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Systems thinking and environmental concern

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ABSTRACT

Systems thinking is thought to facilitate complex decision-making, but relatively little is known about its psychological underpinning. We present three studies that situate a measure of the construct in relation to other dispositional measures that have received more attention in environmental psychology and by testing whether the mindset predicts behavior in a set of novel decision making tasks. In Study 1, we find that systems thinkers tend to believe in scientific consensus, recognize risks posed by climate change, and support policy interventions to address climate change; systems thinking was negatively related to conspiracist and free-market ideation. In Studies 2 and 3 we find that systems thinkers ascribe more value to the natural world — both in monetary terms as well as on social and ecological grounds. The findings suggest that models of environmental cognition can be improved by measuring peoples' tendency to engage in systems thinking.

1. Introduction

The majority of climate scientists agree that the global climate is changing, largely as a result of human activity, and that these changes pose a significant long-term threat to humans and the natural world (Allison et al., 2009; Anderegg, Prall, Harold, & Schneider, 2010; Freudenburg & Muselli, 2010). Scientists and policy makers have an obligation to communicate with the public about these risks and to advocate for a wide range of interventions: targeting "low-level" individual behavior change as well as "high-level" societal reform (Pachauri, Meyer, & Core Writing Team, 2014). Nevertheless, recent polling suggests that roughly a third of the US population denies the reality of climate change, and that only half of citizens agree as to its anthropogenic origins. Moreover, the percentage of climate change deniers has increased in the past several years (Leiserowitz, Maibach, Roser-Renouf, Smith, & Dawson, 2013).

Researchers have identified a number of reasons for climate change skepticism, including a general rejection of science (Diethelm & McKee, 2009; Jacques, Dunlap, & Freeman, 2008; Lewandowsky, Oberauer, & Gignac, 2013), which may be related to the misrepresentation of scientific evidence in the media or by powerful interest groups (e.g., Boykoff, 2007; Jacques et al., 2008; Oreskes & Conway, 2011), conspiratorial thinking (Lewandowsky et al., 2013; Sunstein & Vermeule, 2009; van der Linden, 2015), an unwavering belief in the power of laissez-fair financial markets (Collomb, 2014; Heath & Gifford, 2006; Kahan, Jenkins-Smith, & Braman, 2011; Lewandowsky et al., 2013), and political ideologies (Dunlap & McCright, 2008; Hamilton, 2011; McCright & Dunlap, 2011).

These foundations for climate change denial are made possible, in part, by the inherent complexity and scale of the global ecosystem. Contrary to the experience of most people in history, modern electrical wiring, indoor plumbing, central heating and other mechanisms for controlling our local environment have rendered critical resource flows (e.g., of water and electricity) invisible (Mayer & Frantz, 2004). The relative invisibility of the stocks and flows of environmental resources may contribute to the public's lack of careful consideration about the role of these resources in sustaining natural systems (Sterman & Sweeney, 2007; Sweeney & Sterman, 2007).

Instead, people are more likely to have experiences that seem to contradict a simple conception of global warming. For instance, despite the fact global temperatures are rising, it still gets cold in winter, and there is a tendency to conflate *weather* and *climate* (Gutro, 2005; Hulme, 2009). One disturbing example of such behavior came from Senator Jim Inhofe, chair of the U.S. Senate Committee on Environment and Public Works, who threw a

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snowball onto the Senate floor in February of 2015 to illustrate his view that the global climate was not warming (Plautz, 2015). Although illustrations of rising temperatures are available, these relatively abstract and more psychologically distant representations of aggregated information may be less persuasive to many people than personal anecdotes (Akerlof, Maibach, Fitzgerald, Cedeno, & Neuman, 2013; Spence, Poortinga, & Pidgeon, 2012).

One way that journalists and policy makers have simplified discussions of the global ecosystem is to use economic, cost-benefit terms, which often portray a straightforward trade-off between sustainable environmental policies and economic growth (Shaw & Nerlich, 2015). This practice represents an additional hurdle to mobilizing support for mitigating the dangers of climate change, as people tend to prioritize immediate economic issues (employment, budgets, taxes, trade) over long-term environmental issues (e.g., in a September 2015 poll of US adults, 35% of respondents identified some aspect of the economy as their primary concern facing the country, whereas only 2% named the environment; Gallup, 2015; Leiserowitz, Maibach, Roser-Renouf, Feinberg, & Rosenthal, 2015). Depicting the relationship between the global ecosystem and the economy on a single dichotomous continuum is reductionist, failing to recognize the many inherent benefits of promoting the health of the natural world (Williams, Patterson, Roggenbuck, & Watson, 1992).

As an antidote to more common and pervasive modes of thinking about the natural world, scholars from diverse fields suggest promoting a *systems thinking* mindset (Checkland, 2012; Espejo, 1994; Meadows & Wright, 2008).

1.1. Systems thinking

Systems thinking emphasizes that causes and their effects are often less straightforward than one might intuitively expect. Such a mindset is thought to facilitate the understanding of systems and events as emerging from a dynamic array of interrelated factors, which can have both expected and unintended consequences (Meadows & Wright, 2008). Although there is some disagreement over exactly what *systems thinking* refers to (see Buckle Henning & Chen, 2012), there are several core tenets of the construct that are widely endorsed: They include an emphasis on holism (as opposed to reductionism), an expanded conception of causality (i.e., an appreciation of the fact that a vast array of interacting variables are often responsible for specific outcomes in complex systems), and recognition that systems are constantly changing in predictable and unpredictable ways (Checkland, 2012; Espejo, 1994; Richmond, 1993; Sweeney & Sterman, 2007).

However, despite the broad and interdisciplinary interest in systems thinking, there has been relatively little work on the psychological underpinnings of the mindset: a small number of studies showing that many people do not naturally engage in intuitive systems thinking (Dawidowicz, 2012; Rozenblit & Keil, 2002; Sweeney & Sterman, 2007), but that the principles of systems thinking can be taught — mostly in a corporate or managerial context (Fazey, 2010; Kim, Akbar, Tzokas, & Al-Dajani, 2014; Maani & Maharaj, 2004; Sterman, 2010).

