completed the Systems Thinking Scale, the Analysis-Holism Scale (Choi *et al*., 2007), the Attributional Complexity Scale (Fletcher *et al.*, 1986), and the Connectedness to Nature Scale (Mayer and Frantz, 2004). The campus study, but not the online study, also completed the State-Trait Anxiety Inventory (Spielberger *et al*., 1983), as a measure that we did not expect to relate to systems thinking.

Participants from the internet sample completed the Personal Epistemological Beliefs Scale (Hofer, 2000), Need for Cognition Scale (Cacioppo *et al.*, 1984), Authoritarianism Scale (Adorno *et al*., 1950), the Self-Construal Scale (Singelis, 1994), and Ten-Item Personality Inventory, a measure of the big five personality traits (Gosling *et al.*, 2003).

The measures of Systems Thinking (5), General Epistemic Belief (5), Personality (5), Connectedness to Nature (5), Analysis-Holism (7), Attributional Complexity (7), and Self-Construal (7) included statements that were answered on a 5- or 7-point scale from 'strongly disagree' to 'strongly agree'; the measures of Need for Cognition and Authoritarianism were accompanied with a 5-point scale that ranged from 'extremely uncharacteristic of me' to 'extremely characteristic of me'. Refer to Table 3 for example items and a reliability metric for each instrument.

We were able to recruit a subset of the college sample to complete the Systems Thinking Scale at a second time point (about 2 months after the initial administration of the scales) as part of an effort to gather norming data on linguistic stimuli. The Systems Thinking Scale (but not the other scales) was included in this study so that we could gauge the retest reliability of the measure.

Decision-Making Tasks

Of the nine decision-making tasks, seven were administered to all three internet-based samples (two were omitted from follow-up studies because they seemed redundant with other measures or because they failed to exhibit expected patterns of judgment among participants from sample 2). For every sample, participants completed the company layoff task (described in the succeeding texts) before the others; the order of the remaining tasks was randomized within their respective blocks.

Here, we describe two representative examples of the decision-making tasks: one that was used to assess holistic thinking and one that was used to assess relational thinking. Methodological details for the remaining seven tasks are presented in Table 3 and in the supplementary material.

Holistic Thinking: Company Layoff

Participants were to take the perspective of the CEO of a company that was described as having 'major financial difficulties', which would require cutting salaries and laying off employees (Maddux and Yuki, 2006). Participants were asked attribute responsibility for five outcomes that were increasingly distally related to the initial decision (on a 4-point scale from 'not at all responsible' to 'completely responsible'):

(1) How responsible do you feel for cutting your own salary?
(2) How responsible do you feel for the employees who received pay cuts?
(3) How responsible do you feel for the employees you fired?
(4) How responsible do you feel for the families of the fired employees?
(5) How responsible would you feel if a year later there was an increase in crime in the area?

Samples 3 and 4 were additionally asked to 'estimate the number of people both directly and indirectly affected by the layoffs and pay cuts' using a slide bar that ranged from 0 to 1000.

Relational Reasoning: Plot Identification

In the plot identification task, participants matched a verbal description of a causal system to a visual depiction of the causal system. For instance, one description read:

> Predator/prey populations of animals sometimes follow a very predictable pattern. If the prey population increases in number, the

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Table 3 Measures of holistic and relational reasoning with brief descriptions of the tasks

