Challenging Climate Change Skepticism Through Graphical Curricula

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ABSTRACT

The effects of anthropogenic global warming (AGW) will soon become irreversible absent drastic domestic and international changes in environmental policy. Environmental progress has been hindered by relevant political (e.g. governments) and economic (e.g. big businesses) actors, many of whom are still skeptical global climate change is real and due to humans. Since these actors are most responsive in the face of political or economic costs, building broad public consensus in favor of taking decisive policy actions will likely prove crucial to shaming relevant actors into action. One important tool that can be used to combat skepticism is science communication, be it through statistics, graphs, videos, text or some combination thereof. This experiment looked at the effectiveness of six different interactive graphical curricula at increasing acceptance of global warming amongst an undergraduate class (n=280) at the University of California, Berkeley. Most results were not statistically significant. However, all participants demonstrated modest increases in understanding and acceptance that earth has warmed over the past 200 years, though overall climate change attitudes were small and statistically insignificant. Some academics have proposed that science curriculum are polarizing, which this experiment found little support for. Despite small sample size and inability to establish statistical significance, participants who identified as politically conservative were typically more likely to believe climate change is real after receiving the curriculum. This suggests that interactive graphs could aid in challenging climate change skepticism and should merit attention from educators charged with designing science curriculum for students, though more research must be conducted.

KEYWORDS

global warming skepticism, science communication, belief revision, attitude change, climate literacy

INTRODUCTION

Anthropogenic global warming[1] (AGW) is a serious 21st century public health concern (Azfal 2007). Though the American media reports significant scientific disagreement over the existence and importance of climate change (Siegal 2015, Fox News 2016), actively publishing climate scientists reporting on this debate are in 97% agreement global warming (GW) is real, anthropogenic and alarming (Anderegg et al 2010). Some scientists disagree over how severe the effects of AGW will be, but it is expected to minimally result in massive biodiversity loss, water scarcity, food scarcity and mass migrations of humans (Kerr 2007, Mayhew et al 2008). Conservative estimates indicate that the global community has ~50 years to curb greenhouse gas (GG) emission rates before these impacts become inevitable and irreversible (Harte and Harte 2008). This means time to take decisive actions is running out, but relevant actors (e.g. big businesses, large nation-states etc.) continue to refuse reductions in GG emissions despite pressure from the scientific community, the international community, and climate vulnerable nation-states (Klein 2015). Due to lack of incentive, relevant actors will not change their behavior until they suffer tangible costs (Gell 2014). These costs can be political (such as not being re-elected for office) or economic (such as losing customers), but either way, it is likely that everyday citizens must be convinced that AGW is a serious issue that demands their attention (Gunther 2015). This requires building public consensus (PC), which can be leveraged to hold major culprits of AGW responsible for uncurbed GG emissions.

With this goal in mind, researchers have investigated how to sway climate change skeptics. One major tool that has been used to challenge climate change skepticism is science communication. There are many pedagogical techniques teachers use to convey scientific information, including but not limited to, statistics, graphs, videos and text. Because it is well established that people learn differently (i.e. visual vs. aural vs. read/write vs. kinesthetic) from one another (Fleming 2001), climate change communication needs to be tailored to every unique type of AGW skeptic (who differ based on education levels, political orientation and religious affiliations). However, given that climate science is complex and heavily mathematical (c.f Alley et al 2007), researchers need to decide not only which tools to use when conveying information,

[1] I use this phrase interchangeably with global climate change, climate change and global warming for the purposes of this thesis, but there are nuanced differences drawn in the literature between these phrases.

but also *which* facts to convey given that their audience is often lay and highly politicized (Hoffman 2012). Thus far, four broad types of science curriculum have been researched as potential tools to build consensus on AGW: (1) teaching the mechanism of AGW through variable length texts and videos (ranging from 35 to 400 words and 25 seconds to 5 minutes) (Ranney and Clark 2016); (2) providing graphical based evidence of temperature changes over time (Lewandowsky 2012, van der Linden et al. 2014, Chang 2015); (3) informing regular citizens about the overwhelming amount of scientific consensus in favor of AGW (Ding et al 2011, Lewandowsky et al 2013, Aklin and Urpelainen 2014); (4) providing pertinent statistics in favor of AGW (Munnich et al 2007, Clark et al 2013). While these approaches are not mutually exclusive, it is likely that the effectiveness of each curriculum depends on the demographic traits of the AGW skeptic being targeted.

One major obstacle to designing comprehensive climate science curriculum is disagreement amongst researchers over the utility of communicating climate science to skeptics (see Kahan et al 2011, 2012 vs. Myers et al 2015, Ranney and Clark 2016, van der Linden et al 2016). An ongoing debate in behavioral psychology is whether curricula such as the graphs used in this experiment are polarizing (cf. Kahan et al 2011). Polarization theory maintains that not only are knowledge based interventions that convey scientific information ineffective (i.e. they don't increase acceptance of AGW), but they are actually counterproductive (i.e. they increase skepticism towards scientists and AGW). If the polarization hypothesis is correct, researchers should stop attempting to build consensus on AGW using scientific information. Some empirical evidence suggests polarization occurs (cf. Kahan et al 2011, Kahan et al 2012), though a growing body of literature (such as the citations above) indicates knowledge is worst case ineffective (not polarizing) and best case very effective at changing people's beliefs (see citations above). This experiment contributed to this ongoing debate by providing another data set to test the polarization theory against.

I further aimed to investigate the effectiveness of various interactive graphical curricula collectively referred to as the "BEX"[2] graph interventions. After being given permission to conduct a data analysis of Chang 2015's BEX graph curricula to determine which of the 10 curriculum tested was most effective at increasing acceptance of climate change (Chang 2015), I

[2] BEX is the name Chang 2015 assigned to the robot who guides the participant through the curriculum, which is available in Appendix B.

created four increasingly shorter curricula and one longer curriculum that allowed me to measure how effectiveness of graphical information changed with respect to curriculum length and content. I hypothesized that short BEX interventions will have a statistically significant change on people's attitudes towards AGW, but there would be a point of diminishing returns, where the curriculum was not long enough to meaningfully impart information to the participant that increased their acceptance of AGW. I also examined how results from the new set of BEX curricula differed based on political viewpoints amongst the sample population. I hypothesized that self-identified social and economic liberalism/conservatism would have a significant impact on how participants processed and reacted to scientific information like the BEX curricula. These hypotheses also allowed me to test whether the graphical curricula were polarizing by seeing if the change in attitude was negative. This experiment provides researchers and policymakers more data on the potential utility of interactive graphs in building the public consensus desperately needed to decisively address AGW.