1.1.1. The Systems Thinking Scale

One notable attempt to address this gap in the literature is the development of an instrument designed to measure an individual's tendency to engage in systems thinking, the Systems Thinking Scale (Davis & Stroink, 2016; Thibodeau, Frantz, & Stroink, 2016). The Systems Thinking Scale includes 15 items that are designed to measure core tenets of the mindset along a single continuous dimension (very low to very high in systems thinking). For instance, the survey asks participants to report on the degree to which they conceptualize 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 three samples). The relatively brevity and simplicity of the instrument differentiates it from alternative approaches to measure individual differences in systems thinking (e.g., Sweeney & Sterman, 2007).

Initial work with the instrument has revealed differences in how systems thinkers represent complex problems like environmental dilemmas (Davis & Stroink, 2016) and social issues (Thibodeau, Winneg, Frantz, & Flusberg, 2016), and how people approach problems that require creative thinking (Randle, 2014). Thibodeau et al. (2016), for example, found that systems thinkers tend to recognize longer chains of causality in attributing responsibility for specific outcomes. Importantly, this instrument was designed to measure an intuitive systems thinking mindset (what is sometimes called "Soft" systems thinking, as opposed to more deliberate systems thinking that is aided by computational models and other tools – cognitive and technological – that are more likely to be taught in a course on the topic).

1.1.2. Related constructs

There is significant work on a number of constructs that are theoretically related to *systems thinking*. For instance, *holistic thinking* is a construct that has emerged from the literature on cross-cultural psychology (e.g., Choi, Koo, & Choi, 2007; Nisbett, Peng, Choi, & Norenzayan, 2001) and *relational thinking* is a construct that has been studied more extensively in the context of analogical reasoning and problem solving (e.g., Rottman, Gentner, & Goldwater, 2012; Vendetti, Wu, & Holyoak, 2014). Both emphasize holistic over reductionist styles of reasoning. *Holistic thinkers* tend to recognize distal consequences of events and decisions more readily than non-holistic thinkers (e.g., that a mass layoff will have immediate effects on the personal finances of individuals but may also have long term effects on the social environment of a community). *Relational thinkers* tend to focus on causal relationships between elements of a domain, as opposed to more salient superficial features of the domain, when thinking through complex problems (e.g., recognizing that the structure of an atom is similar to the structure of the universe despite their marked dissimilarity in size; Rutherford, 1911).

Previous work has also studied when, how, and why people justify the social systems in which they live (e.g., Jost, Banaji, & Nosek, 2004). According to *system justification theory*, people are drawn to rationalizing current sociopolitical practices and states (the *status quo*) because of a social and psychological need to see the existing social order as desirable (good, fair, natural). For instance, people tend to anticipate that likely events are more desirable than unlikely ones (e.g., people tend to like a presidential candidate more as their likelihood of winning an election increases; Kay, Jimenez, & Jost, 2002).

In addition, prior work has found that *systems thinking* is related to more general dispositional tendencies (see Thibodeau et al., 2016): Systems thinkers also tend to see the world as complex (i.e., have adopted a more complex *lay epistemology*; Hofer, 2000), like to think deeply about problems (score higher on a measure of *need for cognition*; Cacioppo, Petty, & Kao, 1984), and are more *open* to new ideas and experiences (McCrae, 1996); on the other hand, *systems thinking* was found to be anti-correlated with a tendency to think in more rule-based authoritarian terms (Adorno, Frenkel-Brunswik, Levinson, & Sanford, 1950).

Systems thinking differs from these constructs in important and nuanced ways. First, unlike many of the previously mentioned constructs, *systems thinking* is often paired with the normative claim that the mindset enhances or facilitates complex decision making – that adopting the style of thinking will lead to better outcomes (for the system) and better forecasts about future states of the system. Second, whereas many of these constructs have been applied to social domains (e.g., holistic thinking, system justification theory) or abstract problem solving (relational thinking), systems thinking, in the present context, is treated as more domain-specific, addressing the question: To what extent do people think about the natural world as a complex system? Does variability in this tendency predict the kinds of decisions and judgments that people make on tasks that involve thinking about complex environmental systems?

1.2. Aims of the present work

The current paper seeks to extend previous findings by (a) situating systems thinking in relation to other dispositional and attitudinal measures that have been studied more extensively in the context of environmental psychology, and (b) to test whether variability in systems thinking is associated with variability in conceptions of the natural world.

In Study 1 we present correlations between the measure of systems thinking and existing measures of scientific acceptance, conspiratorial ideation, free market ideation, and political ideology. We fit a structural equation model to illustrate the dynamic relationship among these constructs and to predict climate change risk perception and support for policy interventions designed to mitigate the effects of global warming. In Studies 2 and 3 we ask people to ascribe value — in economic, social, and environmental terms — to ecosystem services.

Our hypothesis is that systems thinking will be positively related to acceptance of science, as science itself is a way of investigating and conceptualizing complex relationships (Rottman et al., 2012). In contrast, we expect that systems thinkers will be less likely to engage in conspiratorial thinking, to unquestionably support laissez-faire economics, or hold a conservative political ideology (e.g., emphasize direct causal relationships and personal accountability; Skitka & Tetlock, 1993), all of which seem to encourage people to narrow the breadth of information they consider when thinking about an issue.

In this way, we expect a consideration of systems thinking to complement existing models of the psychological underpinning of climate change risk perception (e.g., Kellstedt, Zahran, & Vedlitz, 2008; Van der Linden, 2014). Importantly, we also hope that emphasizing systems thinking can provide a psychological foundation for a more positive, nuanced, and embedded conception of the value provided to humans by the natural world. We expect systems thinkers not only to be more attuned to the risks associated with climate change, but also to ascribe more value to the natural world.