Task label	Task description	Judgment
Measures of holistic thinking		
Company layoff	The president of a company was forced to lay off employees and cut salaries.	How responsible is the CEO for *proximal* and *distal* outcomes?
Student accident	A student caused an accident on a busy freeway.	How responsible is the student for *proximal* and *distal* outcomes?
Pool game	A picture of a man playing pool was shown.	How likely is the current shot to affect, for example, the next shot versus a shot taken six turns later?
Wildlife reserve	A picture of a landscape was shown and identified as new wildlife preserve.	What are the implications of establishing (or commercially developing) the preserve?
Murder	A description of a murder was given with 100 potentially relevant pieces of information.	Select the information that the police should consider
Pharmacy mix-up	A medical clinic was described as distributing the incorrect medication, causing several patients to get sick.	How responsible is the pharmacist (proximal cause) and clinic (distal cause)?
Measures of relational reasoning		
Object-matching	Take a moment to examine two pictures: a highlighted object in the first had 'relational' and 'object' matches in the second.	Choose the object in the second picture that goes with the highlighted item in the first picture
Match-to-sample	Three descriptions of causal systems were presented. One was identified as the sample, and two were potential matches: one of which described a similar causal system and the other described a similar domain.	Which of the causal descriptions (potential matches) is more similar to the first?
Plot identification	A verbal description of a causal system was shown above four plots: one plot accurately depicted the verbal description.	Which of the plots best illustrates the verbal description?

predator population overeats and the prey population begins to decline in number. Consequently, the predator population decreases with the scarcity of available food.

Participants were presented with four plots as candidate depictions of the system (refer to Figure 1) and were asked to identify the match (e.g. 'which of the plots below best illustrates how the prey population will change over time, according to the given description?'). For sample 2, this task included two trials; for samples 3 and 4, this task included five trials.

RESULTS AND DISCUSSION

Relationships Between Personality and Demographic Measures

As shown in Table 4, we found expected relationships between the measure of systems thinking and the other personality instruments. In most cases, the results for the college and internet samples were similar. Because the internet sample was larger and more representative of the general population, we focus our discussion on these results. The table reveals significant

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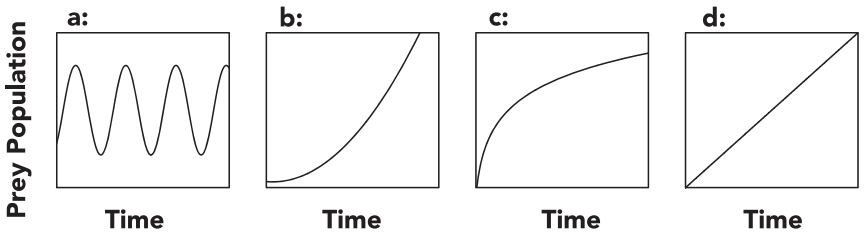

Figure 1 Examples of candidate matches for the plot identification task. In this case, the first plot best represents the verbal description of how the population of prey will change over time

positive correlations between systems thinking and the measures of holistic thinking (i.e. the four subcomponents of the Analysis-Holism Scale and the measure of attributional complexity), sophisticated epistemological beliefs, need for cognition, embeddedness in a physical system (although not in a social system[1]), and openness to experience (but not the other four of the big five personality measures) and a significant negative correlation between systems thinking and authoritarianism.

Furthermore, a confirmatory factor analysis, conducted on personality instruments that were predicted and found to be related to systems thinking (from the Systems Thinking Scale, Analysis-Holism Scale, Attributional Complexity Scale) showed that much of the covariance among these measures (over 31%) could be represented by a single variable that loaded most highly on the Systems Thinking Scale (refer to factor loadings in parentheses of Table 4).

Test–Retest Reliability

In a follow-up study, we tested the stability over time of systems thinking as measured by the scale of Davis and Stroink (2015). Forty-nine introductory psychology students completed the scale at both the beginning and towards the end of a fall semester. There was a significant correlation between scores at the two time points, $r[47] = 0.796$, $p < 0.001$. Students showed higher levels of systems thinking when the scale was administered later in the semester ($M_1 = 70.469$, $sd_1 = 6.696$; $M_2 = 84.837$, $sd_2 = 8.648$), $t[48] = 19.212$, $p < 0.001$, $d = 1.362$. As most of these students were in their first semester of college, it seems likely that this difference can be attributed to educational and life experiences that accompany a person's transition to college. This finding is important for two reasons. First, it shows that the test–retest reliability of the scale is high. And second, it suggests that systems thinking is malleable (e.g. that it can be increased through education).