BACKGROUND

Pedagogical approaches to challenging skepticism

Over the last decade, researchers have tried to challenge and alter skepticism towards evolution and climate change using scientific information. They have designed many methods to accomplishing this goal, but the three over-arching pedagogical approaches have used statistics, graphs, and text. Designing comprehensive, academically suited curricula require understanding which tools (and in what combination) are most effective at conveying science information as well as which facts are most important to communicate to a skeptic. Climate change cognition research intersects with education policy, behavioral psychology and political communication, and it is likely that the ideal curricula will require input from researchers involved in all of these fields. This section provides a brief background on each pedagogical tool currently being used to convey climate change science.

Text based curricula

This approach provides information to participants regarding climate change using words written in text format. Text can be conveyed through numerous mediums, such as essays, articles, poetry, and video presentations, all of which carry their own unique advantages depending on the participant's learning style and demographic profile. Content wise, there are many things a scientist can/should say to a skeptic, and accordingly, researchers have tested the effectiveness of different types of scientific information regarding climate change. For instance, some researchers have focused on conveying the scientific consensus behind climate change (e.g. Ding et al 2011, Lewandowsky et al 2013, Aklin and Urpelainen 2014, van der Linden et al 2016) while others have focused on conveying the mechanism by which greenhouse gas emissions warm the earth (e.g. Ranney et al 2012, Ranney and Clark 2016). Though text based curricula have varied in content, word count, and method of delivery, they have consistently increased AGW acceptance amongst participants, irrespective of demographic variables.

An example of the potential role text based curriculum could play in informing the public and building consensus is howglobalwarmingworks.org, an outreach site started by Professor Michael Ranney and colleagues at UC Berkeley. Using this website and videos that have been empirically tested for effectiveness and accuracy (Ranney and Clark 2016), concerned teachers, activists, and scientists can show skeptics the scientific mechanism behind climate change. Depending on available time and interest, the viewer can choose between explanations ranging from 35 to 400 words and/or videos ranging from 30 seconds to 5 minutes. Ultimately, text based approaches have been repeatedly proven as effective tools in increasing consensus on AGW.

Stats based curricula

Another approach to science communication has focused on the potential effectiveness of providing statistical data that highlights the reality of global warming (Munnich et al 2007, Clark et al 2013, Lewandowsky 2013, Ranney and Clark 2016). Some of these experiments have also tested for reverse causality by giving participants misrepresentative statistics that conclude climate change is not real to see if people would be swayed into believing climate change is a hoax (Clark et al 2013). Using data to communicate information is a well researched strategy and has been well encapsulated using the numerically driven inference (NDI) paradigm (Munnich et al 2003, 2005 and 2007, Garcia et al 2004). NDI establishes that when participants receive statistical data that is significantly different from their original estimate, they are shocked and often reconsider their prior views. Experiments conducted thus far have found participants increase their acceptance or denial (depending on if statistics were pro GW or anti GW) in response to the science curriculum, indicating that this approach has great potential to generate public consensus (and can thereby be manipulated to challenge it).

Graph based curricula

This pedagogical approach utilizes pictures, usually in the form of interactive graphs, to convey the alarming change over time in temperature and climate since the industrial revolution (Lewandowsky 2011, van der Linden et al 2014, Chang 2015). Graphical information tends to be more effective when the participant is forced to interact with the data provided (Ancker et al 2009), e.g. asking participants to interpret results, extrapolate future data points, and pick out the differences between different types of graphs. In fact, graphs are sometimes utilized by climate deniers to show that the uptick in temperature since the industrial revolution (i.e. since ~1880) is merely part of a natural environmental cycle. Therefore, using more precise graphs could be a powerful way to show lay citizens how alarming the temperature fluctuation has been over the last 150 years. However, this approach has not yet been extensively vetted as a means of addressing climate change skepticism, which is why I hope to contribute valuable data and information on the potential utility of this method in tackling climate skepticism.

EXPERIMENT DESIGN

The 6 curricula I designed each consisted of 4 parts and took, on average, 14 minutes to complete. Participants first received a pre-test that measured their attitudes towards AGW and related topics. Participants were then randomly assigned one of six BEX curriculum, which were developed using the methodology below. Next, participant's received a post-test identical to the pre-test, which was used to evaluate what, if any, effect the curriculum had on climate change attitudes. Lastly, participants were given an optional demographic survey.

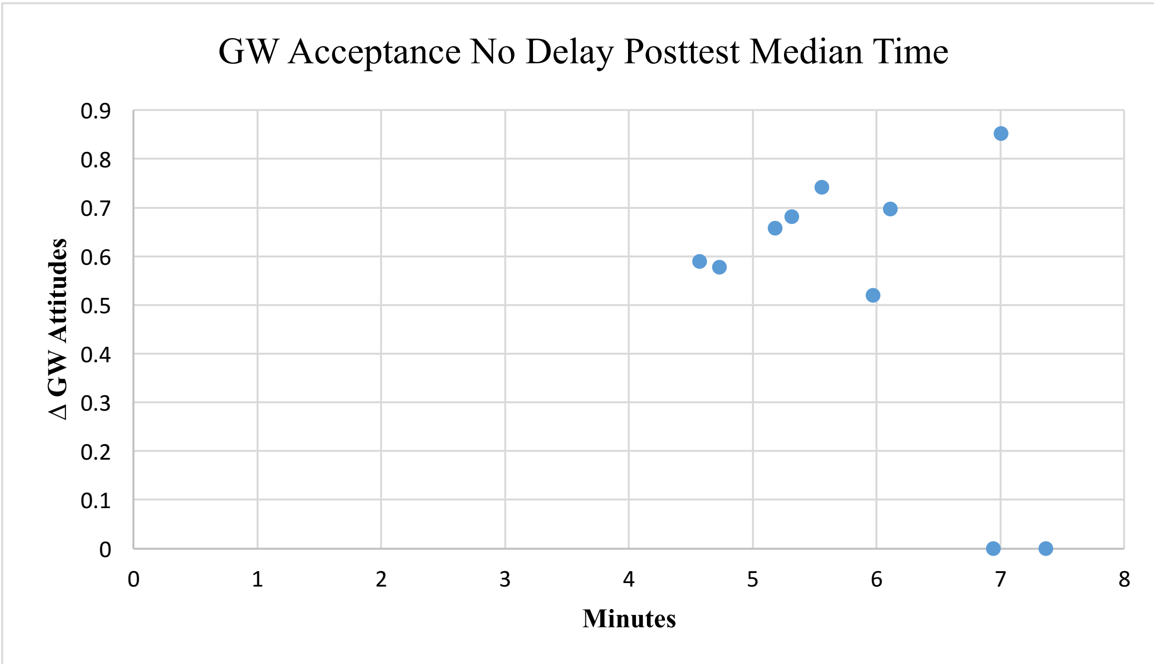
Analyzing 10 previously used graphical curriculum