2. Study 1

The primary aim of Study 1 was to situate a measure of an individual's propensity to engage in systems thinking in relation to several dispositional measures that have been shown to predict and explain attitudes and behaviors related to climate change.

2.1. Methods

2.1.1. Participants

Participants in Study 1, as well as Studies 2 and 3, were recruited and paid through Mechanical Turk from participants who had a good performance record on previous tasks (>90% approval) and lived in the United States. Data from participants who did not complete the study or who had previously completed a related study were excluded from analysis. Demographic information for all three samples is shown in Table 1. The sample sizes for the three studies were set to be fairly large due to the novelty of the work (a slightly larger number of participants were recruited for Samples 2 and 3 because we expected that some of these people would have completed Study 1, for instance).

Of note, recent work suggests that samples from Mechanical Turk show reliable and representative patterns of behavior on the kinds of tasks that we have used (Clifford, Jewell, & Waggoner, 2015; Mason & Suri, 2012; Paolacci, Chandler, & Ipeirotis, 2010). Nevertheless, there were more females than males in each study and samples on Mechanical Turk tend to be skewed somewhat left politically, which may raise concerns about the generalizability of the results to the general public. To address these concerns, we tested for, but did not find, interactions between the participants' gender or political ideology with systems thinking on the dependent measures in Studies 2 or 3.

In prior work, we have found that females and politically liberal individuals (as well as older individuals and people with more education) tend to be more likely to engage in *systems thinking* (Thibodeau et al., 2016). Thus, although there are differences in systems thinking by individual difference factors like gender and political ideology, these factors do not seem to interact with *systems thinking* on the kinds of decision making tasks that we have used. Further, recent work suggests that behaviors and attitudes associated with the political ideology of the Mechanical Turk population mirrors that of the general public (Clifford et al., 2015). We have not, however, systematically explored how *systems thinking* may vary by nationality. Given that our sample consists entirely of participants from the US, an important area of future work will be to test for cross-cultural differences in *systems thinking*.

2.1.2. Materials and design

Participants in all three studies completed several scales to measure attitudinal constructs that have been previously linked directly or indirectly to perceptions of climate change, including a measure of global warming risk perception (Jones, Clark, & Tripidaki, 2012), support for various policy interventions designed to address climate change (Leiserowitz, 2006), systems thinking

Table 1
Demographic information by sample.

	Study 1	Study 2	Study 3
Sampled	450	500	600
Analyzed	440	481	524
Gender: Female	61%	63%	60%
Age	34.4 (12.4)	34.2 (12.0)	36.7 (12.2)
Education: At least some college	85%	85%	86%
Political Democrat	38%	36%	36%
Political Republican	18%	16%	19%
Political Ideology: conservative	42.8 (26.9)	41.1 (26.8)	42.1 (25.9)

(Davis & Stroink, accepted), free market ideology (Heath & Gifford, 2006), conspiratorial ideation (Lewandowsky et al., 2013), and belief in science (Lewandowsky et al., 2013).[1] Table 2 lists these constructs and includes the number of items for each scale, example items, labels, and a measure of internal reliability for all three samples of data.

At the end of the survey, participants answered demographic questions, including their age, gender, educational history, math and science training, political party affiliation (categorically, as Democrat, Independent, Republican, or Other) and political ideology (on a continuous scale that ranged from 0, "Very liberal," to 100, "Very conservative").

Since participants in each of the three studies completed all six of the target measures, we combined the data from the three samples in presenting the results of Study 1. Data analyzed exclusively from Study 1 reveal patterns that are consistent with those of the aggregated data.

2.2. Results

Two analyses reveal predicted relationships between the individual difference measures. First, Table 3 presents pair-wise correlations between the measures and shows that systems thinkers, liberals, people who accept science, reject conspiratorial thinking, and question the unrestricted power of free markets, tended to perceive more risk associated with climate change and to support policy interventions designed to reduce emissions of greenhouse gasses.

Second, we fit a structural equation model of the relationship between the constructs using parcels (i.e., the resultant, aggregated, scores on the individual difference measures, rather than entering the raw item-level data into the model; see Little, Cunningham, Shahar, & Widaman, 2002). Fig. 1 illustrates the model that was found to best explain variability in climate change risk perception and support for policy interventions; it provided a good fit to the data, $\chi^2(2) = 4.005$, $p = 0.135$, $CFI = 0.999$, $RMSEA = 0.026$ ($95\%CI = [0, 0.064]$). The fit of the illustrated model was significantly better than a model that lacked directional links from all five dispositional measures (systems thinking, conspiratorial ideation, scientific acceptance, free market ideology, and political ideology) to the two measures related to climate change (risk perception and policy support), $\chi^2(9) = 1595.7$, $p < 0.001$.

The fit of the model in Fig. 1 was not improved by adding directional links to policy support from systems thinking and conspiratorial ideation, $\chi^2(2) = 4.005$, $p = 0.135$, suggesting that systems thinking had a direct effect on climate change risk perception and an indirect effect on policy support (via risk perception). Controlling for the effects of conspiratorial ideation, scientific acceptance, free market ideology, and political ideology, 38% of the total effect of systems thinking on policy support was mediated by risk perception (Imai, Keele, Tingley, & Yamamoto, 2009; Preacher & Kelley, 2011). For clarity of presentation, covariances between the exogenous variables (e.g., systems thinking, political ideology) were omitted from Fig. 1 (see Table 3 for correlations between these measures).

2.3. Discussion

In this first study we sought to better understand the psychological basis of attitudes toward, beliefs about, and tendencies to engage in behaviors related to climate change. We found relationships between political ideology, belief in scientific consensus, free market ideation, climate change risk perception, and support for policies aimed at addressing climate change. With one exception, these findings were consistent with prior work (Lewandowsky et al., 2013; Tobler, Visschers, & Siegrist, 2012; Van der Linden, 2014; van der Linden, Leiserowitz, Feinberg, & Maibach, 2015).