Demographics

In addition to the relationships described between the measure of systems thinking and the other personality instruments, we found that variability in systems thinking was significantly related to the gender, education, and political ideology of participants in data aggregated from the three internet samples; we did not find a relationship between systems thinking and age. As shown in Table 5, females[2] and people with more education were more likely to engage in systems thinking, while political conservatives tended to exhibit less systems thinking. Because of the covariance between some of these measures (e.g. age and education, $r[1273] = 0.114$, $p < 0.001$), we fit a model in which the four demographic variables were included as predictors of systems thinking (right-most column of Table 5). The model revealed particularly strong relationships between gender and systems thinking as well as political ideology and systems thinking.

[1] This may result from the fact that the Systems Thinking Scale emphasizes the degree to which people engage in systems thinking with respect to the natural world.

[2] Data from two participants who identified their gender as neither male nor female were excluded from these analyses.

Table 4 Correlations between the Systems Thinking Scale and related constructs

Scale	Component	Example item and scale endpoints	Sample 1 (students)	Sample 2 (online)	Cronbach's α (online)
Systems Thinking Scale*		Seemingly small choices we make today can ultimately have major consequences.		(0.805)	0.81
Analysis-Holism	Causality*	Everything in the universe is some related to each other.	0.447**	0.474** (0.577)	0.85
	Attitude towards contradictions*	It is more desirable to take the middle ground than go to extremes.	0.070	0.170** (0.158)	0.78
	Perception of change*	Current situations can change at any time.	0.159*	0.307** (0.443)	0.78
	Locus of attention*	The whole is greater than the sum of its parts.	0.100	0.158** (0.120)	0.79
Attributional Complexity*		I have often found that the basic cause for a person's behaviour is located far back in time.	0.465**	0.508** (0.738)	0.91
Epistemological Beliefs*		Most words have one clear meaning. (reverse scored)		0.485** (0.655)	0.74
Need for Cognition*		I prefer complex to simple problems		0.350** (0.636)	0.94
Authoritarianism*		Obedience and respect for authority are the most important virtues children should learn.		−0.359** (−0.500)	0.80
Connectedness to Nature*		I often feel part of the web of life.	0.355**	0.435** (0.557)	0.89
Self-Construal Scale	Independent	I enjoy being unique and different from others		−0.041	0.84
	Interdependent	It is important for me to maintain harmony with my group.		0.139**	0.80
Ten-Item Personality Inventory	Extraversion	I see myself as someone who is outgoing, sociable.		−0.043	0.46
	Agreeable	I see myself as someone who is generally trusting.		0.047	0.35
	Conscientious	I see myself as someone who does a thorough job.		0.085	0.23
	Neuroticism	I see myself as someone who gets nervous easily.		0.063	0.31
	Openness*	I see myself as someone who has an active imagination.		0.324** (0.536)	0.56
STAI	Positive affect	I feel pleasant	0.120		
	Negative affect	I feel nervous and restless	−0.110		

Confirmatory factor loadings are in parentheses. Asterisks associated with the scale and component columns identify measures that were included in the confirmatory factor analysis. *$p < 0.05$ and **$p < 0.01$, statistically significant relationships between the given measure and the Systems Thinking Scale.

Relationships with Decision-Making Tasks

In this section, we first describe the results of analyses that used the Systems Thinking Scale to predict behaviour on the decision-making tasks and then describe analyses in which we compare the predictive value of the Systems Thinking Scale to the other personality measures.

