Managing our Debt: Changing Context Reduces Misunderstanding of Global Warming

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Abstract

We report an experiment in which a change in the context of a stock-flow reasoning problem leads to a 44% reduction in the use of an erroneous 'correlation heuristic' response. In its original context – a global warming scenario – the majority of participants pattern-match the output of a system to its inputs (i.e., use a correlation heuristic). In the changed context – financial debt management – the majority reason correctly that in-flows and out-flows must converge to stabilize stock. Potential applications for improving communication of climate change science are discussed.

Keywords: stock-flow reasoning; correlation heuristic; climate change

There is overwhelming agreement amongst climate scientists that the globe is warming up, due in large part to increases in the emissions of greenhouse gases (e.g., Anderegg et al., 2010). Despite this consensus in the scientific community, highly divergent opinions about the existence and implications of global warming remain entrenched in the wider community in many countries (e.g., Leiserowitz & Smith, 2010; Leviston & Walker, 2011).

The manifold reasons for this 'disconnect' between the science and belief range from fundamental differences in the way people 'view' the world (e.g., Kahan et al., 2012), to the pernicious attempts to manufacture doubt in the science (e.g., Oreskes & Conway, 2010), to deficits in lay understanding of the mechanisms of global warming (e.g., Bord et al., 2000). Here we focus on this last issue and examine how a change in context might aid understanding some basic science behind how global warming 'works'.

Our experimental task focusses on the relationship between the amount of CO_2 emitted into the atmosphere, the amount of CO_2 absorbed via natural processes, and the resulting 'stock' or concentration of CO_2 that accumulates in the atmosphere. The simple principle that participants need to appreciate to complete this task successfully is fundamental to any system that involves in-flows, out-flows and an accumulating stock. Namely, that a stock will accumulate its in-flows minus its out-flows. Thus water in a bathtub will accumulate the water flowing in from the tap, minus any water flowing out through the drain. If the inflow exceeds the outflow, the tub will continue to fill up with water (e.g., Cronin et al., 2009; Sterman, 2008).

The same principle applies to the simplified climate system we consider in our experimental task: the accumulation of CO_2 in the atmosphere is determined by the in-flow (emissions) and the out-flow (absorptions). If emissions exceed absorptions CO_2 will continue to accumulate; only when emissions and absorptions converge (CO_2 is entering and leaving the atmosphere at the same rate) will the atmospheric concentration stabilize.

A graphical representation of these relationships is shown in Figure 1 (adapted from Dutt & Gonzalez, 2012 and Sterman & Booth-Sweeney, 2007). The top graph shows the accumulated stock of CO_2 in the atmosphere from the period 1900 to 2100. The stock rises steadily until the final period (between 2090 and 2100) where it stabilizes, i.e., remains constant at 950GtC.

