Drawdown

Using Data Visualization to teach complex concepts in climate education

Philip Bell*

Harvard University

ABSTRACT

Climate breakdown is complex and cognitively taxing to understand. Interactive data visualization can help address this challenge. This article explores how visualization can help balance the trade-off between cognitive effort, complexity and cultural salience which is inherent to understanding climate breakdown. The overall aim of the project is to design a website that students can use to learn about climate breakdown. Having worked as a teacher for five years, including organizing global conferences and initiatives on climate education, I felt that there is a surprising lack of resources to teach the complexity of climate breakdown. This project is designed to fill that gap.

Keywords: climate breakdown, education, IPCC, Drawdown.

1 INTRODUCTION

A dominant framework in the domain of climate education is the criteria of Education for Sustainable Development (ESD) 1, 2 and 3 [2]. Level 1 constitutes simply gaining knowledge of sustainability, level 2 involves developing a critical faculty for analysing sustainability information and level 3 constitutes cultivating a reflexive capability to adapt to changing information as sustainability research changes. Much climate education is designed ESD 1, however this project aims to support insights at the level of ESD 2, and possibly ESD 3 [1]. Specifically, this project draws on insights and research from education science, social psychology and data visualization in order to communicate the historical trends in temperature change, IPCC temperature projections under two scenarios and solutions.

2 RELATED WORK

2.1 Climate Visualization

Visualizing climate change data involves a precarious balance between communicating the terrifying urgency of the situation, and being faithful to the uncertainty inherent in climate forecasting. Goudine et. al. addressed this challenge with the Climate Visualizations for Adaptation Products (CVAP) framework [2]. It sets out a multi-dimensional approach, balancing the 'interactivity', 'realism' and 'risk' in visualizing climate breakdown data. Another important attempt to communicate climate reality, while maintaining uncertainty, is the 'warming stripes' visualization by Ed Hawkins. His stated ambition was to provide as simple as possible a visualization of the warming climate without using axes or labels [3]. The SENSES project, carried out by multiple teams from the University of Potsdam and across European Universities, has also pioneered work on visualizing climate projects, including developing an app that allows exploration of different climate scenarios in augmented reality. Their critical insight is that 'Climate Change Scenarios are not predictions of the future, but rather projections of what can happen by creating plausible, coherent and internally consistent descriptions of possible climate change futures.' [4]

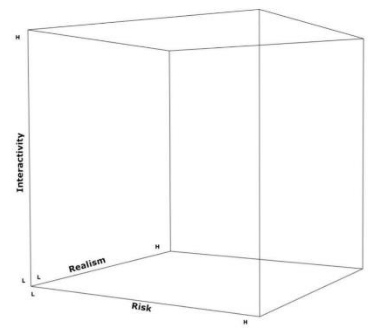

Figure 1: Goudine et. al.'s CVAP framework.

2.2 Climate Communication

Significant research on climate communication within the social psychology community points to the cultural barriers to people understanding climate breakdown. The social Psychologist Per Espen Stoknes has noted that the most serious barriers are 'doom', 'despair', 'distance', 'iDentity' and 'dissonance' [5]. Dan Kahan from Yale University has singled out identity as the critical aspect that mediates Americans' understanding of climate information. In fact, he even argues that 'climate literacy' increases one's chances of being a climate skeptic.[6] As Anthony Leiserowitz and others at the Yale Centre for Climate Communication have pointed out, however, this argument is contingent on a narrow definition of 'climate literacy' (which is more skin to ESD 1 described earlier in this paper).[7] Indeed, this project is designed to broaden this conception of climate literacy using data visualization in the aim of ensuring that climate literacy aimed at ESD 2 or ESD 3 can support a more complex and nuanced understanding of climate breakdown.

2.3 Narrative Visualization and education

Agency

3 METHODS

The overall approach to this challenge follows Munzner's thinking process of characterizing he domain of the problem, abstracting data, encoding techniques and finally algorithm design. [13] Indeed, in order to inform the design of this project some informal usability studies were carried out with students and teachers.