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Table 5 Relationships between demographic measures and systems thinking

	Ranges and distributions	Direct relationship	Model coefficient (β)
Age	18 to 81; *median* = 33	$r = 0.013$	0.012
Female versus male *M*diff [95%CI]	59% Female	2.400*** [1.43, 3.37]	0.347***
Education	Range: [HS grad, Doctorate] Mode: 45% completed Bachelor's	$r = 0.129$***	0.095***
Political ideology	Range: [0, 100]; *median* = 43	$r = -0.337$***	−0.249***

***$p < 0.001$, statistically significant relationships.

In every analysis, the continuous measure of systems thinking was used as a predictor; for ease of presentation, plots divide people into two groups: those who scored above the median on the Systems Thinking Scale (high in systems thinking) and those who scored below the median (low in systems thinking). For brevity, we discuss the results of three of the six holistic thinking tasks in the supplementary material, which revealed patterns that were largely similar to the results presented in the succeeding texts.

Company Layoff

A two-way ANOVA with predictors for systems thinking and judgment (five questions ordered continuously from most proximal to most distally related to the CEO's decision) revealed a main effect of the judgment, $F[1, 1590] = 358.340$, $p < 0.001$, a main effect of systems thinking, $F[1, 396] = 11.340$, $p < 0.001$, and an interaction between the judgment and systems thinking, $F[1, 396] = 11.340$, $p < 0.001$ (refer to Figure 2).

Systems thinkers attributed more responsibility to the CEO overall ($\beta = 0.097$, $SE = 0.029$), especially for distally related outcomes ($\beta = 0.040$, $SE = 0.010$). Planned tests for each of the five questions revealed, first, that there was no relationship between the measure of systems thinking and a judgment of whether the CEO should feel responsible for cutting his own pay (the most proximal judgment), $F[1, 396] = 0.713$, $p = 0.399$ ($\beta = -0.042$, $SE = 0.050$) but that there was a significant positive relationship between systems thinking and each of the other judgments: for cutting employee salaries, $F[1, 396] = 12.53$, $p < 0.001$ ($\beta = 0.175$, $SE = 0.049$), for firing employees, $F[1, 396] = 9.629$, $p = 0.002$ ($\beta = 0.154$, $SE = 0.050$), for the families of fired employees, $F[1, 396] = 18.06$, $p < 0.001$ ($\beta = 0.209$, $SE = 0.049$), and for a potential increase in crime in the area a year later, $F[1, 396] = 5.119$, $p = 0.024$ ($\beta = 0.113$, $SE = 0.050$). As shown in Table 6, these patterns were replicated with samples 3 and 4.

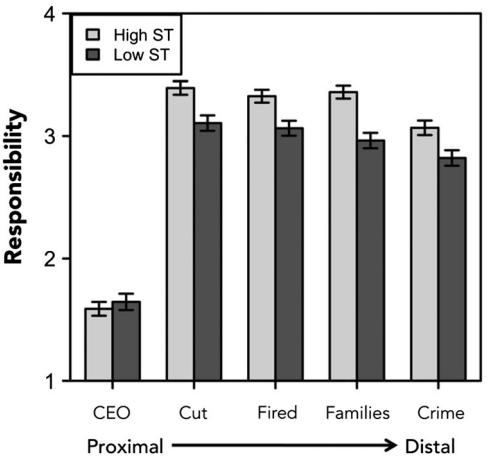

Figure 2 Attributions of responsibility for CEO who was forced to lay off employees and make salary cuts for outcomes that varied in how directly they were related to the CEO's decision (questions further to the right are less directly related to the decision) by systems thinking (median split). Error bars denote standard errors of the means

Additionally, systems thinking was associated with higher estimates of the number of people who were affected directly and indirectly by the layoffs and pay cuts in sample 3, $r[406] = 0.181$, $p < 0.001$, and in sample 4, $r[467] = 0.327$, $p < 0.001$.