The bottom graph depicts the absorption of CO_2 (the green line) which is a fixed constant of 40GtC/decade across the time period, and the emissions (the black line up to 2000) which steadily increases across time. The task facing participants in our experiment was to complete this emissions line for the remaining time period (2010-2100) so that the concentration depicted in the top graph was achieved; specifically, so that the concentration was stabilized by the final period. The additional lines on the bottom graph show an approximately correct (solid blue line) and a characteristically incorrect (red dashed line) response trajectory.
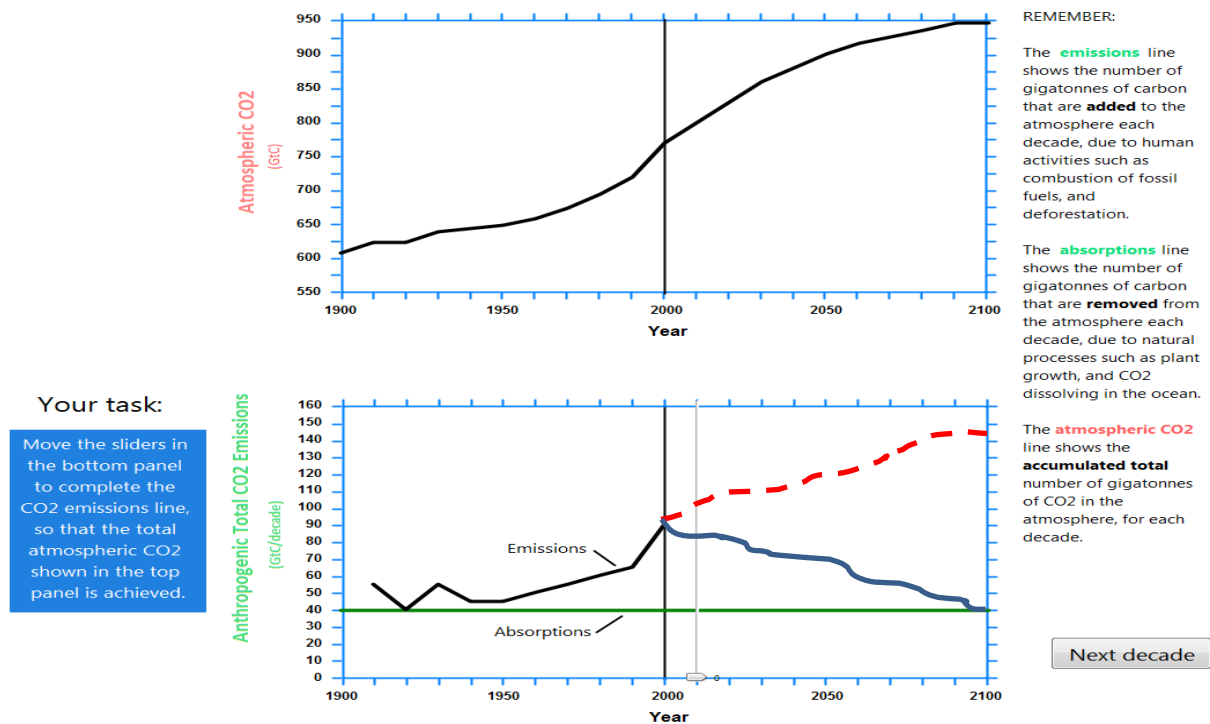
Figure 1: Screenshot showing the Computer Climate Stabilization Task. The participant's task is to complete the emissions trajectory in the bottom graph so that the stabilization of atmospheric CO_2 shown in the top graph is achieved. The solid blue sketched line in the bottom graph shows a correct response trajectory in which the emissions and absorption lines converge at the point of stabilization (2100). The red dashed sketched line is a typical "correlation heuristic" response trajectory in which the emissions line mirrors the trajectory of the accumulation (i.e., continues steadily increasing) – such a response indicates a failure to understand the relationship between emission, absorption and accumulation.

The solid blue line is correct because it takes account of the principle described above. The emission value in each decade is calculated by adding the difference in stock between the current and previous time period to the absorption rate. Thus reading from the top graph in Figure 1 for the first estimate, the stock in 2000 is approximately 770 GtC and in 2010 it is approximately 800GtC. To achieve a net increase of 30GtC in the atmosphere, 70 GtC must be emitted, 40 GtC of which is absorbed via natural processes (the green flat line in the bottom graph). Thus the correct response is 70GtC which is approximately the value of the blue line for that decade. The red-dashed trajectory is incorrect because it fails to take account of the principle – rather, the trajectory simply mirrors that of the accumulated stock, a steady increase.

Despite the apparent simplicity of stock-flow relationships (we all know how to run a bath without flooding the house), participants presented with tasks like that shown in Figure 1 overwhelmingly produce responses akin to the red-dashed line instead of the blue line (e.g., Cronin et al., 2009; Sterman & Booth-Sweeney, 2007). The standard explanation of such erroneous responding is over-reliance on pattern-matching or use of a 'correlation heuristic' whereby participants reason that the output of a system

should "look like" (be positively correlated with) its inputs (Cronin et al., 2009; Sterman, 2008).

In the climate task such reasoning leads to people to think that if the concentration is 'going up' then so too should the emissions and thus they sketch a rising emissions trajectory that looks like the accumulation line in the top graph. Such reasoning is not confined to the climate task, however. Responses consistent with the adoption of a correlation heuristic have been observed across a range of task contexts (e.g., water tanks, bank accounts, people entering and leaving a shop) and formats (bar graphs, line graphs, tabulated numbers, and even simple text descriptions) (e.g., Cronin et al., 2009; Sterman & Booth-Sweeney, 2007).