3.1 Problem Domain

The overall domain of the problem is climate education. In order to reduce cognitive load, especially when interactivity is involved, an 'interactive slide-show' approach to narrative visualization was adopted (rather than another form of narrative visualization which requires more cognitive load), according to Segel's framework of narrative genres. [8] Indeed, critical to the sequencing was the titles of each visualization, which were designed to weave a coherent path through the different datasets that were visualized. As Hullman has noted, titles are critical for situating the narrative of the visualization. [9] The text introducing each visualizations aims to be both motivating and providing a coherent and clear explanation of the links between the visualizations.

3.2 Data

Multiple datasets were used to visualize different aspects of climate breakdown. NASA historical emissions data were used to visualize past climate change, Our World in Data was used to visualize which sectors most contributed to emissions, IPCC scenario data was used to visualize projected temperature rises and Drawdown data was used to visualize the impact of potential solutions.

Due to the large numbers of datasets used there were also multiple data transformation decisions taken. One example is the use of average annual temperatures in the 'climate stripes' and temperature projections map visualizations and plotting over 100 years, rather than a shorter timeframe. A second example is the use of annual CO2 sequestering estimates from the Drawdown solutions data, rather than the total sequestering by 2050. The reason that annual data was more appropriate in this instance was so that users were able to understand how much sequestering can take place in the short time-frame that is necessary to address climate breakdown.

3.3 Overcoming Complexity in Temperature Data

Two visualizations were explicitly designed to support learners to better understand climate breakdown. Firstly, a climate stripes visualization was used to situate the historical warming trends in perspective. Normally a line chart is used to encode warming temperature data, partly because of the perceptual dominance of the positional encoding channel. Therefore, it is possible that this is not the perceptually optimal encoding choice, and this is an example of a significant trade-off being made in the design space for this project. However, there is some evidence to suggest that using hue in this instance is a particularly striking and memorable way to encode a warming climate, and therefore address the 'realism' dimension of climate breakdown understanding. [3] However, this has not been rigorously tested, and therefore it would be useful to directly compare the use of positional encoding compared to colour in future. Indeed, from informal user studies I found that some students fail to understand what the visualization is without more contextual detail (such as axes. Therefore, axes were added and users can interactively retrieve the temperature at each year, which further reinforces the fact that the stripes are visualizing temperature. Indeed, a benefit of the visualization is that it clearly shows the complexity of climate breakdown (the temperature does not increase uniformly) but at the same time it communicates the overwhelming nature of the temperature rise. Therefore, through providing more support via axes, titles and interactivity this visualization is aimed to better help users with understanding the complexity of the data, yet maintaining the striking increase in warming trends. Though hue is not the most effective encoding channel for warming, in this instance it provides a striking aesthetic experience for the user and evokes curiosity. Therefore, with the added affordances described, this visualization is designed to overcome the complexity of understanding past temperature data.

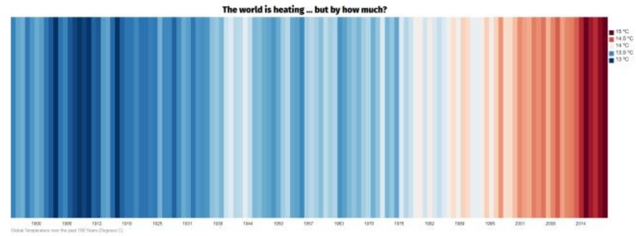

Figure 2: Interactive Climate Stripes

Climate modelling is contentious and complex. In order to provide some insight into the fact that future warming is contingent (as the SENSES project has clearly demonstrated is critical to climate breakdown understanding) two separate IPCC scenarios were provided in the climate effects map. This is two of the four SRES 'storyline scenarios' created by the IPCC.[10] Indeed, although the full complexity of the four separate scenarios is not visualized, it is hoped that by providing two separate scenarios, and also by providing users the ability to toggle between 20,40 and 60 years future warming, will allow users to gain a more nuanced insight into the contingency of warming projections. In order to contextualize the warming, annotations are added, which provide narrative information about the warming, while users can mouse over different degrees of warming. Secondly, by allowing to the user to look at temperature countries on a country-by-country basis using a tooltip may allow users to more easily insert themselves into the narrative of the data.