Spearheaded by Professor Michael Ranney and Charles Chang, the Reasoning Group at UC Berkeley created 10 graphical curricula in 2015. The graphs were given to 732 participants on Amazon's Mechanical Turk (Mturk), an online marketplace for survey research (Chang 2015). I started my experiment by doing data analysis on the 10 curricula ran by Chang 2015 to see which curriculum was the most effective at altering climate change attitudes. This required first calculating the average time spent on each curriculum, which resulted in the following data (Table 1).

Table 1. Analysis of Chang 2015 Graphical Curricula. First step of data analysis was to calculate time spent per treatment intervention (i.e. curriculum). See Appendix A for description of curriculum acronyms.

Curriculum	Required Time	Average Time	Median Time	Minimum time	Δ Global Warming Acceptance Pre to Immediate Post test	Global Warming Acceptance Pre to 9 day delayed Post test
BFO	4.53	9.20	7.36	5.06	N/A	N/A
BFS	4.53	8.63	7.00	5.02	0.852	0.715
BFSN	4.53	8.93	6.94	4.88	N/A	0.48
MFS	3.57	7.07	5.97	3.89	0.520	0.615
MPS	3.17	6.01	5.18	3.47	0.657	0.568
MPSE	3.17	6.67	4.73	3.37	0.577	0.510
UFS	4.53	8.53	6.11	4.53	0.697	0.736
AFS	3.57	7.40	5.56	3.88	0.741	0.482
APS	3.17	7.07	5.31	3.45	0.681	0.451
APSE	3.17	6.33	4.57	3.38	0.589	0.445

Each condition had roughly 70 participants. Median time was used to analyze which condition caused the largest change (Δ) in GW attitudes in the shortest amount of time. Average time is the measure most frequently used to compare change in attitude, but I decided to use median time instead. Because Chang 2015 was run on an internet platform (i.e. Mturk), many people took random, unexpected breaks while completing the experiment, skewing the average and making the median a more reliable measure of the 50th percentile.



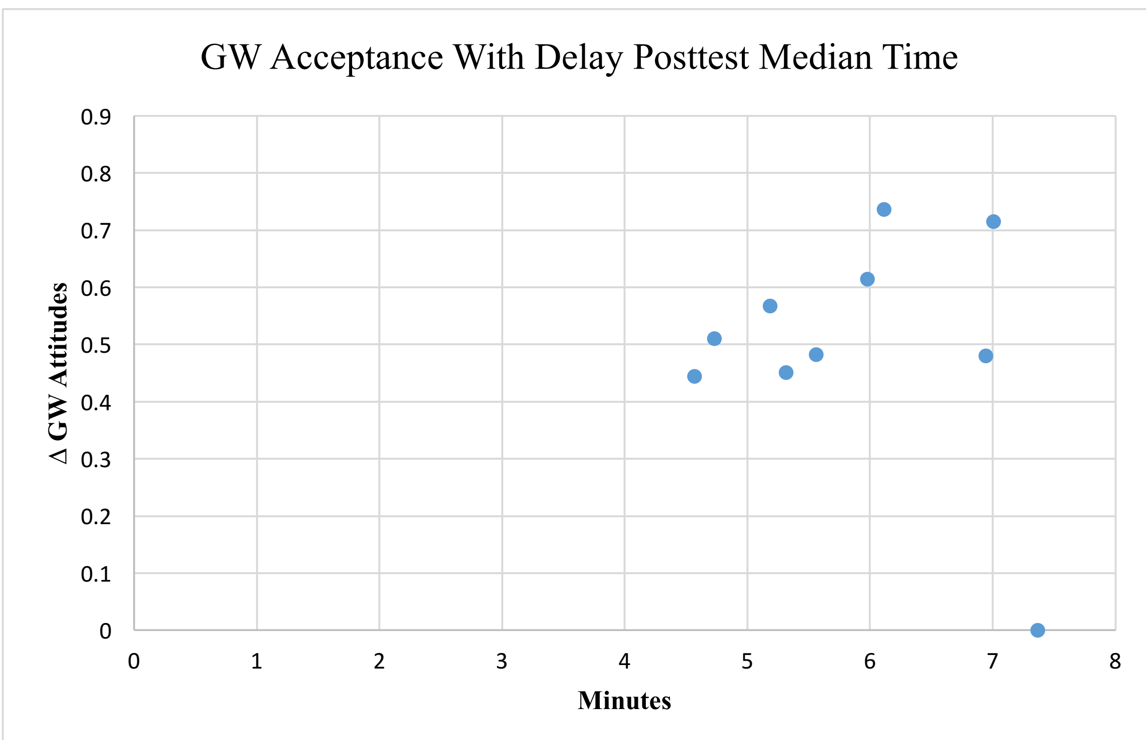


Figure 1. **Scatter Plots for median time spent on each curriculum of condition versus ΔGW Acceptance.** Delay post test was nine days post intervention, no delay post test was immediately after intervention.

Some curricula changed GW attitudes more quickly (in terms of time) than others (Figure 1). The end goal was to discover which graphical intervention increased AGW acceptance the most in the shortest amount of time. Thus, the next step of the data analysis was to find the slope of each curriculum as a function of time and AGW acceptance (Table 2 and 3).