Couching the explanation of this erroneous behavior in terms of a heuristic begs the question of *why* the heuristic response is so readily adopted. Heuristics are typically invoked in an attempt to reduce the effort associated with performing a task (e.g., Shah & Oppenheimer, 2008). One account (Kahneman & Frederick, 2002) suggests that heuristic responding combines elements of attribute substitution and natural assessment. A participant faced with a hard question about a particular target attribute (e.g., the emissions trajectory) tends to answer a different but easier question (e.g., what does the concentration trajectory look like?). Thus the question about the target attribute is responded to by substitution of a more readily accessible

heuristic attribute. The accessibility of this heuristic attribute is determined by the extent to which its properties are naturally assessed – that is via some routinely used cognitive procedure (similarity, fluency, availability, etc.). The visual availability of the accumulation trajectory in the climate task (i.e., the functional form of the line in the top graph of Figure 1) may well contribute to it being readily 'substituted' for the correct attribute.

This visual similarity cannot, however, be the only trigger to adoption of the correlation heuristic because, as noted earlier, its use has been observed in other contexts and in non-graphical tasks (although the majority of studies have used some kind of graphical representation, e.g., Cronin et al., 2009). Thus a more likely candidate for the prevalence of such heuristic responding is simply that stock-flow tasks are not the kinds of things that we think about regularly, thus we find them difficult, and readily revert to simpler solutions. While we may be able to run a bath – thus exhibiting behavior consistent with understanding the principle of accumulation – it does not necessitate an abstract appreciation of such knowledge.

Furthermore our experience with such systems does not typically involve making sequences of decisions about the rates of change of in-flows and out-flows *across time*. Rather they involve a single decision *within* a particular time period. For example, when running a bath we know that we need to put the plug in, turn the tap on and then turn it off before the tub overflows. While this involves (periodic) monitoring of the water level, there is only one interaction with the system (turn off the tap) and the outflow is typically constant (i.e., zero, unless we have a leaky bath).

This analysis of so called 'stock-flow-failure' (Cronin et al., 2009) suggests two aspects that might be important for reducing reliance on a correlation heuristic response. First, the elements of the problem need to be sufficiently accessible or familiar that participants answer the question they are being asked rather than an 'easier' but wrong one. Second, the problem needs to be one in which people have some experience in dealing with the elements *across time* and preferably one that involves multiple decision points.

We reasoned that a candidate scenario that features many of these desirable attributes is financial debt management. Most of us can readily intuit that if we spend more than we earn then we will get in to debt, and that if we keep spending more than we earn that debt will continue to increase. Unlike the bathtub, debt management involves sequential, discrete monitoring of income and expenditure and is something that many of us grapple with *across time* ("I will pay off that credit card by the end of year!"). Figure 2 shows how the climate task depicted in Figure 1 can be readily transformed into a 'financial' debt management task.

The top graph in Figure 2 depicts the size (in dollars) of the debt incurred by an individual across a period of 21 weeks. Just like the CO_2 accumulation in Figure 1, the debt increases from just over $600 in Week 1 and then stabilizes at $950 in Week 21. The bottom graph of Figure 2 depicts the amount the person earns (the green line) – which is fixed

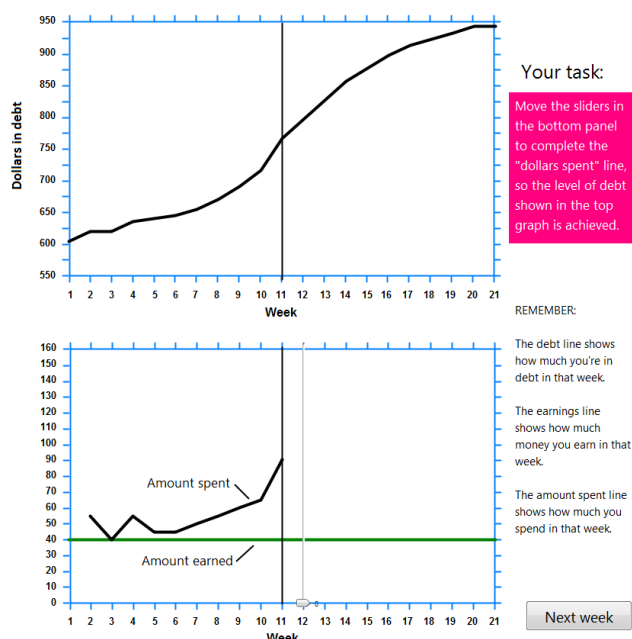at $40 per week, and the amount the person is spending. The amount spent gradually rises to a peak at $90 by Week 11.