Murder

As predicted, participants higher in systems thinking identified more pieces of information

Table 6 Summary of results from samples 3 and 4 on the decision-making tasks

	Sample 3	Sample 4
Company layoff		
Main effect of ST	$F[1, 406] = 14.14^{***}$	$F[1, 467] = 27.99^{***}$
	$\beta = 0.113$, $SE = 0.030$	$\beta = 0.156$, $SE = 0.030$
Main effect of outcome	$F[1, 1630] = 323.28^{***}$	$F[1, 1874] = 268.54^{***}$
	$\beta = 0.320$ $SE = 0.018$	$\beta = 0.267$, $SE = 0.016$
Interaction	$F[1, 1630] = 4.16^{*}$	$F[1, 1874] = 5.47^{*}$
	$\beta = 0.036$, $SE = 0.018$	$\beta = 0.038$, $SE = 0.016$
Murder		
Main effect of ST	$F[1, 406] = 18.98^{***}$	$F[1, 467] = 36.70^{***}$
	$r[406] = 0.211^{***}$	$r[467] = 0.270^{***}$
Plot identification		
Main effect of ST	$F[1, 406] = 14.23^{***}$	$F[1, 467] = 34.97^{***}$
	$r[406] = 0.184^{***}$	$r[467] = 0.264^{***}$
Object matching		
Main effect of ST	$F[1, 406] = 5.21^{*}$	$F[1, 467] = 18.60^{***}$
	$r[406] = 0.113^{*}$	$r[467] = 0.196^{***}$
Match to sample		
Main effect of ST	$F[1, 406] = 9.12^{**}$	$F[1, 467] = 7.64^{**}$
	$r[406] = 0.148^{**}$	$r[467] = 0.127^{**}$

$^{*}p < 0.05$, $^{**}p < 0.01$, and $^{***}p < 0.001$, statistically significant relationships.

that were potentially relevant to the crime, $F[1, 396] = 9.593$, $p = 0.002$ ($r[396] = 0.154$, $p = 0.002$). As shown in Table 6, these patterns were replicated with samples 3 and 4.

Pharmacy

The final task related to holistic thinking, which asked participants to attribute blame to a pharmacist or a clinic involved in a medication mix-up, was subjected to a two-way ANOVA with predictors for systems thinking and target of blame (to the pharmacist or clinic). The model revealed a main effect of systems thinking, $F[1, 396] = 18.330$, $p < 0.001$, the target, $F[1, 396] = 92.110$, $p < 0.001$, and a marginal interaction, $F[1, 396] = 3.254$, $p = 0.072$.

As shown in Figure 3, systems thinkers were more likely attribute blame for the outcome to the pharmacist and clinic overall. Although we predicted that systems thinkers might be especially likely to blame the clinic, we did not find support for this hypothesis. We did not include this measure for samples 3 and 4 because it was conceptually very similar to the company layoff task.

Relational Reasoning

As expected, we found that systems thinkers engaged in more relational reasoning, as measured by the object-matching $F[1, 396] = 3.152$, $p = 0.077$ ($r[396] = 0.089$, $p = 0.077$), match-to-sample $F[1, 396] = 9.804$, $p = 0.002$ ($r[396] = 0.155$, $p = 0.002$), and plot identification tasks, $F[1, 396] = 6.527$, $p = 0.011$ ($r[396] = 0.127$, $p = 0.011$) (refer to Figure 4). As shown in Table 6, these patterns were replicated with samples 3 and 4.

Table 7 summarizes the results of the decision-making tasks.

CONTRASTING PERSONALITY MEASURES AS PREDICTORS OF THE DECISION-MAKING TASKS

We also tested the efficacy of the systems thinking measure as a predictor of behaviour on the decision-making tasks by contrasting it to the other personality instruments. We conducted separate analyses for each of the nine decision-making tasks tested with sample 2 (the first online sample, which included the nine personality instruments and decision-making tasks) by (a)

