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Climate change cognition and education: given no silver bullet for denial, diverse information-hunks increase global warming acceptance

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Climate change's particular 'perfect storm' problem-nature requires educators and communicators to acknowledge that a *single* 'silver bullet' intervention that eliminates ignorance and denial regarding global warming may never emerge. However, diverse kinds of information-hunks and educational initiatives do *incrementally* increase acceptance (and alarm) regarding climate change, thus decreasing ignorance/denial. We herein describe advances in several climate education realms, including in-school and extra-school youth learning—along with post-school, general public, climate change communications. Our review includes lenses on socio-emotional learning, social justice, and techniques for addressing misinformation. Finally, we describe a particular set of ten hunks of experimentally vetted information, generally taking less than five minutes, that our laboratory has shown effective in boosting acceptance that global warming is occurring and concerning.

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Introduction

It is fitting that this topic resides within the *cognitive science* category, because the phrase 'climate change cognition' was introduced by Ranney *et al.* to the Cognitive Science Society at its 2013 annual meeting (in Ranney *et al.*'s [1] title/talk, and during Clark *et al.*'s [2] presentation, and so on). Even then, climate change cognition was convolved with education, given that our laboratory's budding public-education site, HowGlobalWarmingWorks.org [3] was also introduced at that conference (orally—during Ranney *et al.* [1] and Clark *et al.* [2]).[4] We will return to such public-outreach efforts, but we will begin with a broader pedagogical perspective.

Despite increasing worldwide concern and awareness about climate change (which is, roughly, the set of effects associated with global warming), we must ask: What content from this complex realm should be taught—and how? Climate change is arguably even more interdisciplinary than cognitive science itself, being underpinned by chemistry, physics, biology and geography—as well as the social sciences (e.g. equity notions from psychology) and humanities (e.g. ethics from philosophy). How can we reconcile this 'perfect storm problem' with the formats of typically subject-siloized curricula and suboptimal citizen education? Few laypeople (and only a minority of college teachers) understand even the *basic* physical-chemical mechanism of global warming [4], even though Ranney captured much of it in a 13-word sentential haiku [5, p. 139]:

Global Warming's Mechanism
Earth turns sunlight to
IR light that's sponged by folks'
Greenhouse gases glut.

Learning this mechanism (usually through 400 or more words, for example, see Refs. [4,6•]) yields more science-normative climate attitudes. However, beyond crucially coming to understand that global warming is due to an anthropogenic (i.e. human-caused) greenhouse effect,[5] climate change is difficult to recognize from personal experience. Furthermore, climate change's socio-scientific complexities challenge learners *and* instructors—who approach the topic with varying degrees of understanding, acceptance, and concern.

Although some propose that climate education should focus overwhelmingly on conveying the *science* to learners, there are additional, crucial, elements involved in preparing people to best face uncertain futures—including ways

[4] Regardless of phrasings, Ranney *et al.* [1] were hardly the first to connect climate change and education/cognition.
[5] Global warming is thus due to an *extra* greenhouse effect on top of the effect that preceded burning by humans.

to successfully manage the changing climate's impending risks and impacts. Regardless of how science-intensive it is, an educational intervention generally includes one or more hunks of information, often associated with, or embedded in, attractive learning activities. We intentionally use the rather informal word 'hunk' in this article, rather than 'chunk,' partly because the latter relates more (in cognitive psychology, etc.) to information retrieval and channel limits—as it ubiquitously connotes a set of basic familiar units grouped and stored together in one's (e.g. short-term, '7 ± 2' capacity) memory. In contrast, although curricula can obviously vary dramatically in size, by a *hunk* of information, we mean 'some thematically coherent informative material' that, in scope, is both far from elemental yet also far from comprising an exhaustive treatment of a topic.

The following five sections briefly review realms of global warming psychology and climate change pedagogy. Starting just below, we begin with a focus on youth instruction, before moving on to knowledge-enhancing hunks that are, while accessible to many children, also suitable for the general adult public.

Youth learning outside the classroom

A lack of time and curricular opportunities to address climate change directly in the classroom (among other reasons[6]) have led such educational efforts to be typically addressed rather *informally* [7] and/or in *hybrid spaces* (e.g., school/community gardens), as parts of civic initiatives. The Boys and Girls Club's 'Science, Camera, Action!' after school program, for instance, combines after-school climate change science (including sustainable solutions) with off-site digital photography [8•]. 'In-nature' activities are also common introductions to environmental education, particularly for to preschoolers [9]. Such place-based, participatory, and action-oriented programs have been shown to increase science's relevance for students and improve school science performance [8•,9].

