ESTIMATING CLIMATE CHANGE NUMBERS: HOW TOLERANCE FOR ERROR CAN SUPPORT SCIENCE LEARNING

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Texts presenting novel statistics can shift learners' attitudes and conceptions about controversial science topics. Research suggests that such science learning can be supported by bolstering targeted mathematical reasoning skills, though these benefits were found to be strongest among people with mid/high prior knowledge. Our project aimed to build on this research by identifying specific skills that might have contributed to such learning. We conducted ten think-aloud interviews with undergraduate and graduate students as they estimated climate change data before being shown the scientifically accepted value. Findings highlight that students with higher prior knowledge tended to have a higher tolerance for error in their calculations, a willingness to make casual "back-of-the-envelope" calculations, and often interpreted quantitative feedback in terms of its scientific meaning rather than in terms of a measure of performance.

Keywords: conceptual change; integrated STEM; numerical estimation; science education

Misconceptions about controversial science topics are widespread. For example, as of September 2020, 43% of adults in the USA incorrectly believe that human activities are not the primary cause of climate change (Marlon et al., 2020). Misconceptions about climate change are held even among individuals who believe that climate change is real (Thacker & Sinatra, 2019). Fortunately, there are several approaches that exist to shift climate change misconceptions, and one approach that shows promise makes use of pertinent statistical information.

Numerical data (e.g., statistics) found in the news can be a catalyst for changing minds about science topics. For example, prompting people to estimate just a handful of statistics about climate change and then presenting them with the actual value can shift their attitudes, beliefs, and misconceptions to be more aligned with scientists (Ranney & Clark, 2016). The evidence further suggests that the impact of such an intervention can be enhanced by bolstering targeted numerical estimation skills that support the processing and interpretation of numbers, and that such impacts are moderated by motivational and affective factors (Thacker, 2020). However, findings from this research showed that the benefits of mathematical instruction were strongest among individuals in the middle/upper range of prior climate change knowledge.

This project aimed to address this gap by examining the role of prior knowledge more closely and to identify specific skills among medium-high learners that support the learning that occurs when people engage with climate change data. Specifically, we compliment Thacker's (2020) prior quantitative research on this topic using data from ten think-aloud interviews with undergraduate and graduate students as they estimated climate change numbers before being shown the true value and identified specific skills that supported subsequent learning. First, we summarize relevant theory.

Theoretical Framework

Conceptual Change

The Plausibility Judgments for Conceptual Change model posits that novel information can incite conceptual change because it prompts learners to appraise or reappraise the plausibility of their existing beliefs (Lombardi, et al., 2016). This model predicts that when people encounter novel information such as novel climate change data, they first process the data for validity (e.g., Richter & Maier, 2017) and then make a judgment of the plausibility of the conception supported by the new information. Plausibility judgments can be either implicit or explicit, and the extent to which an individual explicitly evaluates the plausibility of a conception depends, in part, on their motivation, emotion, and views about knowledge. More explicit evaluations of plausibility lead to an increased potential for conceptual change. In sum, Lombardi et al's (2016) model predicts that the extent to which people engage with and learn from numerical data is influenced by their motivation, emotion, and their ability to process and interpret numbers.

Numerical Estimation

One way that learners process and interpret numbers is by estimating whether they seem reasonable (e.g., Reys & Reys, 2004). Research on *measurement estimation* concerns the explicit estimation of real-world measures (Bright, 1976; Dowker, 2005; Sowder & Wheeler, 1989) and is useful for understanding factors that help people judge whether real-world quantities are reasonable. Findings suggest that peoples' estimation accuracy and judgments of reasonableness improve when they use measurement estimation strategies, such a tolerance for error (Shimizu & Ishida, 1994) and use of the benchmark strategy—the use of given standards and facts that can be applied by the learner through mental iteration and proportional reasoning to better estimate and judge the plausibility of real-world quantities (Brown & Siegler, 2001; Joram et al., 1998). For example, a person's estimate of the number of jellybeans in a container is likely to be more accurate, and they will be a better judge of the reasonableness of other peoples' guesses if they are first told the number of jellybeans in a different container. Measurement estimation strategies may therefore support people's comprehension and evaluation of given real-world quantities.

Attitudes and Knowledge

Attitudes are another factor that may influence learning from climate change data. Attitudes can be thought of as the valenced (e.g., positive or negative) evaluation of an object, person, or event and are expressed as behaviors, affects, and beliefs (Eagly & Chaiken, 1993). According to Sinatra & Seyranian (2016), knowledge and attitudes are related and can be thought of as adhering to a 2x2 axis. Knowledge can either be consistent or inconsistent with scientifically accepted views and can be either positively or negatively valenced, yielding four categories of attitude and knowledge, each representing a different approach that a person might take to learning climate change. Briefly, these four combinations are *pro-justified* (favorable attitude and accurate knowledge), *pro-unjustified* (favorable attitude and inaccurate knowledge), *con-justified* (negative attitude and accurate knowledge), and *con-unjustified* (negative attitude and inaccurate knowledge; Sinatra & Seyranian, 2016). This study, in particular, concentrates on differences between justified and unjustified learners (i.e., higher and lower prior knowledge).