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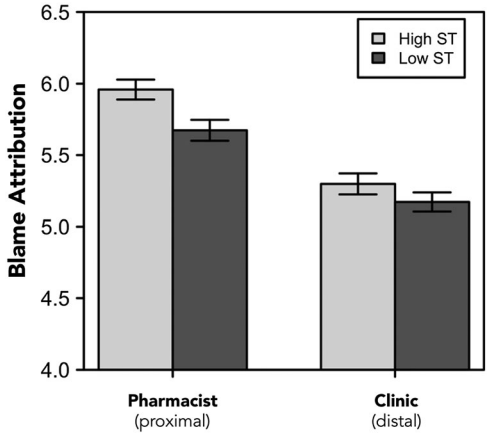

Figure 3 Attributions of blame (importance of cause) to the pharmacist and clinic by systems thinking. Error bars denote standard errors of the means

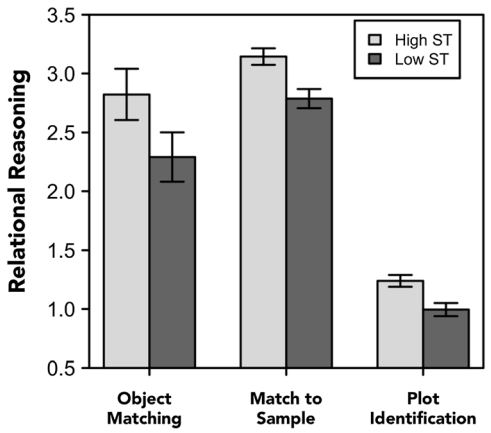

Figure 4 Tendency to engage in relational reasoning as measured by an object-matching, match-to-sample, and plot identification task, as a function of systems thinking. Error bars denote standard errors of the means

fitting a linear model with a predictor for systems thinking (as well as an interaction between systems thinking and question when appropriate—i.e., for the tasks related to a company layoff, student accident, wildlife preserve, pool game, and pharmacy) and then (b) adding a predictor(s) for a given personality measure to test whether including it improved the fit of the model. We did this for each of the 16 personality measures and report cases in which the fit of the model improved at the $p < 0.01$ level (i.e. a more conservative threshold than the $p = 0.05$ level, which helps to protect against finding false positive results, which would be expected by chance as a function of running multiple tests).

This series of analyses revealed two notable patterns in several main effects of the personality measures on decision making which are shown in Table 8. First, the trait measure of conscientiousness was a significant predictor of performance on several tasks: associated with greater attributions of responsibility to the pharmacist and clinic who were involved in the prescription mix-up and more relational reasoning in the plot identification task. This may reflect a tendency for conscientious participants to engage more deeply in the tasks overall (which were administered online) or to think about complex causes in a way that is not captured by the measure of systems thinking (or other measures of holistic thinking). The latter account may also explain relationships between the measure of epistemological beliefs and need for cognition on the relational thinking tasks.

Second, effects of participants' perception of change on identifying potentially relevant evidence for the murder scenario and relational

Table 7 Summary of results related to the influence of systems thinking on the decision-making tasks

Summary of results related to decision-making tasks	
Measures of holistic reasoning	Hypothesized main effects of systems thinking were found for the company layoff, murder, and pharmacy tasks Hypothesized interactions related to systems thinking in the predicted direction were found for the company layoff task but not for pharmacy mix-up
Measures of relational reasoning	Hypothesized main effects of systems thinking were found for all three measures of relational thinking

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Table 8 Main effects of the personality measures on decision-making tasks after taking the influence of the Systems Thinking Scale into account

Task	Personality measure
Company layoff	None
Murder	Perception of change (from AHS), $F[1, 395] = 7.041$**
Pharmacy	Conscientiousness, $F[1, 395] = 9.347$**
Object-matching	Epistemological belief, $F[1, 395] = 13.870$***
	Need for cognition, $F[1, 395] = 8.395$**
Match-to-sample	Perception of change (from AHS), $F[1, 395] = 8.961$**
	Epistemological belief, $F[1, 395] = 7.020$**
Plot identification	Epistemological belief, $F[1, 395] = 6.704$**
	Conscientiousness, $F[1, 395] = 6.729$**

**$p<0.01$ and ***$p<0.001$, statistically significant relationships.

matches in the match-to-sample task suggest that the measure of systems thinking may also miss out on aspects of peoples' tendency to attend to the full breadth of a problem or scene.