The exception was a positive relationship between conspiracist ideation and climate change risk perception (in the structural equation model); prior work had found a negative relationship between peoples' tendency to engage in conspiratorial thinking and recognition of risks associated with climate change (Lewandowsky et al., 2013). The positive finding in this case may be spurious, as the correlation between risk perception and conspiracist ideation was non-significant when variability in the other independent measures is not controlled for ($r = -0.025$, $p = 0.346$). Alternatively, the relationship that we find in the model (when controlling for, e.g., belief in scientific consensus and free market

Table 2
Dispositional measures and perceptions of climate change, with example item(s) from the questionnaires, end-point labels, and measures of reliability from samples collected (Cronbach's α).

Measure	Example item(s) and scale	Reliability		
		Sample 1	Sample 2	Sample 3
Systems thinking (15 items)	Seemingly small choices can ultimately have major consequences. 5-point scale: "Strongly disagree" to "Strongly agree"	0.79	0.78	0.79
Free market ideology (6 items)	An economic system based in free markets unrestrained by government interference automatically works best to meet human needs. 5-point scale: "Definitely no" to "Definitely yes"	0.71	0.77	0.82
Conspiratorial ideation (13 & 5 items)	The Apollo moon landings never happened and were staged in a Hollywood film studio. 5-point scale: "Definitely no" to "Definitely yes"	0.91	0.74	0.75
Acceptance of science (10 & 7 items)	The HIV virus causes AIDs. 5-point scale: "Definitely no" to "Definitely yes"	0.86	0.76	0.78
Climate change risk perception (13 items)	How concerned are you about the following potential consequences of climate change? (e.g., soil erosion, floods, drought). 8-point scale: "Not at all" to "Extremely concerned"	0.92	0.92	0.93
Policy support (8 & 3 items)	Kyoto Protocol; Mileage standards for cars; Business energy tax 5-point scale: "Oppose strongly" to "Support strongly"	0.84	0.66	0.75

[1] This measure was divided into three subcomponents in prior work (Lewandowsky et al., 2013): acceptance of science unrelated to climate change; acceptance of science related to climate change; and belief that issues related to climate change have been resolved. For conceptual clarity, and because of the high correlation between measures, we present a single aggregated measure of the degree to which participants accept science.

Table 3
Correlations between individual difference measures and perceptions of climate change. All values are statistically significant at the $p < 0.001$ level except for the relationship between conspiratorial thinking and risk perception ($p = 0.529$).

	Political ideology	Acceptance of science	Free market ideology	Conspir'l ideation	Risk perception	Policy support
Systems thinking	−0.33	0.485	−0.375	−0.192	0.345	0.377
Political ideology		−0.486	0.439	0.19	−0.328	−0.458
Acceptance of science			−0.55	−0.32	0.525	0.638
Free market ideology				0.245	−0.421	−0.557
Conspiratorial ideation					−0.025	−0.232
Risk perception						0.495

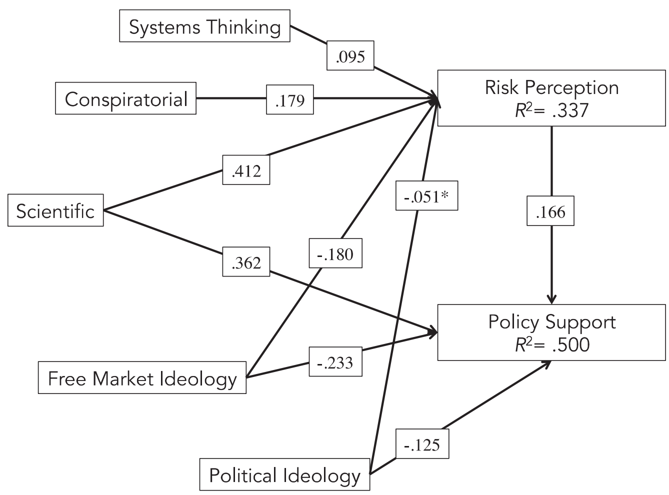

Fig. 1. Path analysis. A structural equation model of the effects of individual difference variables and narrative prevalence on blame attribution and policy support (with standardized path coefficients). All relationships significant at the $p < 0.001$ level, with one exception: the relationship between political ideology and risk perception ($p = 0.044$).

ideation) may reflect a difference between the populations from which the current and previous samples were drawn: whereas Lewandowsky et al. (2013) sampled participants from blogs devoted to discussing climate change, participants in the current sample came from a more general online pool. People who spend time reading blogs about climate science and identify as conspiratorial thinkers may be particularly likely to discount risks associated with climate change. Among the general population, on the other hand, people who engage in conspiratorial thinking may, in fact, show increased concern for risks posed by climate change — possibly because people who tend to engage in conspiratorial thinking are simply more attuned to (or worried/paranoid about) risk in general. That said, more recent work has shown that exposure to conspiracy theories related to climate change decreases peoples' willingness to engage in pro-environmental behavior (van der Linden, 2015), suggesting that even if people who tend to hold more conspiratorial beliefs about climate change are not more likely to behave in ways that could mitigate the effects of these risks.

The model presented in Study 1 makes a novel contribution to this literature by identifying a systems thinking mindset as a relevant dimension among a constellation of attitudes and beliefs that are associated with the recognition of the risks posed by climate change. The tendency to engage in systems thinking was negatively related to free market and conspiratorial ideation and positively related to a left-leaning political ideology and belief in science, as well as to climate change risk perception. The strength these correlations suggests that systems thinking is at once deeply related to these other constructs while also maintaining an important degree of independence: it adds a novel dimension to past analyses of climate change risk perception.

In addition, systems thinking may capture variability in a wider array of conceptions about the natural world: systems thinkers may recognize the value inherent to the natural world and not just the risks associated with environmental decline. We test this possibility in Studies 2 and 3.

3. Study 2

In Study 2, participants were asked to ascribe monetary value to an array of ecosystems (e.g., open oceans, forest, lakes/rivers, cropland) based on the "ecosystem services" they provide. This task was adapted from a recent report suggesting that the global value of all ecosystem services to humans is worth over $120 trillion per year and that significant value (between $4 and $20 trillion) is lost yearly due to unsustainable resource use (Costanza et al., 2014).