Table 2: Slope for Median Length of Experiment vs. Change in GW Immediate Posttest. Participant acceptance of AGW per minute was equal to slope of median time and ΔGW pre to post test.

Curriculum	Median time of participants (Minutes)	Global Warming Acceptance Pre to Post (No Delay)	Slope
BFO	7.36	N/A	N/A
BFS	7.00	0.852	0.122
BFSN	6.94	N/A	N/A
MFS	5.97	0.52	0.087
MPS	5.18	0.657	0.127
MPSE	4.73	0.577	0.122
UFS	6.11	0.697	0.114
AFS	5.56	0.741	0.133
APS	5.31	0.681	0.128
APSE	4.57	0.589	0.129
Correlation		0.643	

Table 3: Slope for Median Length of Experiment vs. Change in GW with 9-day delayed post test. The slope established how much ΔGW acceptance participants experienced per minute of the intervention.

Curriculum	Median time of participants (Minutes)	Global Warming Acceptance Pre to Post (With Delay)	Slope
BFO	7.36	N/A	N/A
BFS	7.00	0.715	0.102
BFSN	6.94	0.480	0.069
MFS	5.97	0.615	0.103
MPS	5.18	0.568	0.110
MPSE	4.73	0.510	0.108
UFS	6.11	0.736	0.120

AFS	5.56	0.482	0.087
APS	5.31	0.451	0.085
APSE	4.57	0.445	0.097
Correlation		0.539	

Increase in participant acceptance of GW acceptance (on a 1-9) per minute of each curriculum was measured using the slope values (Table 2 and 3). For example, MPS = 0.127 (Table 2) suggested that each minute of the MPS curriculum increased participant acceptance of GW by 0.127 points on the 1-9 Likert scale. On the immediate post-test, the curriculum labeled AFS was most effective (i.e. had the steepest slope, followed by APSE, APS, and MPS (Table 2). Note that BFO and BFSN had no slope values because the conditions had no immediate post-test (part of Chang 2015's experiment design, Appendix A), so change in GW attitude could not be measured. The correlation coefficient test between Median Time and change in GW Acceptance was high (0.643), indicating inter-reliability between these 2 variables.

On the 9-day delayed post-test, UFS was the most effective condition (i.e. had the steepest slope), followed by MPS, MPSE and MFS, respectively (Table 3). These results support MPS (i.e. Moving Partial Span) graphs as the most effective intervention tested by Chang 2015. The combined slope of MPS with and without a delay was .2364 (.1096 + .1268). This was the highest combined slope out of all the 10 curriculum, and MPS also was the 3rd fastest intervention in terms of medium time. Because I measured effectiveness as maximal change per minute of time, MPS was a clear relative "winner" vis-à-vis other curriculum.

Creating varying lengths of the MPS condition

Once I determined that the MPS curriculum of Chang 2015's study was most effective, I created 5 different lengths of the MPS condition. These new curricula were designed to be roughly 80% (~128 seconds), 60% (~96 seconds), 40% (~64 seconds), and 20% (~25 seconds) the length of the original MPS condition. Additionally, I designed one curriculum that included all of the MPS condition plus two other graphs from previous experiments, which was called the 191+ second curriculum (see Appendix B for details). Thus, the most effective curriculum from Chang 2015 functionally became the control for my experiment, allowing me to test 5 different interventions against the control. Through an iterative editing process, I cut 50-150 words from the MPS curriculum as it became successively shorter in length (Appendix B). This allowed me to test the impact curriculum length had on GW acceptance, which helped determine the optimal graphical approach to conveying scientific information regarding AGW.

Pedagogical approach to curriculum design

I had many ways to shorten the graphical curriculum. Ultimately, I divided the MPS curriculum into 6 components and cut one component every time the curriculum became shorter (Appendix B). The simplest graph curriculum was to show the change in temperature over time since the industrial revolution and ask participants if they thought the temperature was increasing or decreasing. However, graphs seemed to become more powerful pedagogical tools when they were interactive, which forced participants to think more critically about the data they were analyzing. Interactivity can be achieved through many methods. Due to time constraints, we chose the following: (1) providing analogous graphs (Chang 2015 chose Dow Jones Industrial Stock graphs since 1880 as the comparison graph) and asking participants to identify which graph was which (i.e. switch questions); (2) asking participants to extrapolate what the next five data points on the graphs should look like given the trends they have observed; (3) providing participants an objective third party guide as they looked at and processed the various graphs (we choose a robot named BEX); (4) telling participants that some of them have been deceived and received graphs that were mislabeled, and asking them to identify if they were part of that cohort. All of these approaches encouraged participants to delve deeper into the information being provided by the graphs, which allowed me to test how much, and which types, interactivity aided in graphical curriculum.

METHODS

Study System Description

This study was created and distributed using Qualtrics survey software. Qualtrics provided URL links for participants to take the experiment and then aggregated their responses, which were analyzed using Microsoft Excel and R. I received permission to reuse questions from

Chang 2015's pretest, post-test and demographics survey, and designed my own intervention treatment (i.e. the curricula) using the process described above.

I distributed the 6 curriculum amongst a lower division undergraduate class at the University of California, Berkeley during Spring 2016. This class was titled "Intro to Culture & Natural Resource Management", and it was offered through the Environmental Science and Policy Management Program (class code ESPM 50). I received permission to distribute the experiment from Dr. Kurt Spreyer, who taught the class and offered small amounts of extra credit to his students if they participated.

Students had seven days to take the experiment. The class received one in person announcement and two wo email reminders, with phrases such as climate change and global warming deliberately omitted to avoid influencing the participants. I randomized ESPM 50 into six groups using the last three digits of each student's identification number (see Appendix C for details). Each group received a unique URL link to one of the six interventions. Of the 313 students in ESPM 50, 281 students attempted the experiment and 260 completed it (n=260).

Data collection methods

Exclusion Criteria

Questions were included on both the pre and post test to control for participants that did not take the experiment seriously and simply clicked through for extra credit. Specifically, participants were asked "please simply select the number equal to five minus three" and "please simply answer "Mildly Agree" for this item". In total, each experiment contained four catch questions (i.e. two on the pre-test and two on the post-test). Additionally, timers were set on each webpage of the experiment to force participants spent time reading and understanding the information being conveyed.