Figure 2: The Financial Task: A participant's task was to complete the 'amount spent' line in the bottom graph to ensure stabilization of the debt depicted in the top graph. A correct response required the 'amount spent' and the 'amount earned' lines to converge by 'week 21'.

The task facing the participant is to complete the 'amount spent' line to reflect the debt trajectory shown in the top graph. To do this successfully requires realizing that the 'spending' and 'earning' lines need to converge by Week 21. (For simplicity, participants were told that their debt incurred no interest.)

It is clear that the fundamental (deep) characteristics of the problems illustrated in Figure 1 and Figure 2 are the same, only the surface characteristics have changed (cf., Gonzalez & Wong, 2011). Both tasks require understanding the relations between in-flows (emissions or spending), out-flows (absorption or earnings), and stock (CO_2 concentration or financial debt). Despite these basic similarities, we hypothesized that the financial debt scenario would trigger the correct intuition more readily (i.e., stop spending more than you earn) than the climate scenario and thus inhibit 'correlation' heuristic responding. In short, participants should be more accurate in plotting the trajectory when given the financial context than the climate context.

We tested this hypothesis in two ways: first we compared participants given only the climate task depicted in Figure 1 with participants given only the financial task in Figure 2. Second we developed another version in which

another group of participants were given the climate task but were invited to think about it as one of financial debt management. In other words, we provided explicit links between the two contexts (e.g., "You might find it helpful to think about emissions as the amount you are spending", etc.). We predicted that participants in this additional condition would perform more accurately than those given the 'pure' climate task and possibly as well as those given the 'pure' financial task. This latter prediction was based on related work on analogical encoding (Gentner, Loewenstein, & Thompson. 2003), in which people are better at solving a problem when they are able to compare similar analogous cases prior to undertaking a target task. If the explicit links to the financial debt scenario facilitate abstraction of the basic principle (i.e., that in-flows and out-flows need to converge in order for stock to stabilize) then performance might be commensurate with the 'easier' version of the task.

We report these three conditions as a single experiment to facilitate presentation, although in reality they were run sequentially.

Experiment

Participants

Seventy-five undergraduate students from the University of New South Wales took part in the study in return for course credit. There were 44 females and the mean age was 19.92 (SD = 3.40). Each condition was run sequentially over a 4 month period, so participants were not randomly allocated to conditions. No participant completed more than one condition.

Experimental Design and Procedure

Participants were given one of three versions of the basic stock-flow tasks described in the introduction (see Figures 1 and 2). For the Climate Task the graphs were adapted from ones used by Dutt and Gonzalez (2012). In each condition the main task was to complete the trajectory in the bottom graph of the display. This was done via moving on-screen slide controls that plotted the line for each time period discretely. Thus participants made 10 predictions in total. At the conclusion of these predictions participants were invited to make a second attempt (if they wished to) and could readjust any or all of the sliders before finalizing their response.

Participants in the Climate Task and Climate Financial Context condition were given some initial introductory text about climate change and global warming (adapted from Dutt and Gonzalez, 2012). Those in the Financial Task received no additional information. Participants in the Climate Financial Context condition were given additional instructions drawing explicit links between financial debt management and the climate task. These instructions appeared first on a preliminary screen and then alongside the graphs (to the left of the display shown in Figure 1) and remained there throughout the prediction attempts.

Prior to making the predictions participants in all conditions answered three comprehension questions that required reading off some numbers from both the upper and lower graphs in the display and typing in the responses.

Results

All participants answered the comprehension questions correctly, suggesting that they were able to read the graphs accurately.