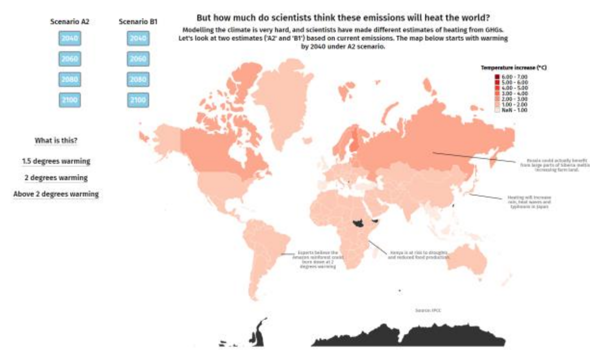

Figure 3: Two Scenarios of Warming

3.4 Addressing Cultural cognition

In an attempt to make users more aware of their priors, a 'You draw it' style chart was used to allow users to consider their own initial guesses of which industries contribute most to climate breakdown. Initially I considered using this technique to elicit users' priors on temperature rise, however I decided that where emissions comes from is more culturally loaded. Specifically, people who are vegan may think that agriculture contributes a greater proportion, while people who are car-users might not initially assume that cars play such a large role in generating emissions. Indeed, the aim of this visualization is to allow users to consider their own biases in terms of the causes of climate breakdown in the anticipation that considering one's biases will more likely allow the user to think about this topic in a nuanced way. Indeed, Hullman, taking a Bayesian approach to modelling how users gain graphical inferences, argues that users may update their beliefs more after perceiving the uncertainty in their own priors. [11]

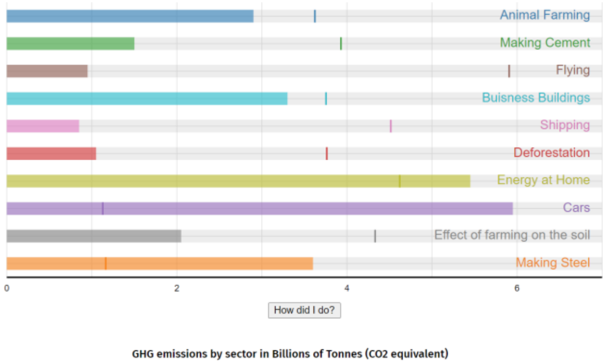

Figure 4: Obtaining priors about who is to blame for climate breakdown.

3.5 Overcoming Doom

Educational research and social psychology research converge in observing that agency and self-efficacy are critical for people to be able to overcome the barriers of 'doom' and 'dissonance' which can prevent a nuanced understanding of climate breakdown. [5][12]

In order to support this, Drawdown solutions data was visualized in two steps, to support students to gain insights while reducing cognitive load. The first step is for students to explore the solutions, and learn about them using a circle-packing visualization. Circle packing is not the most effective form of visualizing data if you want to be able to very clearly identify the precise values of a particular solution, but it is a useful way to visualize the relative impact of different solutions. Size was used to encode the amount of Greenhouse gas that could be sequestered due to the dominance of size as a perceptual encoding channel. Indeed, this provides some pre-attentive support to the user to contextualize and begin to categorize solutions, which they would not be receiving from a table of solutions. Another reason circle-packing was used was so that users could get an idea of broadly which sectors of solutions would be most impactful before 'drilling down' into the details of the visualizations. They can access these details 'on demand' through the tooltips. Indeed, this is due to the complexity of the data. I initially thought that the tooltips were too distracting, however from the informal user studies I gained feedback that the tooltips were useful to understanding the solutions, especially the more obscure ones. Indeed, the solutions themselves are obscure and have complicated non-obvious names. Therefore, simply presenting the solutions may be overwhelming and, since this data is hierarchical, it is useful to cluster the solutions into groupings of the sectors. Thus, when users drill down into the definitions of each sector using the tooltips, they already have some contextualized knowledge of what domain that solution resides in.