Measuring curriculum effectiveness

I measured change (Δ) in GW attitudes by measuring the difference in pre and post test GW attitude scores. I used a coding template developed in the Reasoning Group to rate participant knowledge/attitude towards global warming. Each participant was asked 26 pre and post test questions that were identical in content but presented in randomized order. Of these 26 questions, eight were specifically climate change related. The eight climate change questions were averaged to assign an overall GW attitude to each participant. All questions were on a 1-9 scale, where one represented "extremely disagree" and nine represented "extremely agree" (see Appendix D for exact text of questions).

Because measuring climate change attitudes entails interrelated yet different components (e.g. does it exist, are humans responsible, is it concerning), the eight climate change measures, collectively denoted as GWAttitude, were also scored and coded into five sub-categories (Appendix D has details on sub-categories). Thus, I measured the average change in attitude of each participant for a total of six categories: (1) GWAttitude, (2) GWExist, (3) GWExCon, (4) GWAnthro, (5) GWAnCon, (6) GWWill (Appendix D). I tested each category for robustness using paired t-tests, which gave p-values indicating significance. Using these methods, I could test if the curricula increased acceptance of GW. Because I conducted this analysis for each separate curriculum, I was able to test my first hypothesis, i.e. was there a relationship between curriculum length and effectiveness.

Demographic impact on curriculum effectiveness

Participants were asked to complete an optional, 11 item demographic survey at the end of this experiment. I used the demographic information to analyze results based on political orientation. Specifically, participants were asked to self-assess social and economic conservatism on a 1-9 scale, where 1 represented "Very Liberal" and 9 represented "Very Conservative". Though the following measures were not tested for relationships to GW acceptance in this paper, participants were also asked to provide political party affiliation, whether they supported the Tea Party, number of science classes taken in college (including Advanced Placement courses from high school), gender, ethnicity, religious affiliation and to self-assess religious dedication. Due to small sample size (n=280), demographic data could not be analyzed in relation to each treatment intervention. Instead, I analyzed demographic data in relation to all the curriculum combined, treating each participant's ΔGW attitude on the same scale though there were significant differences in each group's treatment intervention (i.e. graphical curriculum).

Polarization theory

Polarization asserts that scientific knowledge is most likely counter-productive at building climate change consensus, especially amongst conservatives. Thus, I tested for polarization using several methods: (1) net change in GW attitudes across all curricula, (2) net change in GW attitudes for each curriculum, (3) net change in GW attitudes for each sub-category of climate change attitude and (4) total change in GW attitudes as a function of social and economic conservatism. The last method in particular allowed me to isolate polarization since I grouped all the conservatives and looked at how specifically they responded to the graphical curricula.

RESULTS

Participants had small (but statistically insignificant) changes in overall climate change attitudes after receiving the BEX curricula (Table 5). Participants also had modest increases in acceptance that the earth was warmer (i.e. the GWExist measure) than it was 200 years ago (Table 6), though these increases were also not statistically significant ($p >> 0.05$). Changes in the other four measures (i.e. GWAnthros, GWExCon, GWAncon, GWWill) were small and insignificant (Appendix E). This population sample had a high starting AGW acceptance (average pre-test score was >7 on a 1-9 scale) and was less likely to identify as conservative on both economic and social issues (Table 7, 8). Amongst participants who identified as conservative on social and fiscal issues, the BEX curricula had modest (but insignificant) increases in climate change attitude and belief that the earth has gotten warmer over the past 200 years, indicating a lack of polarization (Table 9, 10). The notable exception were participants who identified as economically conservative. They experienced a statistically significant ($p < 0.05$) decrease in climate change acceptance, though the power of this statistic was not strong (see discussion for further analysis).

Exclusion results

Out of 281 total participants, 260 completed the entire pre test, curriculum, and post test (Table 4). Of the remaining 260 participants, 48 participants answered at least one of the four catch questions incorrectly, resulting in their exclusion from the dataset (Table 4). Ultimately, the sample size used for calculations was n=212. All but one participant filled out demographic information.

Table 4. Exclusion criteria. Total of 69 participants were excluded from data analysis due to lack of full results or incorrect answers to catch questions.

Condition	25 Seconds	64 Seconds	96 Seconds	128 Seconds	191 Seconds	191+ Seconds	Key	Total Sum of Participants
Starting n =	**46**	**51**	**49**	**42**	**46**	**47**		**281**
N remaining after 1st exclusion	45	41	46	41	43	44	Did participant complete the full experiment?	260
N remaining after 2nd exclusion	38	34	34	34	36	36	Did participant answer the catch questions correctly?	212

Overall effectiveness

The primary measure for effectiveness was ΔGW attitudes, which quantified the average difference of participants from post to pre test on climate change related questions (eight in total).

Table 5. BEX Curriculum impact on overall climate change attitude.

Condition	N=	Δ GW Attitude	Pre Test Ave	Post Test Ave	P value
25 seconds	38	-0.079	7.625	7.546	0.406
64 seconds	34	0.059	7.213	7.272	0.725
96 seconds	34	0.099	7.015	7.114	0.509
128 seconds	34	-0.114	7.224	7.110	0.508
191 seconds	36	-0.052	7.292	7.240	0.751
191+ seconds	36	0.188	7.177	7.365	0.277

Participants had small but insignificant (p >> 0.05) changes in attitude on each curriculum (Table 5). The pre-test average was ~7.2 across all curriculum, which indicated participants already "agreed" climate change was real and anthropogenic prior to receiving the curriculum (Table 5). Because the BEX curricula were geared towards illustrating the change in temperature over the last 200 years, GWExist (which specifically asked about temperature trends over the last 200 years) was also tested for significance.

Table 6. BEX Curricula impact on acceptance that earth has gotten warmer in past 200 years (i.e. GWExist).

Condition	N=	Δ GWExist	Pre test Ave	Post test Ave	P value
25 seconds	38	0.500	7.632	8.132	0.156
64 seconds	34	0.265	6.853	7.118	0.477
96 seconds	34	0.206	6.882	7.088	0.475
128 seconds	34	0.059	7.029	7.088	0.837
191 seconds	36	0.056	7.194	7.250	0.825
191+ seconds	36	0.222	7.167	7.389	0.450

Given that participants already averaged ~7 on GWExist before receiving the pre-test, the increase in acceptance during the post-test was notable. This increase was consistent across all curricula, but was much smaller on the 128 and 191 second curriculum. But, given that the p-values were >> 0.05, these results were non-significant (Table 6). The remaining four measures had small changes in attitude and were not significant, and were thus excluded from the results analysis (see Appendix E for these results).