Although there are drawbacks to using monetary value as the sole metric for gauging the actual worth of the environment (see, e.g., Akerman, 2003; Norgaard, 2010; Raymond et al., 2013; Spangenberg & Settele, 2010; Williams et al., 1992), there are clear benefits to using such an exercise as a psychological measure. Peoples' prior experience with financial decisions provides a context for evaluating the worth of the natural world: both for participants (e.g., how does the value of open oceans compare to the US GDP?) and in evaluating responses (e.g., how much do people value open oceans, relative to the US GDP?).

In addition, asking people to ascribe value to the natural world emphasizes the benefits of a healthy environment, rather than highlighting personal risks associated with an instance of environmental degradation such as climate change, and it may be less susceptible to the influence of certain biases (e.g., with a political worldview that opposes government intervention on behalf of the environment on principle). As a result, the task is well suited to test hypothesized relationships between systems thinking and conceptions of human-environment relationships and complements the measure of risk perception used in Study 1.

We predicted that people who tend to engage in systems thinking would ascribe more value to the natural world, as these participants would be more likely to see themselves as embedded within the broader human-ecological context (Mayer & Frantz, 2004).

3.1. Methods

3.1.1. Participants

Five hundred participants were recruited to participate in Study 2. See Table 1 for demographic information about the sample.

3.1.2. Materials and design

In Study 2, we investigated how people would ascribe value to ecosystem services and tested which dispositional measures predicted these judgments (see Fig. 2 for an illustration of the task). In

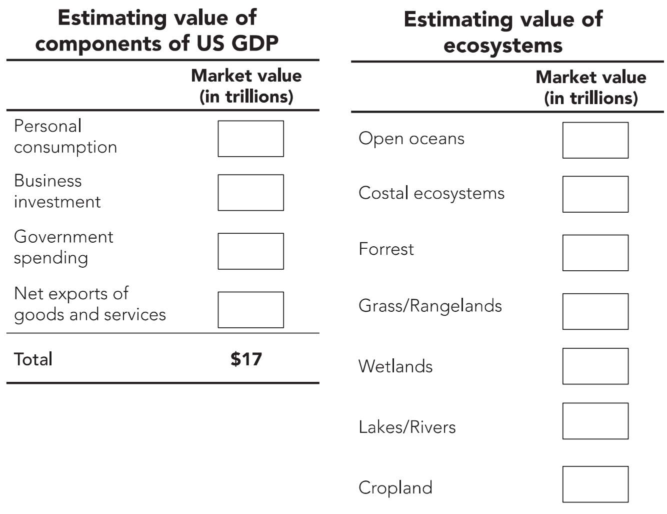

Fig. 2. Depiction of the GDP and ecosystem valuation tasks. Participants were asked to estimate the value of various components of US GDP (in trillions of dollars), which were constrained to sum to 17. Then participants were asked to estimate the value of various ecosystems (also in trillions of dollars), which was not constrained to sum to any particular value. The two sets of estimates were made on separate screens.

order to provide a context for the ecosystem valuation task, participants were first presented with information about the GDP of the United States:

Gross domestic product (GDP) is the market value of all recognized goods and services produced within a country in a year. The most recent estimate of GDP for the United States was approximately $17 trillion. The total GDP for all counties in the world in 2013 was over $72 trillion (China has the second-biggest GDP at about $9 trillion).

Before completing the ecosystem valuation task, participants were asked to estimate how much of the US GDP's $17 trillion came from each of the four major components of the US GDP: personal consumption, business investment, government spending, and net exports of goods and services. Participants' estimates were constrained so that they would sum to 17.

Then, participants were asked to make a similar set of estimates for seven ecosystems. Instructions for this task read:

Recent analyses indicate that ecosystems provide a range of services that are of fundamental importance to human well-being, health, and livelihoods.

The value of these services can be estimated in monetary terms (like GDP). In your view, what is the total value of ecosystem services around the world?

Participants were asked to ascribe monetary value (unconstrained) to seven ecosystems: open oceans, costal ecosystems, forest, grass/rangeland, wetlands, lakes/rivers, and cropland.

On the following screen, participants were asked to estimate the amount of ecosystem service value that had been lost globally over the past 15 years. This was a multiple-choice question with 5 options: a) less than $1 trillion; b) between $1 and $5 trillion; c) between $5 and $10 trillion; d) between $10 and $20 trillion; and e) greater than $20 trillion.

At the end of the survey, participants completed the same set of dispositional measures and demographic questions from Study 1.

3.2. Results

To analyze the value participants' ascribed to the natural world, we summed estimates of the worth of the seven ecosystems. The modal range of this total was fairly close to that of the US GDP ($17 trillion), suggesting that participants may have been anchored by this number (Tversky & Kahneman, 1974): 36% of participants estimated that the total value provided to humans from the natural world was between $10 and $40 trillion. However, a small number of extremely high estimates ($max = 1038$) skewed the distribution and led us to cap estimates over $1000 trillion at $1000 trillion ($n = 22$; 5%). In order to correct for the remaining skew ($M = \$161.1$ trillion; $median = \$56$ trillion), we log transformed the measure of total value; this correction was confirmed by a Mardia Test, $ps > 0.05$.

Table 4 shows participants' estimates of value for the seven components of the ecosystem from participants who were identified as high or low in systems thinking (based on a median split of systems thinking scores), which are also contrasted against the values estimated by Costanza et al. (2014). Overall, participants tended to giver higher estimates than Costanza et al. (2014) for the value of oceans, forests, lakes/rivers, and cropland and lower estimates for the value of costal ecosystems and wetland. This may reflect the semantic accessibility of the ways in which forests, oceans, lakes/rivers, and croplands support aspects of the economy (e.g., food comes from cropland, lumber from forests); people may have a harder time calling to mind the many ways in which other components of the ecosystem provide value to humans. For instance, people may not be as familiar with the role of wetlands (swamps, marshes, bogs) in feeding waterways, trapping floodwaters, recharging groundwater supplies, and filtering pollution (EPA, 2015).