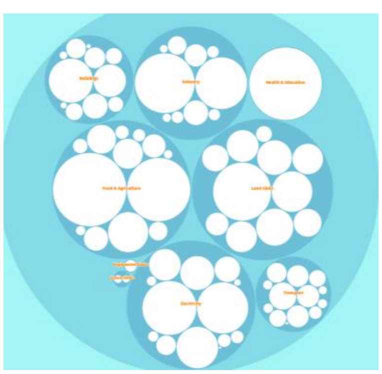

Figure 5: Supporting insights into solutions

This solutions-oriented visualization, which presents a large number of possible ways to reduce climate emissions, is a key aspect of reducing the sense of doom that students might feel about climate breakdown. A second way in which this is addressed is through users actually piling solutions into a solution-space. This directly calls upon the user to show agency in dealing with climate breakdown, and demonstrates through the sheer range of solutions the many options that are available. The amount of Greenhouse gases sequestered is updated as the user inputs solutions into the solution space. Indeed, when this insight is linked to the contingency of possible climate scenarios (established through the map previously) this is aimed at providing the user with a clear sense of self-efficacy for dealing with climate breakdown and addressing the 'doom' barrier Stoknes identified. [5]

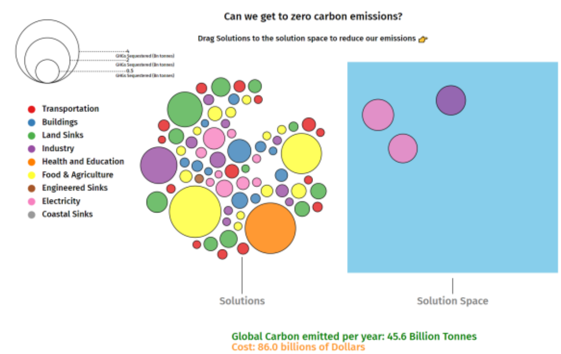

Figure 6: Supporting agency through interactive solutions strategies

4 Results

As mentioned previously, informal user studies were conducted with five users (a mixture of students and teachers) in order to assess whether the users were gaining the desired insights from the data visualizations. While these do not validate the data visualizations, they did provide useful information, and it is possible to draw some tentative insights from them.

4.1 Case Study: Teacher

One case study conducted involved feedback from a teacher using the website. They are prominent educator, and therefore may not be representative of teachers without a strong background in climate education. They noted that they would use this as a resource because of the 'strong scaffolding' and 'interactive' way to teach climate breakdown, especially the focus on a wide range of solutions, many of which are not normally taught in schools. The user elaborated with some flourish that 'the "filling up the solution space" I think phenomenologically transferred the "weight" of the solutions, and how much is needed to course correct climate change.'

4.2 Case Study: Student

Secondly, some students who used the visualization commented that the tooltips on the solutions circle-packing visualization were useful, which informed the fact that they were kept in the visualization. Previously, several pages teaching concepts of the greenhouse effect were included in the website, which were subsequently removed as a result of feedback that they made the experience less cohesive.

5 DISCUSSION

5.1 Advances

Users appeared to find the experience of using the visualizations interesting and informative. Indeed, the use of the 'you draw it' style bar chart was particularly challenging and interesting to the users because it changed their understanding of their own biases, even though most of the users were very knowledgeable about climate breakdown. This does not validate that this is the case, but it does suggest that this is worthy of further exploration. Indeed, some users found the experience of using the map to observe temperature change projections emotional. Seeing the overwhelming nature of the projected rises, alongside the climate stripes shown previously had an affective impact on the users. It therefore may be useful to test this further to measure whether the 'realism' dimension of Goudine et. al.'s CVAP framework was effectively encoded through the map and climate stripes.

5.2 Continuing Challenges

Multiple challenges remain unaddressed by this project. Firstly, the climate stripes visualization only provides global-level data, which avoids allowing the user to understand regional variation. Users expressed surprise that the Northern Hemisphere appears likely to heat more than the Southern Hemisphere. Indeed, therefore there is an incoherence between the climate stripes and the map, which does show global variation. This challenge is made more serious by the fact that the maps showing warming increase do not necessarily show the impact of potential warming. For example, Russia will likely receive more warming compared to Kenya, however the problems raised may still be much more serious for Kenya because it starts from a relatively high baseline temperature compared to Russia. Though I tried to use labels to contextualize the differential effects of different countries, it would have been better to encode the effects of different levels of temperature rises on different areas of life (agricultural production, life expectancy or water access, for example). Secondly, the users focused more on cost than I had anticipated when they were trying to convert solutions into the solution-space. Indeed, this is not necessarily the intended insight because (especially in light of the seriousness of the data presented previously on the website) we might expect the act of reducing emissions should have been the overriding concern of users.