Political demographic data

The population sample largely self-identified as moderate or liberal on both economic and social issues (Table 7 and 8).

Table 7. Economic Conservatism. 1 represented extremely liberal on economic issues, 9 represented extremely conservative. Percentages represent what proportion of each curriculum identified as 1, 2, 3 and so on.

Curriculum	1	2	3	4	5	6	7	8	9
25	5.26%	7.89%	23.68%	18.42%	21.05%	7.89%	7.89%	2.63%	5.26%
64	0.00%	5.88%	38.24%	11.76%	35.29%	2.94%	5.88%	0.00%	0.00%
96	11.76%	8.82%	17.65%	11.76%	23.53%	11.76%	2.94%	2.94%	5.88%
128	8.82%	5.88%	14.71%	11.76%	32.35%	14.71%	8.82%	2.94%	0.00%
191	11.11%	0.00%	30.56%	13.89%	30.56%	2.78%	8.33%	0.00%	2.78%
191+	5.56%	13.89%	16.67%	19.44%	22.22%	16.67%	0.00%	2.78%	2.78%

Table 8. Social Conservatism. 1 represented extremely liberal on social issues, 9 represented extremely conservative. Percentages represent what proportion of each curriculum identified as 1, 2, 3 and so on.

Conditions	1	2	3	4	5	6	7	8	9
25	10.53%	15.79%	39.47%	10.53%	10.53%	7.89%	5.26%	0.00%	0.00%
64	14.71%	20.59%	44.12%	11.76%	8.82%	0.00%	0.00%	0.00%	0.00%
96	11.76%	14.71%	38.24%	17.65%	8.82%	2.94%	2.94%	0.00%	0.00%
128	14.71%	5.88%	23.53%	23.53%	23.53%	2.94%	5.88%	0.00%	0.00%
191	25.00%	5.56%	41.67%	8.33%	11.11%	5.56%	2.78%	0.00%	0.00%
191+	16.67%	25.00%	22.22%	19.44%	16.67%	0.00%	0.00%	0.00%	0.00%

Not a single participant identified as Extremely Conservative on social issues (Table 8). Less than 10% of participants identified as Significantly Conservative or Extremely conservative on economic issues (Table 7). This population sample was not representative of the average AGW skeptic, who have tended to self-identify as conservative on social and economic issues.

Effectiveness compared to political orientation: analyzing polarization

Results were also analyzed as a function of political ideology. Specifically, participants self-identified social and economic ideology. I tested to see if changes in GW Attitude and GW existence differed based off of how liberal or conservative a participant was (Table 9 and 10).

Table 9. Changes in GW attitudes as a function of political viewpoints on social issues. N was calculated across all curriculum rather than for each curriculum due to small sample size. P-values are based off of paired t-test ran in Python.

Social Attitudes	1	2	3	4	5	6	7	8	9
Δ GW Attitudes	0.03	-0.04	0.05	0.01	0.00	-0.20	1.19	0	0
p value	0.800	0.377	0.420	0.949	0.967	0.702	0.086	0	0
Δ GW Exist	0.24	0.07	0.22	0.38	0.14	0.43	1.33	0	0
p value	0.284	0.807	0.153	0.276	0.750	0.918	0.103	0	0
N=	34	30	74	32	28	7	6	0	0

Table 10. Changes in GW attitudes as a function of political viewpoints on economic issues. N was calculated across all curriculum rather than for each curriculum due to small sample size. P-values are based off of paired t-test ran in Python. Bolded values were significant.

Econ Attitudes	1	2	3	4	5	6	7	8	9
Δ GW Attitudes	-0.04	0.00	0.00	0.08	**-0.70**	0.02	-0.08	0.34	-0.10
p value	0.800	1.000	0.970	0.549	**0.010***	0.808	0.773	0.627	0.84897
Δ GW Exist	0.36	0.07	0.22	0.22	0.14	0.15	0.50	1.50	0.00
p value	0.085	0.766	0.309	0.425	0.579	0.748	0.364	0.235	1.000
N=	14	15	50	32	58	20	12	4	6

There was a significant negative relationship between economic moderates and increased GW attitude acceptance, indicating polarization (Table 10). This relationship was not found for economic moderates on the GW existence measure, and was similarly not found amongst participants who identified as social moderates (Table 9, 10). Polarization was not observed for any other cohort of participants (all negative changes in attitudes were non-significant), and depolarization was observed for several of the participants (i.e. positive increases in attitude and acceptance) who identified as conservative, though these results were also insignificant (Table 9, 10).

DISCUSSION

Policymakers, scientists and educators need to convince the general public that climate change is real and anthropogenic before relevant actors will be pressured into aggressively curbing greenhouse gas emissions (Klein 2015). The results from this experiment substantiate claims that science curricula such as interactive graphs might play a vital role in challenging climate change skepticism (Cook and Jacobs 2014), though the results from this experiment need to be tested further due to lack of statistical significance. BEX graphical interventions resulted in modest to large increases in acceptance that the earth has become warmer over the last 200 years, indicating a lack of polarization (Table 6). However, economic moderates had more negative global warming attitudes after receiving the graphs, which polarization would predict (Kahan et al 2011) (Table 10). It is likely that this result was not replicable and due to random chance as opposed to polarization, making my results largely inconclusive on the polarization debate.

The impact of experiment design on ∆AGW attitudes

I found that length of graphical curriculum mattered depending on which type of climate change attitude measure was analyzed. For instance, when analyzing overall change in climate change attitude, the longest curriculum was most effective at increasing acceptance (Table 5), though the second longest curriculum was not the next most effective curriculum, indicating this conclusion may not be robust. However, when analyzing specifically the acceptance that earth has become hotter over the last 200 years, the shortest and simplest curriculum caused the largest increase in acceptance, contrary to the diminishing returns hypothesis. Psychological research indicates that simplest explanations are sometimes most effective at conveying complex information (Hargie 1986). However, it is also possible that simplest explanations are most effective when measured simply, which is what ∆GWExist (one question) does, especially compared to ΔGWAttitude (eight questions). Ultimately, this experiment does not have enough robust data to come to meaningful conclusions on this topic, though future studies using these curricula could provide valuable insight. Deciding the length of the curriculum is important to optimally communicating scientific information on climate change, since it directly influences the quantity and quality of content presented to the participant by educators.