New, expanded forms of citizen science—engaging students in community-based research—increasingly complement such programs inside and outside of classrooms [10,11]). Climate change is also increasingly being introduced to students in explicitly interdisciplinary ways—for instance, as a humanities-curriculum element [12•]. Simulations or video games introducing students to climate change's impacts in familiar formats also represent a burgeoning interest-area [13]. An extension of this gamification approach to inspiring engagement is represented by recent uses of escape rooms to foster climate change learning [14].

[6] Teachers are occasionally inhibited from classroom climate change instruction due to real, or assumed, local socio-political inhibitions (e.g. from parents, students, or administrators).

Although out-of-school programs and game-based approaches introducing climate change are acknowledged to trigger students' early environmental interest, they are limited compared to formal schooling in their ability to support the long-term development of such initial motivations [15]. Recent Next Generation Science Standards (NGSS) reforms address this concern—ostensibly working to bring climate change into the classroom and motivate teachers to promote climate literacy through more active/participatory teaching modes (e.g. modeling and evidence-based explanations [16]). However, some view these reforms as presenting an overly human-centric model of climate change that avoid notable socio-political [17] and environmental justice aspects [18•].

Tackling misinformation in the classroom

An increasingly important objective of climate change education is to foster citizens' reasoned decision-making by providing them the tools to critically evaluate (purported or purportedly relevant) information. Given the highly politicized, 'post-truth' era of climate communication, a classroom strategy gaining ground is to directly address climate-relevant misconceptions [19,20,4] and climate change dissenter arguments [21]. These misconceptions are often introduced alongside refutation texts explicitly addressing them [22,23] or as stimuli for students to prepare evidence-based counterarguments against [24]—given that knowledge revision increases when misconceptions and correct information are co-activated [25,26].

More traditional ways to incorporate climate literacy and instruction involve developing students' evaluative judgments regarding source-trustworthiness [27] and the explanatory power of supportive evidence [28], often through the use of metacognitive prompts or explicitly generated curricula [29; see also Ref. 30]. Related programs target climate literacy through general scientific reasoning, which highlight aspects including the scientific method [31] and critically evaluating connections between evidence and explanations [32].

Emphasizing scientific practices when teaching climate change is additionally advantageous because it can enhance motivation for both students and teachers, with teachers who identify as scientists (and who support pedagogies that model scientific practices, for example, data collection/analysis to generate arguments/conclusions) being more likely to foster students' interests [33]. Rather than detracting from content learning, such instructional scaffolds have been shown to (a) help students think more critically about new information, (b) develop students' epistemic inferences and judgments—thus facilitating knowledge construction and deeper content learning [5,34]—as well as (c) increase student enjoyment and curiosity upon encountering conflicting sources [35].

Socio-emotional and social-justice education

Along with strengthening knowledge and encouraging pro-environmental behavior, there are growing calls for environmental education to meet learners' *emotional* needs, especially as information about climate change's impacts become more salient—and future projections become increasingly overwhelming and concerning. Parents and teachers are often unfamiliar with how to address students' emotions regarding the environment [36], despite the emotions' important roles in learners' coping strategies [37] and subsequent engagement in mitigation actions [38].

Such efforts to address learners' emotions about climate change focus on information and activities that both cultivate resilience and stimulate students' realistic hopes (versus impossible optimism) for the future [39]. Education focused on cultivating students' sense of hope thus typically involves focusing on available, practical, solutions/pathways to sustainable futures [40,41]—a notable challenge, given climate change's 'wicked' nature (e.g. being incomplete, complex, or having no clear or obvious solution) [42].

Another component of educating for hope involves conveying climate change's impacts, alongside the adaption and mitigation strategies used to manage them [43,44]. Solutions or mitigating actions currently covered in classrooms, however, tend to focus on local, tangible, and implementable options [45]—as well as individual, rather than collective, actions [46]. This may lead to overly simplistic understandings of the complex interdependence of global consumption and production networks [47], inhibiting students from considering themselves as active, agentic citizens capable of participating in (or from expressing themselves about) sustainability-related issues. Some believe that hopeful, more socially transformative education should involve explicitly introducing learners to the (largely overlooked, re classrooms) democratic and political challenges of tackling climate change [48]—and cultivating an awareness of the importance of collective, collaborative action [7,49] and civic engagement [50,51].