6 FUTURE WORK

6.1 Complexity

The major barrier with supporting users to understand the complexity of the climate change data is assessing what knowledge the user already has about climate breakdown. Therefore, a useful way to achieve this would be to either assess the user, and use this to adapt the visualizations that are subsequently shown to them, or allow them to choose a level of complexity of the visualization journey. Indeed, this is a major pillar of effective teaching, known as 'differentiation'. Secondly, it would be important to visualize the amount of greenhouse gases in the atmosphere (and not just the amount that is being emitted per year, as is shown the solutions to solutions space visualization). Indeed, this would allow students to more clearly see that reducing emissions to zero will still not solve the problem of climate breakdown. Secondly, the extent to which different solutions will impact the overall amount of CO2 in the atmosphere could be more effectively encoded using size, for example by visualizing a bath filling up or being emptied (as in the famous MIT en-roads static visualization). [14]

6.2 Cultural Cognition

In order to increase the amount to which users are open to changing, updating or adopting more nuanced points of view it would be useful to visualize how other users had responded to the 'you-draw-it' style chart.

6.3 Doom

In order to further work on reducing 'doom' it would be useful for users to also explore the action space, alongside the solution space. The current solutions visualizations could be seen as 'solutionism' where solutions are presented but are not clearly associated with political or action-oriented paths to achieving this change.

7 CONCLUSION

In conclusion, it appears that this project provided an attempt to addressing the complexity, cultural cognition and doom barriers to teaching climate breakdown. The visualizations attempt to balance the realistic insights necessary (from the interactive climate stripes and scenarios maps) to really grasp the severity of the climate situation, while also assuaging the doom associated with climate breakdown data through providing interactive and exploratory solutions visualizations. However, there were still severe limitations to the approach. Firstly, users were not conceptually made aware of the total amount of CO2 in the atmosphere, and therefore only a part of the challenge was visualized. Secondly, the difference between the heating in different parts of the world, and the subsequent effects was not drawn out, and therefore users were not supported to develop nuanced insights into the differential effects of climate breakdown. Therefore, more research is needed to address these central challenges in climate communication and climate education.

REFERENCES

[1] W. Scott & P. Vare, Learning for a Change: exploring the relationship between education and sustainable development. *UNECE*, 2009.

[2] A. Goudine, R. Newell and Christopher Bone. Seeing Climate Change: A Framework for Understanding Visualizations for Climate Adaptation. In *International Journal of Geo-Information*, 9, 644, 2020.

[3] E. Dawkins, Climate Lab Book: Open Climate Science, retrieved from http://www.climate-lab-book.ac.uk/2018/warming-stripes/ (2018).

[4] K. Dittrich et. al. SENSES: Visualization and Communication of Climate Change Scenarios. Retrieved from https://uclab.fh-potsdam.de/projects/senses/#:~:text=SENSES%20Visualization%20and%20Communication%20of,by%20using%20advanced%20interactive%20visualisations. [May 2021]

[5] P. E. Stoknes. Rethinking climate communications and the 'psychological climate paradox'. Energy Research and Social Science, 1(2014):161-170.

[6] D. Kahan et. al. The Polarizing impact of Science literacy and numeracy on perceived climate change risks. *Nature Climate Change volume 2,* pages732–735 (2012).

[7] S. van der Linden et al. Culture versus cognition is a false dilemma. *Nature Climate Change*, 7, 457(2017).

[8] E. Segel & J. Heer. Narrative Visualization: Telling Stories with Data. *IEEE InfoVis* (2010).

[9] Visualization Rhetoric: Framing Effects in Narrative Visualization. Jessica Hullman and Nick Diakopoulos. *IEEE InfoVis.* 2011.

[10] IPCC Special Report: Emissions Scenarios, retrieved from https://www.ipcc.ch/site/assets/uploads/2018/03/emissions_scenarios-1.pdf, 2018.

[11] Why Authors Don't Visualize Uncertainty. Jessica Hullman. *IEEE InfoVis.* 2019.

[12] J. Dillon, Communicating global climate change: issues, policy, actions and dilemmas, in *Communication for engagement in Science and Technology*. 2011.

[13] A Nested Model for Visualization Design and Validation. Tamara Munzner. *IEEE InfoVis.* 2009.

[14] Enroads Interactive Visualization, 2021, Retrieved from https://www.climateinteractive.org/tools/en-roads/.