The key dependent measure of interest is the emissions/spending estimate made for each decade/week. Each participant made 10 initial estimates and then had the opportunity to change each estimate on a second attempt. Figure 3 shows the mean estimates for the 10 time periods averaged across both attempts by participants in the three conditions (very few participants changed their initial answers when given the opportunity to make adjustments). The figure also plots the correct trajectory calculated by adding the difference in stock between the current and previous time period to the out-flow (see introduction for an example).
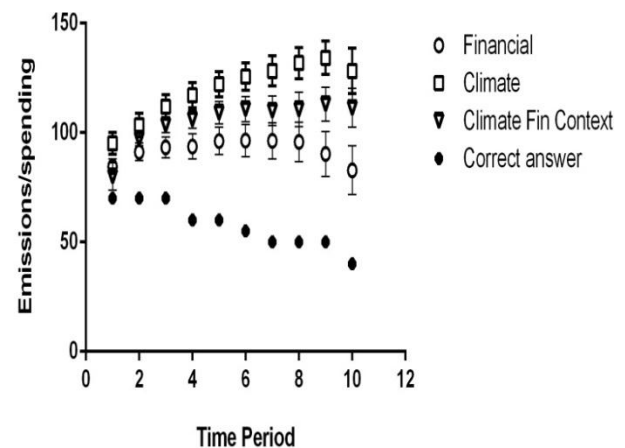

Figure 3: The mean emission/spending estimates for each time period averaged across the two attempts made by participants (error bars are SEM). The asterisks are the correct values for each time period – see text for details. Financial refers to the debt-management task, Climate to the standard task and Climate Fin Context to the climate task with instructions inviting participants to consider the problem as one of debt-management.

Three features of the data are noteworthy: 1) participants given the 'pure' financial debt management task perform most accurately (on average) showing the correct downward trajectory; 2) those given the pure 'climate frame' display (on average) an upward trending 'correlation heuristic' response; 3) those participants given the standard climate task but with instructions to consider it as a debt-

management problem (Climate Fin Context) fall in-between the two other groups in terms of accuracy.
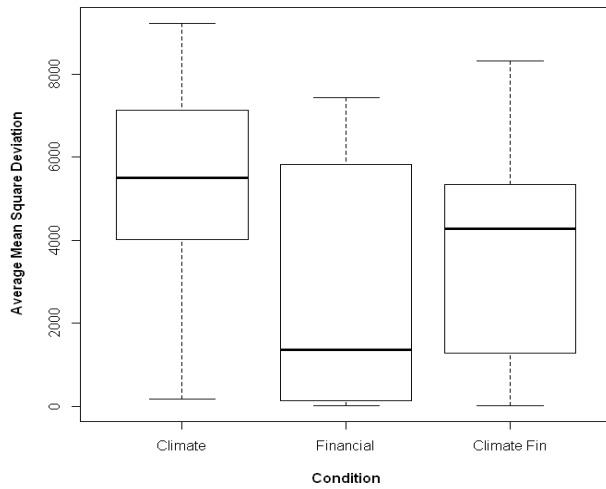

Figure 4: A boxplot showing the average MSD between the correct response and the estimates (average across the two attempts) in each condition. Solid line is the median response.

These general impressions are confirmed in an alternative way of graphing the data shown in Figure 4. To examine whether the differences apparent in Figure 4 were statistically reliable we used a default Bayesian t–test (Rouder, Speckman, Sun, Morey, & Iverson, 2009). We assume, for fairness, that the null hypothesis and the alternative hypothesis are equally plausible a priori. The t-test then allows us to determine the posterior plausibility of the null hypothesis and the alternative hypothesis. We denote the posterior probability for the null hypothesis as $p_{BayesH0}$. When, for example, $p_{BayesH0} = .9$, this means that the plausibility for the null–hypothesis has increased from .5 to .9.

As predicted, participants given the Financial context made significantly better (lower MSD) estimates than those given the standard climate task ($p_{BayesH0} = .01$). In addition, participants given the Climate task with the financial context as a guide made more accurate estimates than those given the standard climate task ($p_{BayesH0} = .24$). For the difference between the Financial condition and the Climate Financial Context the null hypothesis is more plausible ($p_{BayesH0} = .75$).

The data in Table 1 showing classifications of individual performance supports the interpretation provided by Figures 3 and 4. When a correct response is coded as ensuring that in-flow and out-flows converge by the final time period, over half (52%) of the participants given the 'pure' Financial task showed correct stabilization compared to only 2 people given the pure climate task (8%). In addition 7 participants given the climate task with the financial context instructions achieved the correct stabilization pattern.