This experiment was also designed to test the added value of each phase of the BEX Curriculum. The control experiment (which was the optimal experiment ran in Chang 2015) in this study had 6 phases: Introducing BEX, DJIA Graphs + Rating, Temperature Graphs + Rating, Differentiation, Extrapolation and Switch (Appendix B for description of each phase and accompanying questions). Phases of the graphical curricula differed in pedagogical approach. For example, extrapolation graphs forced participants to plot how temperature would change in the future whereas differentiation questions forced participants to identify if they could tell the difference between DJIA and Temperature graphs. Temperature and DJIA rating questions forced participants to process the information from the graphs and summarize results using Likert scales. Specifically, I was interested in testing the added value of providing participants an objective guide for the graphs (i.e. the BEX Robot), extrapolating future data points on climate change graphs, and comparing climate change graphs to similarly trending stock market graphs. But, due to small sample size and selection bias (i.e. UC Berkeley students were not skeptical of climate change), results did not provide relevant insights on the value of each phase. However, it is clear that, at minimum, even amongst UC Berkeley students, simply providing participants the graphical data of temperature from 1880 onwards and asking them to identify how it has trended is sufficient to cause modest increases in acceptance that climate change has indeed occurred in the past 200 years. This indicates some types of graphical curricula may be more effective at challenging skepticism than others.

BEX Demographics and Polarization

The curriculum effectiveness depended in part on the demographic profile of the participant. It is well established that climate change attitudes are not formed in a vacuum (Silverstone 1995). They are often influenced by political viewpoints (Bedford 2015), since each political party has self-serving agendas that are not always consistent with scientific beliefs

(Padolsky 2006, Krosnick and MacInnis 2015). Participants who identified as fiscally or socially conservative were less likely to initially believe in climate change, even at UC Berkeley. However, even the most skeptical UC Berkeley student still averaged above a 5 (on a 1-9 Likert scale) on the climate change measures, which indicated that UC Berkeley is not a good study site to observe how climate change skeptics respond to information like the BEX graphs. Additionally, decreased pre-test acceptance of climate change as conservatism increased suggests that perhaps political views supersede other relevant demographic variables like education status when it comes to belief formation on the climate change debate. This is consistent with findings that climate change skeptics tend to identify as politically conservative, even when highly educated (Olsen 2014). Ultimately, demographic data from UC Berkeley confirmed that university settings are not the ideal place to test the effectiveness of science curricula like mine (Sear 1986).

Despite the inherent limitations to the data set, conservatives in this data set were typically more convinced by the BEX curricula compared to their liberal counterparts (Table 9 and 10), indicating a lack of polarization. The major exception to this was participants who identified as moderates on economic issues (Table 10). They experienced a –0.7 decrease in accepting climate change (on a 1-9 scale) after receiving the BEX Curriculum, which could be explained by polarization. However, there are at least two concerns with polarization driving the decrease in acceptance for moderates. First, statistically significant decreases in acceptance were not observed with participants that were more conservative than moderates, which should have occurred if polarization was the causal factor behind the -0.7 decrease. Second, the net effect of the interventions was consistently positive (albeit by small amounts and statistically insignificant p-values), which would not have occurred had the curricula been polarizing. Ultimately, this experiment points to the need for continued research on the polarization debate. It is also possible that graphs such as the BEX curriculum must be combined with other effective curriculum, such as statistics, metaphors and mechanistic knowledge, to better measure whether polarization occurs.

Limitations

First, participants were UC Berkeley undergraduates, who were not representative of the United States population (Sear 1986). The average global warming skeptic is less educated and more conservative than this population sample, which helped skew the results presented above. Because most participant's started at a seven on the 1-9 scale used to measure climate change acceptance, a ceiling effect could explain the small change in attitudes from post to pre test. This was compounded by a small sample (~35 people per condition). Second, asking participants to answer climate change questions on a 1-9 scale may have skewed results. Some researchers argued that a 1-9 Likert scale makes it difficult for participants to differentiate exactly where they fall on the scale for any given topic, especially compared to a 1-5 scale (Krosnick and Fabrigar 1997). This could mean that participants could have been increasing their post test average by one to two points, given the minute difference between a 7 and 8 on this experiment. Others have argued that measuring changes in environmental attitudes is not a good proxy for how individuals will behave (Kaiser et al 1999), which means the applicability of this experiment to building public consensus may in hampered.

Future directions

Future studies on interactive graphs will be strengthened by using a nationally representative sample. Combining these BEX curriculum with other empirically tested curriculum (such as videos, statistics, etc.) would provide valuable insight into how mixed curricula approaches change attitudes towards AGW comparatively to non-mixed approaches (Desanctis and Jarvenpaa 1989), since some educators suggest that people often need to see the same information in multiple ways to learn the info well (Bybee and McInerney 2015). This will require time and effort—it is possible that every combination of pedagogical tools will have to be tested to try and find the comparatively most optimal curriculum for each type of skeptic (e.g. the educated skeptic vs the uneducated skeptic, the politically zealous skeptic vs. the apolitical skeptic, the religious skeptic vs the non-religious skeptic and so on). This will be challenging because it is hard to find population samples who are simultaneously skeptical of climate change and willing to learn about the science of climate change

Broader Implications

This experiment advances research in climate literacy and science communication. Specifically, this experiment provides more data on the ongoing debate over the potential for polarization from scientific information. Additionally, this experiment helps further the empirical data on interactive graphs as a tool for challenging climate change skepticism. It is likely that climate change communication through a variety of tools, including graphs, can challenge skeptics to reconsider their opinions and attitudes on climate change. The key question moving forward is which, if any, permutations of pedagogical techniques are most effective at challenging skepticism. Hopefully, such curriculum can play a vital part in convincing climate change deniers that their views are premised on suspect science and addressing anthropogenic climate change should become a top international and domestic priority.