Relatedly, many theorists advocate for a more transformative, emancipatory, and/or innovative climate change pedagogy. This would engage with, and acknowledge, the largely inverse relationship between the responsibility for, and the impacts of, climate change [52•]—as well as power structures associated with gender, race, and class that affect students' positions as both learners and sustainable actors [53]. Employing a social justice lens to explore climate related issues on both local *and* global scales additionally provides the metacognitive benefit of fostering students' perspective-taking—thus (a) helping them connect their prior experiences/perceptions with others' viewpoints [54] and (b) expanding both the scope of their concerns and their willingness to personally effect more sustainable changes [55].

Scientific, technological, and cultural considerations

Despite a burgeoning educational focus on climate change's more socio-political and emotive aspects, there remains widespread ignorance and misconceptions about the science of climate change (e.g. Ref. [4]) among students [56], teachers [57] and textbooks [58]—which have not sufficiently emphasized human activity as the overwhelming cause of climate change [59]. Some debate exists regarding the utility of facts in climate change education (e.g. Refs. [44,6•]) compared to more value-driven messaging [19]. However, it is clear that a basic understanding of climate change's underlying mechanisms (particularly global warming's physical-chemical mechanism; for example, [4])—*especially* if combined with cultural elements—are important for one to effectively reason about our planet's current transformation [60].

Ranney's [61] Reinforced Theistic Manifest Destiny (RTMD) theory melds six scientific and cultural constructs involving climate change. For instance, RTMD successfully predicted 15 relationships among people's acceptance of global warming and five religio-scientific-political constructs: higher power(s), an afterlife, creation, evolution, and nationalism. Moving beyond RTMD's correlational success into the causal realm, Ranney *et al.* [6•] showed that decreasing Americans' sense of nationalism increased their acceptance of global warming, and that the relationship is bicausal: that is, increasing Americans' acceptance of global warming (through scientific and/or statistical information) *also* decreases their levels of nationalism. In this way, RTMD represents a cultural theory (in keeping with van der Linden *et al.* [60]), even though it (and affiliated paradigms, such as Numerically Driven Inferencing; [5]) has spawned many experiments that show that information can overcome culturally infused intransigence regarding accepting global warming's reality/dangers.[7]

Regarding the communication of science content, technological facilitation (e.g. simulations and computer-based visualizations) provides an increasingly popular way to communicate climate models and climate change's mechanisms to youths (e.g. Ranney *et al.*'s [4] classroom-based Experiment 5). The uptake of such technology partly reflects the data gathering practices of climate scientists [62], but it also enables the use of features such as virtual investigations and interactive feedback that

[7] Veridical information rarely *immediately* and *fully* overcomes cultural influences, although it is possible. Consider the few people who honestly believe that Earth is planar, for instance; their arguments often start to crumble when asked for testable diagnostic predictions engaging representative data (*cf.* phlogiston, ether, etc.).

Table 1a

Samples of five of the ten ways that brief information reduces denial that global warming is occurring/threatening, Part 1