We tested which dispositional measure best predicted participants' total valuation of the ecosystem by fitting a linear multiple regression model with nine predictors to the aggregated estimates of ecosystem value (see Table 5). We then used a stepwise model selection algorithm from the MASS library in *R* to identify the model that best fit the data (*R* Core Team, 2013; Ripley et al., 2014; Venables & Ripley, 2002), the results of which are shown in Table 5. This algorithm takes a maximally parameterized model and tests alternatives that include subsets of predictor variables by comparing AIC values (by both pairing down from the maximally parameterized one and working up from the minimally parameterized one) in order to find the best fit for the data. Two variables — systems thinking and risk perception — were revealed to be significant predictors of participants' estimates. Systems thinkers and people who recognized risks associated with climate change tended to ascribe more value to the ecosystem (see Fig. 3).

We also found significant correlations between the estimate of total value and the degree to which participants accepted science, adopted a free market ideology, and supported policy interventions; however, these variables were significantly correlated with each other (see Table 3) and the multiple regression model showed that the most reliable predictors of participants' estimates came from the measures of systems thinking and risk perception.

We similarly analyzed estimates of how much global ecological value had been lost over the past 15 years. Most participants (52%) thought that between $1 and $10 trillion in ecosystem services had been lost in this time period (6% estimated that less than $1 trillion had been lost; 21% estimated that more than $20 trillion had been lost). There was a significant positive correlation between estimates of total value and estimates of lost value, $r[479] = 0.387$, $p < 0.001$: people who ascribed more value to global ecosystems also thought more value had been lost in recent years.

As with the estimates of ecosystem value, a multiple regression model revealed that systems thinking and risk perception significantly predicted estimates of lost value (see Table 5). Systems thinkers and people who perceived more risk associated with climate change tended to think that more value had been lost. The

Table 4
Estimates of value provided by Costanza et al. (2014) and by participants in Study 2. Participants were identified as high or low in systems thinking based on a median split of scores on the systems thinking scale.

	Ocean	Costal	Forest	Grass/Rangeland	Wetland	Lakes/Rivers	Cropland	Total
Costanza et al. (2014)	21.9	27.7	16.2	18.4	26.4	2.5	9.3	122.4
High in systems thinking	31.9	26.4	28.4	24	22.3	26.1	32.2	191.3
Low in systems thinking	21.5	17.1	22.7	15.7	13.8	17.5	26.5	134.8

Table 5
Relationships between the individual difference measures and the two measures related to participants' estimates of ecosystem valuation. Asterisks indicate statistical significance at the $^{*}p < 0.01$, $^{**}p < 0.01$, and $^{***}p < 0.001$ levels.

Measure	Total Value			Change in Value		
	r[479]	β	SE	r[479]	β	SE
Systems thinking	0.187^{***}	0.140^{**}	0.047	0.307^{***}	0.195^{***}	0.046
Political ideology	−0.086			-0.177^{***}		
Acceptance of science	0.122^{**}			0.265^{***}		
Free market ideology	-0.128^{**}			-0.294^{***}	-0.153^{**}	0.048
Conspiratorial ideation	−0.019			−0.079		
Risk perception	0.190^{***}	0.144^{**}	0.047	0.327^{***}	0.204^{***}	0.048
Policy support	0.139^{**}			0.296^{***}		

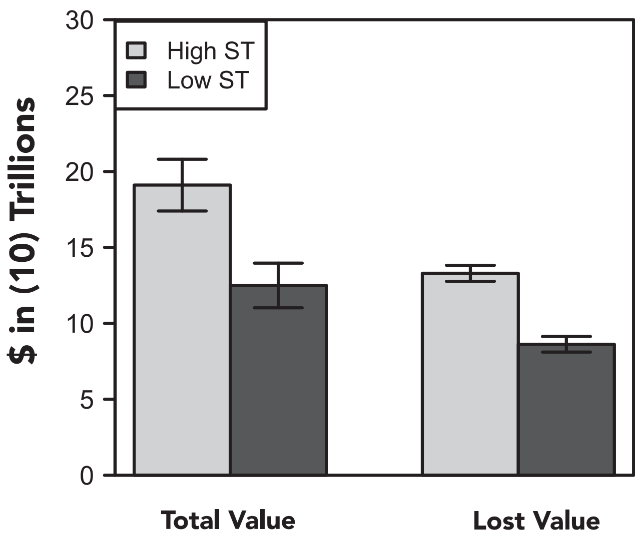

Fig. 3. Ecosystem valuation (in 10 s of trillions) and an estimate of ecosystem value loss (in trillions) by a median split on systems thinking. Error bars denote standard errors of the means.

model also revealed that free market ideation was a significant predictor of this judgment — associated with lower estimates of value loss. Fig. 3 illustrates the amount of value ascribed to ecosystem services and value lost over recent years as a function of systems thinking.

3.3. Discussion

In Study 2 we used an ecosystem valuation task to examine how systems thinking, along with other relevant psychological constructs, influenced conceptions of value for the natural world. The task was designed to gauge an aspect of environmental cognition that may not be captured by other types of self-report measures: a global and positive, rather than personal and negative, sense of value for the natural world. For communities not faced with existential threats from drought, increased disease, and flooding, considering environmental value in a global ecosystem services model may better capture the evaluative task that individuals face when they act as voters and consumers.

We found that systems thinking was highly predictive of these estimates: both current value and value lost, as was the measure of climate change risk perception, and better than more extensively studied constructs like scientific acceptance or political ideology. This suggests that systems thinkers recognize risks associated with climate change (Study 1) and ascribe greater value to ecosystem services more than non-systems thinkers (Study 2), consistent with the conceptual underpinning of the construct.