On one hand, these findings can be viewed as identifying limitations to the measure of systems thinking—and where appropriate, researchers interested in systems thinking may wish to include the Systems Thinking Scale in conjunction with other personality instruments (e.g. conscientiousness, perception of change). However, given the relatively small number of main effects of the personality measures from what theoretically could have been found (on nine tasks with 16 personality measures), we take a much more positive perspective. The measure of systems thinking seems to capture a wide range of behaviour at least as well, if not better, than many other personality instruments that have been used to study how people reason about complex systems.

GENERAL DISCUSSION

We have situated a measure of systems thinking in relation to a set of personality measures and decision-making tasks from the literatures on holistic thinking and relational reasoning. Using four samples of participants (from a population of college students and a population recruited online), we found expected relationships between the Systems Thinking Scale and eight personality instruments. We found that the measure of systems thinking was particularly related to peoples' tendency to represent causal complexity, as measured by two scales that have been used extensively to study variability in holistic thinking (a subcomponent of the Analysis-Holism Scale and the Attributional Complexity Scale), as well as four measures of peoples' general tendency to engage in 'deep' thinking (epistemological beliefs, need for cognition, authoritarianism, and openness).

We also found some evidence that the Systems Thinking Scale was related to existing measures of embeddedness (as measured by the Connectedness to Nature Scale and a measure of interdependent self-construal). We plan to further explore the relationship between systems thinking and embeddedness in future work.

Finally, analysis of the demographic variables suggested that systems thinking may be more common among females, liberals, and people with more education.

A set of decision-making tasks further revealed that the measure of systems thinking predicted important variability in peoples' actual tendency to represent complex causal relationships, to attend to the full breadth of a system, and to recognize dynamic patterns of change (core tenets of the conceptual foundation of systems thinking)—as well or better than existing personality measures. We found that participants who identified as high in systems thinking showed patterns of reasoning consistent with findings from cross-cultural work on holistic thinking on several measures (e.g. of a company layoff and a murder scenario) and with findings from the literature on relational reasoning related to analogy and problem solving, thereby helping to validate the measure of systems thinking.

However, it should also be noted that we did not find predicted relationships on every measure (e.g. an interaction between systems thinking and attributions of blame related to a pharmacy mix-up; refer also to supplementary

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material), which represent important opportunities for future research.

One possibility is that there may be specific kinds of domains in which the Systems Thinking Scale is more likely to predict nuanced behavioural tendencies and judgments. For instance, the scale may be particularly well suited for studying how people think about natural rather than social systems and when people recognize their role in the system (i.e. when they value and feel embedded in the target domain). A second possibility is that participants may have become fatigued as a result of completing the full set of personality measures and decision-making tasks. It is worth noting, for instance, that we found the predicted interaction between systems thinking and judgments of responsibility in the company layoff scenario, which was always presented as the first decision-making task. Although two of the other decision-making tasks were almost identical in structure to the company layoff scenario (student accident and pool game), these tasks yielded mixed results, suggesting that participants may have been engaged in tasks that were presented later in the study.

In future work, we will seek to further explore the relationship between the systems thinking and existing psychological constructs and measures. In addition, we will aim to test normative claims that have emerged from the interdisciplinary focus on systems thinking: whether systems thinking facilitates decision making related to complex systems (i.e. leads people to make judgments that might be considered better or more accurate) and how systems thinking can be promoted. In line with this goal, our use of the term 'mindset' to describe peoples' tendency to engage in systems thinking is intentional: We think that certain kinds of interventions can encourage people to think holistically, to represent complex causal relationships, and to recognize the dynamic and cyclical nature of systems.

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