Way (of ten) and sources	Sample
1. Representative statistics about greenhouse gases, temperature, glaciers, and the scientific consensus—with participants' estimates followed by feedback [4,5,6•].	'*In a 2009 study published by the National Oceanic and Atmospheric Administration, for every 100 temperature record lows there were ___ record highs.*' {Answer = 204} (From Ref. [5], p. 159.)
2. Representative and misleading statistics mixed together. See #1 for a representative statistic; a misleading-statistic example (from Refs. [4,29]) is:	'*According to the National Oceanic and Atmospheric Administration, the average global temperature changed by ____ degrees F between 1940 and 1975.*' {Answer = -0.18}
3. Texts that increase understanding of global warming's physical-chemical mechanism—for instance, this part of a 400-word text (e.g. Ref. [4], pp. 73−74—and www.howglobalwarmingworks.org/400-words.html) that includes, among much more text:	'[. . .] *When Earth absorbs sunlight, which is mostly visible light, it heats up. Like the sun, Earth emits energy—but because it is cooler than the sun, Earth emits lower-energy infrared wavelengths. Greenhouse gases in the atmosphere (methane, carbon dioxide, etc.) let visible light pass through, but absorb infrared light—causing the atmosphere to heat up. The warmer atmosphere emits more infrared light, which tends to be re-absorbed—perhaps many times—before the energy eventually returns to space. The extra time this energy hangs around has helped keep Earth warm enough to support life as we know it. (In contrast, the moon has no atmosphere, and it is colder than Earth, on average.)* [. . .]'
4. Videos that increase understanding of global warming's physical-chemical mechanism [6•]; for instance, a 4.8-minute video (www.howglobalwarmingworks.org/in-under-5-minutes-ab.html) with a 596-word script (www.howglobalwarmingworks.org/transcripts.html) that includes, this portion among much more:	'[. . .] *Greenhouse gases absorb infrared light because their molecules can vibrate to produce asymmetric distributions of electric charge, which match the energy levels of various infrared wavelengths. In contrast, non-greenhouse gases, such as oxygen—that is,* O_2*—don't absorb infrared light, because they have symmetric charge distributions even while vibrating.* [. . .] *To wrap up, we'll quickly summarize the mechanism of global climate change: Earth transforms sunlight's visible energy into infrared light, and infrared energy leaves Earth slowly because it's absorbed by greenhouse gases. As people produce more greenhouse gases, energy leaves Earth even more slowly—raising Earth's temperature even more than it has already gone up. That's how global warming happens!*'
5. Comparing graphs of Earth's average temperature to the inflation-adjusted Dow Jones Industrial Average (a proxy for the US/World's stock market) from the 1880's to today (e.g. Ref. www.howglobalwarmingworks.org/2graphsba.html).	A narrative about an alien robot ('Bex') that inadvertently lands on Earth and wants to understand its trends (see Ref. [5], p. 150−151 and [6•]). Participants realize that that the graphs all always increase, and that it is often hard to tell which graph represents temperature and which represents stock valuation.

foster student inquiry. The deployment of such technology advantageously accommodates individual learning pathways and provides opportunities for rich quantitative-data and qualitative-data generation that are helpful for evaluative purposes. Examples of such technology often employ model-based learning [63] or incorporate interactive visualizations to illustrate submacroscopic, mechanistic climate change processes [4,6•,64•].

Post-classroom incremental learning: still no single denial-reducing silver bullet

The delivery of mechanistic and other scientific information through texts, graphs, videos, maps, and/or salient statistics has also been demonstrated to be effective at both increasing factual knowledge and increasing acceptance/concern regarding global warming (i.e. to reduce denial that global warming is happening or threatening; [4,6•]).[8] However, as with those who would deny fully vetted COVID-19 vaccines' safety/effectiveness, there is not (yet, anyway) a single 'silver bullet fact' that will eliminate climate change *denial*.[9] Rather, Ranney *et al.* [6•, p. 89] suggest that one's denial is typically like a table with (e.g. 3–4 of a subset of about a dozen) legs that likely need to be knocked out for a particular individual's 'table of denial' to plummet; what knocks out any particular denial-leg may be a well-crafted hunk of information.

Our laboratory has experimentally demonstrated nine ways to increase anthropogenic global warming acceptance with normative *scientific* information (i.e. beyond *nationalism* concerns)—all without polarizing participants. These ways include (1) representative statistics directly involving global warming both in isolation [4,6•] and when (2) mixed with misleading statistics [29], (3) texts

[8] Controversial and inconvenient science often spawns denial in political, financial, and religious stakeholders—and in those who fear (or are convinced to fear) change. Global warming quintessentially spawns such denial, among arguably easier cultural transitions such as accepting heliocentrism—or tobacco's downsides.

[9] Please note we *only* use 'silver bullet' in this article to refer to eliminating general denial about central dimensions regarding climate change (i.e. doubts that global warming is happening, anthropogenic, or worthy of concern). We do *not* refer to the perhaps thornier issue of doubts about *particuar* solutions that will/may eliminate climate change itself (e.g. techniques that quickly end greenhouse gas emissions [such as energy conservation] or technologies that might extract greenhouse gases from the atmosphere [such as artificial photosynthesis]).