4. Study 3

In recognition of the deep limitations of the ecosystem services model as an actual tool for environmental communication, we test a different method for measuring ecological value in Study 3.

4.1. Methods

4.1.1. Participants.

Six hundred participants were recruited to participate in Study 3. See Table 1 for demographic information about the sample of participants.

4.1.2. Materials and design

In Study 3, participants read a semi-fictional description of a tuna fishery surrounding the Alor archipelago in Indonesia, where overfishing, spurred by technological development, population growth, and international demand, threatened the local population's chief source of revenue and sustenance (i.e., a "wicked" problem; Rittel & Webber, 1973).

Immediately after reading the narrative participants were asked four "catch" questions, which were used to identify participants who might not have closely read the scenario. Data from participants who correctly answered at least three of these questions were included in subsequent analyses ($n = 544$ for analysis; data from 54 participants, 9%, were excluded on this basis).

Afterwards, participants answered questions about the value of the fishery to the surrounding economic, social, and ecological systems. Three blocks, each with four questions, were designed to probe participants' attitudes toward the fishery in economic, social, and ecological terms. In each block one question each was designed to measure participants' conception of (a) the importance of the fishery, (b) the relative impact of current fishing practices compared to traditional or sustainable alternatives, (c) the role of the fishery in the economy, social life, or ecology of the surrounding area, and (d) potential consequences of fishery destruction. Blocks and questions within blocks were randomized between participants.

For instance, in the block of economically-framed questions, participants were asked to estimate (a) the average wage of fishermen, (b) how using dynamite instead of traditional net fishing would affect wages, (c) the percentage of the local economy supported by the fishery, and (d) the impact that losing the fishery would have on the local economy. In the block of socially-framed questions, participants were asked to estimate (a) the importance of the fishery to the well-being of residents, (b) the role of the fishery in community traditions, (c) the role of the fishery in supporting community relationships, and (d) the impact of losing the fishery on future generations of residents. In the block of ecologically-framed questions, participants were asked to estimate (a) the importance of the fishery for local flora and fauna, (b) the effect of using dynamite on coral reefs, (c) the percentage of reef destruction that would have to occur in order to irreparably damage the fishery, and (d) the number of years coral reefs would survive with current fishing practices in place.

Some questions asked participants to respond with a percentage, using a sliding scale (e.g., "How much do you expect using dynamite instead of traditional net fishing would increase a fisherman's annual net income?"); other questions asked participants to make a rating on a 4- or 5-point scale (e.g., "How much more damaging do you think blast-fishing is for the coral reefs compared to net fishing?" on a 5-point scale that ranged from "Not more damaging at all" to "Extremely damaging"). Due to the variability in ranges, we scaled responses to the questions before averaging them.

Separate measures of economic, social, and ecological value were computed for each participant by averaging their responses to each set of four economic, social, and ecological system-related questions (Cronboch's $\alpha = 0.64$). To support this approach, we conducted an exploratory factor analysis on the raw data, which revealed three principal components that clustered into the three target domains, which explained 66% of the total variance in responses (see Table 6).

After answering these questions, participants were asked the same set of background questions from Studies 1 and 2 (measures of systems thinking, acceptance of science, free market and conspiratorial ideation, risk perception related to climate change, and support for various policy interventions designed to address climate change, as well as the same set of demographic questions).

4.2. Results

A repeated measures ANOVA with a within-subjects factor for value frame (economic, social, environmental) was fit to participants responses with dispositional measures (systems thinking, free market ideology, conspiratorial thinking, scientific acceptance, environmentalism, political ideology) and climate change related measures (risk perception, policy support) included as covariates — including tests for main effects of these measures and for interactions with the value frame.

The model revealed four main effects: positive relationships between systems thinking, $F[1, 515] = 174.228$, $p < 0.001$ ($r[522] = 0.486$, $p < 0.001$), scientific acceptance, $F[1, 515] = 5.628$, $p = 0.018$ ($r[522] = 0.402$, $p < 0.001$), climate change risk perception, $F[1, 515] = 25.601$, $p < 0.001$ ($r[522] = 0.398$, $p < 0.001$), and fishery value (i.e., regardless of whether the value was conceptualized in economic, social, or ecological terms), and a negative relationship between free market ideation and overall fishery value, $F[1, 515] = 11.886$, $p < 0.001$ ($r[522] = -0.332$, $p < 0.001$). That is, systems thinkers, people who accepted science, and people who recognized the risks associated with climate change tended to ascribe more economic, social, and ecological value to the fishery, whereas people who ascribed to a free market ideology tended to ascribe less value to the fishery.

We also found several interactions between the dispositional measures and the value frames that bear more directly on our theoretical question: between value frame and systems thinking, $F[2, 1030] = 34.853$, $p < 0.001$, between value frame and free market ideation, $F[2, 1030] = 8.563$, $p < 0.001$, and between value frame and risk perception, $F[2, 1030] = 3.610$, $p = 0.027$ (see Fig. 4 and Table 7).

Estimates of economic value were impacted the least by variability in systems thinking, free market ideation, and risk perception. Regardless of whether people were high or low in systems thinking (or free market ideation or risk perception), they tended to report similar estimates of economic value associated with the fishery. However, participants high in systems thinking, high in risk perception, or low in free market ideation tended to value the fishery more for social and ecological reasons than people low in systems thinking, low in risk perception, or high in free market ideation.

4.3. Discussion

In Study 3 participants were asked to distinguish between three commonly invoked imperatives for ecological reform: the protection of economic, environmental, and social capital. Consistent with our predictions and the results of Studies 1 and 2, systems thinking was positively correlated with estimates of economic, social, and ecological value for the fishery. Recognition of the social and ecological value of the fishery in particular distinguished systems thinkers from non-systems thinkers.