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APPENDIX A: Explanation of Chang 2015 Intervention Conditions

Variables tested—

(1) Effect of giving span vs moving average graphs
(2) Effect of including all 1 year, 4 year, 8 year, and 16 year averages for temperature and Dow Jones Industrial Average (DJIA) or only including the 1 and 16 year averages
(3) Effect of misidentifying temperature and DJIA graphs, and asking participants if they can identify which graph is which
(4) Effect of including an extra pre test asking for extrapolation
(5) Effect of including no pre test
(6) Whether the knowledge “sticks’ with participants after a few days, as tested through a delayed post test

Condition acronyms—

BFS = Full BEX Experiment, with pretest, intervention (including all span and moving graphs), posttest, and delayed posttest
BFO = Full BEX Experiment without pretest
UFS = Full BEX Experiment where the temperature and DJIA graphs are misidentified and switched
MFS = BEX Experiment with all moving graphs, no span graphs
MPS = BEX Experiment with partial moving graphs (only 1 and 16 year averages included), no span graphs
MPSE = BEX Experiment with partial moving graphs (only 1 and 16 year averages included) and expanded pretest asking participants extra extrapolation and differentiation questions
AFS = BEX Experiment with all span graphs, no moving graphs
APS = BEX Experiment with partial span graphs (only 1 and 16 year averages included), no moving graphs
APSE = BEX Experiment with partial span graphs (only 1 and 16 year averages included) and expanded pretest asking participants extra extrapolation and differentiation questions
BFSN = Full BEX Experiment without an immediate post test

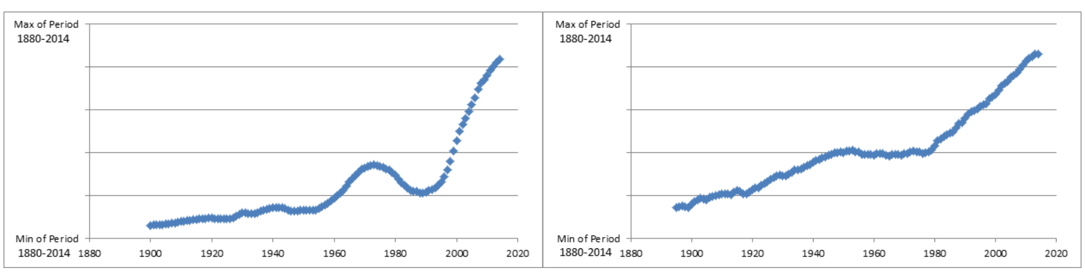

Figure 2. Examples of moving average graphs provided to participants as part of the BEX curriculum. Graph on the left is Dow Jones Industrial Average 16-year moving average since 1880’s. Graph on the right is 16-year moving average of Temperature as recorded by NASA since 1880. Example questions that incorporated such graphs included (depending on the curriculum design):

- how is each graph trending?
- which graph is stock and which is temperature? This question is asked near the end of the curriculum once participants have seen and learned about both graphs.
- extrapolate the next 30 years of expected data points for each graph

APPENDIX B: Pedagogical Design of BEX graphs

Figure 3. **Design of different BEX Curricula.** 191 Second Original was identical to MPS version of Chang 2015's experiment. The following is a description for each question stem:

- Questions labeled DJIA or Temp rating asked participants to answer if they thought the trend on the respective graph was increasing, decreasing or staying the same using a 1-9 scale of confidence (9 being extremely increasing and 1 extremely decreasing).
- Extrapolation questions asked participants to plot the next five data points (which corresponded to 20 years, i.e. 2015-2035).
- Differentiation questions asked participants to identify which graph was Earth Temp and which was DJIA
- Switch questions asked participants to determine if we had switched their graphs without telling them or if we had correctly labeled each graph

APPENDIX C: Randomization of ESPM 50

Table 11. Randomizing ESPM 50 Class List. UC Berkeley undergrads are given eight-digit Student Identification Number. We randomized the class list by asking students to click on a corresponding survey link to their last three SID digits, which provided the following N for each condition

# participants	last 3 digits
53	0-139
53	140-333
53	334-496
53	497-662
53	663-819
54	820-999

APPENDIX D: Measuring Climate Change Attitudes

Table 12. Breakdown of Climate Change Measure. Participants were asked these questions on both the pre and post test. We measured the change in attitude (and thus the curriculum's effect) using the difference between the averaged post-test score and pre-test score for each participant.

Exact language on Qualtrics	Sub-Categorization
Human activities are largely responsible for the climate change (global warming) that is going on now.	Anthropogenic
Global warmings or climate changes, whether historical or happening now, are only parts of a natural cycle.	Anthropogenic
If people burned all the remaining oil and coal on Earth, the Earth wouldn't be any warmer than it is today.	Anthropogenic
I am confident that human-caused global warming is taking place.	Anthropogenic
I am concerned about the effects of human-caused global warming.	Anthropogenic + Concern
I would be willing to vote for a politician who believes human-caused global warming doesn't occur.	Willingness
Global warming (or climate change) isn't a significant threat to life on Earth.	Existence + Concern
The Earth isn't any warmer than it was 200 years ago.	Existence

These questions were prefaced with the following text: "Please respond to the following items by indicating the degree to which you agree with each statement-by selecting a number on the 1 (Extremely Disagree) to 9 (Extremely Agree) scale below.

Please answer honestly regarding your true thoughts and beliefs. We underline words that might be easy to misread like "not" and "don't", but please be sure to read each item carefully."

APPENDIX E: Data on remaining climate change measures

Table 13. Unreported changes in climate change attitudes posttest to pretest. Climate change attitude was comprised of six measures (Appendix D), two of which were broken down in the main paper. The remaining four are presented here. Significant results are bolded.

Condition	N=	Δ GW Attitude	Δ GWAnthros	Δ GW ExCon	Δ GWAnCon	Δ GWWill
25 seconds	38	-0.079	-0.178	-0.184	-0.132	-0.105
64 seconds	34	0.059	0.007	0.118	-0.029	0.088
96 seconds	34	0.099	0.147	-0.118	0.235	-0.118
128 seconds	34	-0.114	-0.162	-0.382	0.088	-0.029
191 seconds	36	-0.052	-0.104	0.389	-0.194	-0.250
191+ seconds	36	0.188	0.167	0.028	0.250	0.333
Sum		0.017	-0.020	-0.025	0.036	-0.013