Table 1b

Five more of the ten ways that brief information reduces denial of global warming's reality/threat (Part 2)

Way (of ten) and sources	Sample
6. Sea-level-rise maps (focusing on Southern Florida or the Southeast U. S. more generally; see Figures 1 and 2 (p. 6–7)), and economic information (pp. 4–5), from Ref. [44]).	Including, among other information: (a) actual (and one projected) negative impacts on home sales in high-flood-risk coastal areas, and (b) projected dollar-value property losses by the year 2100.
7. Text that explains carbon dioxide's effects on an individual's cognitive abilities [67] that includes, among much more text:	'[. . .] *Carbon dioxide (CO_2) is toxic to humans at high concentrations, creating a condition known as hypercapnia, which can result in death. Even at more moderate CO_2 concentrations, studies find that breathing air with elevated CO_2 can have a negative impact on a person's reasoning and mental abilities.* [. . .] *One study concludes that the best way to prevent this hidden consequence of increasing atmospheric CO_2 is to reduce fossil-fuel emissions*. [. . .]'
8. A video [in German] explaining the consequences of climate change [65]	see https://osf.io/xeu67/
9. Texts that explain why climate scientists are generally trustworthy [68] such as this portion:	'Scientists also don't just accept global warming because they want to get along with other scientists. That's mostly the opposite of how scientific rewards work. Scientists treasure any chance to show that the vast majority of their peers are incorrect: that's how Einstein-types achieve fame. [. . .] About 98% of climate scientists accept human-caused global warming even while wishing it were false—and having incentives to disprove it. This reflects the very high probability that climate change is truly happening.'
10. Supra-nationalistic statistics that question the U.S.'s international status—with participants' estimates followed by feedback [6•]. An example:	'*The United States ranks ____ of 42 Peer Nations for percentage of births that are to teen mothers (15–19 years old).*' {Answer = 1st} (See Ref. [5], p. 166 for full item-set.)

or (4) videos explaining global warming's physical-chemical mechanism [4,6•,65] (and replicated by [66]), (5) graphs of Earth's temperature (since the 1880's) compared to graphs of stock-market value [6•] (also see Ref. [5]'s graphs), (6) maps and economic information regarding sea-level rise [44], (7) a text explaining how increased CO_2 concentrations can reduce human thinking abilities [67], (8) a video explaining the consequences of climate change [65], and (9) texts about why climate scientists should largely be trusted [68].[10] Examples of the compelling global warming statistics, and some of the other kinds of interventions (e.g. mechanistic explanations and temperature-rise graphs), can be found at our public-outreach site: HowGlobalWarmingWorks.org [3], which has spawned over one million page-views. Tables 1a and 1b show samples of some of the *ten* brief, compelling kinds of information-hunks that our laboratory has shown to be successful in normatively revising beliefs about climate change. (Regarding the global warming statistics—way #1 in Table 1a—other researchers [69,70] have found that even a single statistic regarding the scientific consensus about the acceptance of climate change is compelling to many people, representing a gateway belief. This scientific-consensus element also appears explicitly or implicitly in several other of the ten ways, including in the sample-quote of way #9 in Table 1b [about why climate scientists are generally worthy of trust, as well as about science's reward structure].).

[10] Facts and statistical information about global warming's impacts have been *particularly* reliably effective at generating belief revision and changed attitudes when *surprising* numbers [25] or graphics [6•] are provided.

Conclusion

Climate change cognition and education are unique in both cognitive psychology *and* in science education (and the uniqueness, presumably, partly explains the existence of this journal issue). Most obviously, climate change education includes contentious elements—rather like evolution education [61], in contrast to teaching photosynthesis or even plate tectonics—because it triggers calls for, and fears about, massive economic and behavioral changes. Because burning fossil fuels causes global warming, the fossil-fuel industry's status is uniquely central regarding climate change cognition—which explains why pollsters conduct surveys about *global warming* acceptance but rarely about *photosynthesis* acceptance (or even whether continents have moved). Global warming's unique threat to humanity is largely why climate change education (and not, e.g. photosynthesis education) is an intense societal venture.

The overarching aim of climate education, as a cognitive-communicative venture, is to help people develop understandings, competencies, and emotional coping mechanisms that can be applied to an increasingly uncertain and poorly defined possible-future (e.g. regarding recent fires and electricity outages: [71]). Although such learning has previously been difficult to place in more traditional classroom curricula, technological innovations—along with inquiry-based and participatory pedagogies that encourage critical thinking and creative engagement—

offer promise for youth-education ventures about climate change. For the *general* populace, a diversity of brief global warming interventions (e.g. information-hunks shorter than five minutes each;[11] see Tables 1a and 1b) have also been shown to be effective at 'moving the needle' toward accepting climate change's reality and dangers (in lieu of a single, 'silver bullet,' wisdom-boost). If nothing else, the rise of fake news and society's response to the COVID-19 pandemic have sensitized people to the need for veridical information that enables them to make informed choices about the future.

Author contributions

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Conflict of interest statement

Nothing declared.

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