5. General discussion

Results of three studies highlight the value of considering a construct like systems thinking in environmental cognition. Study 1 showed that systems thinking was related to several attitudinal and

Table 6
Correlations between aggregated conceptions of economic, social, and ecological value of the fishery with each other and with four factors that emerged from a principal components analysis (amount of variance explained in parentheses). Note the relationships between the first three factors and the three target domains; correlations with a fourth factor are shown to illustrate the relationships between the three domains and first three factors. Asterisks indicate statistical significance at the $^{*}p < 0.01$, $^{**}p < 0.01$, and $^{***}p < 0.001$ levels.

Domain	Social	Ecological	PC 1 (0.44)	PC 2 (0.13)	PC 3 (0.09)	PC 4 (0.07)
			Social	Economic	Ecological	NA
Economic	0.251^{***}	0.047	0.414^{***}	0.760^{***}	-0.214^{***}	0.285^{***}
Social		0.380^{***}	0.932^{***}	-0.080	-0.097^{*}	-0.124^{**}
Ecological			0.583^{***}	-0.333^{***}	0.533^{***}	0.355^{***}

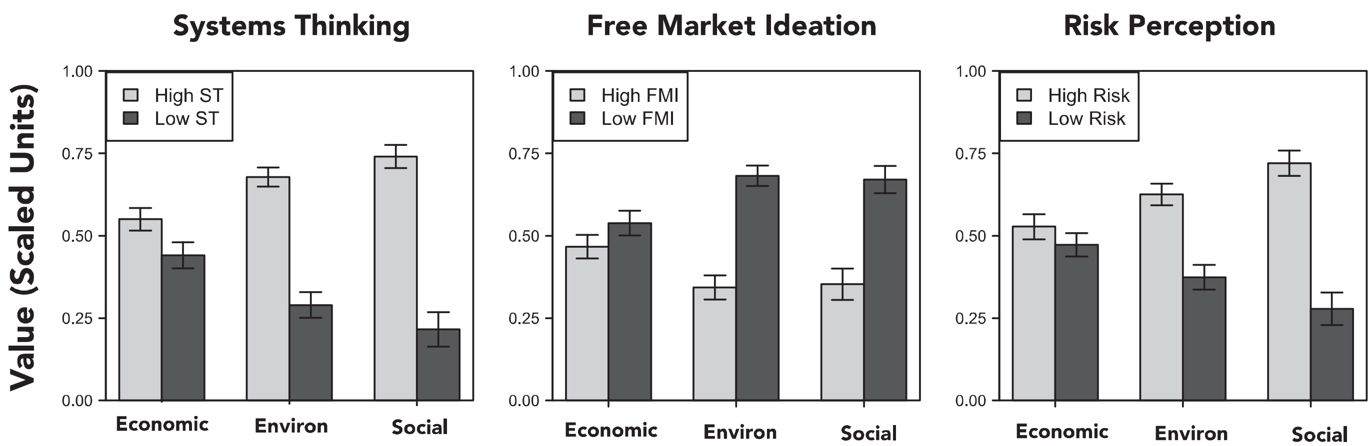

Fig. 4. Value of fishery to surrounding economy, environment, and society by systems thinking, free market ideology, and climate change risk perception. Error bars denote standard errors of the means.

Table 7
Correlations between dependent variables (i.e., systems thinking propensity, free market ideology, and climate change risk perception) and estimates of value in economic, environmental, and social terms. Asterisks indicate statistical significance at the $^{*}p < 0.01$, $^{**}p < 0.01$, and $^{***}p < 0.001$ levels.

	Economic value	Environmental value	Social value
Systems thinking	0.112*	0.444***	0.452***
Free market ideology	−0.045	−0.404***	−0.256***
Risk perception	0.112*	0.360***	0.356***

dispositional measures predictive of climate change risk perception and policy support. Studies 2 and 3 showed that systems thinking was related to ecosystem valuation — both when framed in economic terms and when framed in social or ecological terms.

The present research contributes to a recent empirical effort to better understand the psychological underpinnings of systems thinking (Davis & Stroink, 2016; Thibodeau et al., 2016; Thibodeau et al., 2016) and builds on body of empirical and theoretical work that seeks to uncover foundations of environmental reasoning (Feinberg & Willer, 2011; Heath & Gifford, 2006; Kahan et al., 2011; Klöckner, 2013; Lewandowsky et al., 2013; Tobler et al., 2012; Van der Linden, 2014). Future work will aim to investigate the malleability of systems thinking in more detail – when and how can people be encouraged to engage in systems thinking? – and explore relationships between how people think about social and natural systems.

At a high level, an emphasis on systems thinking may be seen as an attempt to promote a kind of "wisdom" among the general public with regard to environmental decision making (Schwartz & Sharpe, 2010; Staudinger & Gluck, 2011; Sternberg, 1990). In this context, systems thinkers recognize the possibility of unintended consequences in making consequential decisions and think more broadly about the array of potentially relevant antecedents and consequences of any given decision or behavior.

One important reason for including systems thinking in models of environmental cognition is that the mindset may be more malleable than, for instance, political ideology or belief in scientific consensus (Meadows & Wright, 2008; but see van der Linden, Leiserowitz, Fenberg, & Maibach, 2014, 2015 for evidence that belief in scientific consensus is malleable and affects intentions to engage in pro-environmental behavior). Although the current studies are all correlational (i.e., participants were not manipulated to think in a more or less systemic way through any sort of prime or intervention), prior work has found that systems thinking can be increased through educational interventions (Fazey, 2010; Kim et al., 2014; Maani & Maharaj, 2004) as well as more subtle manipulations — like exposing people to linguistic or visual metaphors that highlight complex relational structure (Flood & Jackson, 1991; Thibodeau & Boroditsky, 2011, 2013; Thibodeau, et al., 2016; Vendetti et al., 2014).

For instance, describing a national park as the "backbone" of a park system seems to situate the park in a larger body and specify a set of relationships between that park and the whole system. In contrast, describing a national park as a "pearl" of a park system seems to emphasize the beauty of the park, but leaves the relationship between this park and the rest of the elements in the system only weakly specified. In other words, exposing people to highly systemic, relational metaphors may provide more systemic mental models that help to promote systems thinking.

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