Table 1: Classification of Individual Responses as achieving correct stabilization of the system (i.e., in-flow and out-flow converge by the final time period).

Correct Stabilization (N of Participants)		
Experiment	Correct	Incorrect
Financial	13	12
Climate	2	23
Climate + Fin	7	18

Discussion

Our experiment sought to address reasons for the well-documented 'stock-flow failure' observed when participants are asked to make judgments about changes to in-flow, out-flow and accumulated stock across time.

In the first instance we showed a clear replication of participants' inability to 'solve' the stock-flow task when it is presented in the context of the climate system. This result dovetails neatly with those reported in the literature (e.g., Sterman & Booth-Sweeney, 2007) and suggests that procedural differences between our and previous studies are not crucial for eliciting correlation heuristic-consistent responding.

In particular, our task differed from those used before in that we required participants only to make estimates of the emissions (in-flow) rather than both emissions and absorption rates (out-flow) (see Sterman & Booth-Sweeney, 2007). We suspected that this change might make the task somewhat easier but it appeared not to affect performance. Likewise the fact that our 'stabilization period' was not as long as in previous studies (i.e., only one time period) did not appear to affect the failures to stabilize. (Note that the instructions stated explicitly that the emissions stabilized by 2100, and the comprehension questions suggested that participants could read this aspect of the graph.) Finally, the change to a computer interface rather than the hand-drawn sketches used previously (e.g., Dutt & Gonzalez, 2012), appears to be a useful progression that allows a more accurate quantitative approach to analysis while not affecting the over-all pattern of responding.

In contrast to the relatively negative conclusions that can be drawn from the climate task, an optimistic (glass half full) interpretation of the Financial Task context is that (some) participants can 'do' stock-flow reasoning. Given the low-base of accurate performance in these tasks (e.g., Cronin et al., 2009), any manipulation which leads to over 50% of the sample getting the answer (approximately) correct is newsworthy. Our working hypothesis is that the financial context helps because the familiar principle (don't spend more than you earn if you want to avoid debt) is readily intuited thereby inhibiting the correlation heuristic response (cf. Kahneman & Frederick, 2002; Shah & Oppenheimer, 2008). Moreover, the familiarity of projecting thoughts about debt management *across time* - because people often cannot pay off a debt in one go - helps understanding of the in-flow, out-flow and stock relationship.

Clearly though the familiar context on its own is not enough for all participants – just fewer than 50% still failed to stabilize, and most of those gave responses consistent with a correlation heuristic response. As related literature has shown, the relationship between context familiarity and accuracy on these tasks is not straightforward (e.g., Booth-Sweeney & Sterman, 2000; Brunstein et al., 2010; Moxnes & Saysel, 2009) and more research is needed to identify exactly which aspects of context facilitate reasoning, and why.

This sentiment is borne out by the results of our third condition – climate with the financial context as a guide. Provision of the 'readily intuited principle' (don't spend more than you earn) was enough for just over a quarter (28%) of the sample to understand the task, and led to significant improvements in accuracy relative to the climate task instruction alone. Thus for these participants at least, the additional explanation in terms of a familiar context seemed to improve the understanding of one aspect of the science behind global warming. However, the remaining participants could not (or did not) apply the principle correctly to the unfamiliar context.

An important question arising from this work is whether participants who perform the climate tasks accurately differ in attitudes towards taking action on global warming from those who exhibit 'stock-flow failure'. As noted in the introduction, although some authors argue that differences in 'world view' are more important than scientific understanding (e.g., Kahan et al., 2012), other studies suggest positive correlations between understanding and willingness to act (e.g., Leiserowitz & Smith, 2010). Indeed Sterman (2008) argued that failures in stock-flow reasoning may well contribute to the tendency to take a 'wait-and-see' approach on addressing global warming.

Although we collected some data on attitudes and intentions to behave pro-environmentally, the paucity of accurate performers on the climate versions of our task, made it difficult to draw any strong conclusions in this regard. Future work will attempt to address these limitations by building on the successful context manipulations found here and by targeting more heterogeneous (non-student) populations with more divergent opinions about global warming. Such studies could provide important findings to help in getting the message about global warming both heard and heeded (cf., Newell & Pitman, 2010).

Acknowledgments

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