Building on this theoretical framework, we contend that numerical estimation is an essential mathematical skill that helps individuals evaluate and learn from scientific data. Further, such learning can be magnified when people hold attitudes that enable receptivity and deep engagement with new evidence. As such, the purpose of this research was to develop a learning intervention that leverages these ideas and to also explore specific pre-existing skills and knowledge that benefit learners when they engage with climate change data. Therefore, our research question is: *What prior skills and knowledge support the learning that occurs when people engage with an intervention that exposes them to novel statistics?*

Methods

The Estimation Game

To build upon an existing learning intervention (Thacker, 2020), we used a design-based research (DBR) approach to guide the development of an online estimation game. As is characteristic of design-based research, the design, implementation, and revision of the intervention occurred over several iterations (Anderson & Shattuck, 2012). Though design iteration cycles are still underway, the current product of this research is an online, open-source number estimation game with a built-in numerical estimation strategy intervention that can be easily shared with practitioners and the general public online (http://143.110.210.183/).

In the intervention, people are asked to estimate climate change numbers before being shown the true value. The estimation process is thought to elicit relevant background knowledge that is restructured when incorporating the true value (e.g., Ranney & Clark, 2016; Rinne et al., 2006). Half of these prompts also include a "hint," (or benchmark value, Brown & Siegler, 2001; Joram et al., 1998) that can be mathematically manipulated to better estimate the unknown value.

The estimation game can also be modified by the researcher to present participants with instruction on numerical estimation strategies prior to estimating values. This instruction consists of a short text that encourages participants to draw from their background knowledge and think mathematically when estimating numbers. Specifically, it emphasizes the use of benchmark values by rounding and rescaling them based on one's expectations. This is followed by a worked example and a check for understanding (see Thacker, 2020 for more detail). Half of our participants received this modification.

Participants and Procedure

We conducted ten audio and video recorded "think-aloud" interviews (Desimone & Le Floch, 2004) with graduate and undergraduate students as they interacted with the estimation game. Students attended a large Hispanic serving institution in the Southern USA and identified as Female (90%), Hispanic/Latino (50%), White (30%), Black (10%), and mixed-race (10%).

While "thinking aloud," these students (a) completed a pretest of prior knowledge (Lombardi et al., 2013) and climate change attitudes (Lombardi et al., 2012), (b) engaged with the estimation game, with half of the participants receiving the modification that included math instruction, and then (c) completed a post-test identical to the pretest.

Analysis. Survey data was used to identify individuals with high/low prior knowledge and positive/negative climate change attitudes. Recordings were transcribed and open-coded by two independent coders for varying dimensions of student thinking (Corbin & Strauss, 2004), with special emphasis on examining strategies used by students when estimating climate change numbers among individuals with high and low prior knowledge.

Findings

Survey Results

Results revealed that, at pretest, all participants believed that climate change is real. All ten participants rated the statement, "climate change exists and is caused by humans" as plausible, ranging from 6 (somewhat plausible) to 10 (highly plausible; M = 8.02 out of 10). Yet, despite these generally positive attitudes, about half of participants held misconceptions (e.g., 50% of students disagreed that the "average sea level is increasing"). Pretest knowledge scores averaged at 65% correct. Climate change knowledge improved at posttest (94% correct); no participants disagreed that the "average sea level is increasing" at posttest.

All participants held attitudes that were consistent with scientists, yet many held conceptions that were not. As such, we divided our qualitative analyses into categories of students with positive attitudes but low and high knowledge at pretest (pro-unjustified and pro-justified, respectively). Participants were coded as having low knowledge if they scored below the median (those who scored 57% correct or less) on the knowledge pretest. Based on this criteria, six participants were coded as "Pro-Justified" while four were coded as "Pro-Unjustified."

Qualitative Results: Pro-Justified vs Pro-Unjustified Learners

All students made use of background knowledge and most used mathematical operations to modify given information to better estimate unknown information. However, what distinguished those in the high prior knowledge group from those in the low prior knowledge group was their tolerance for error implicit in the calculations (see also Reys et al., 1982; Shimizu & Ishida, 1994). Another important difference was that these students interpreted quantitative feedback in terms of its scientific meaning (e.g., "Wow, that number is different than what I expected") rather than as a reflection of their performance (e.g., "Wow, I got the answer wrong").

To exemplify these codes, we present an excerpt from an interview with a female preservice teacher and undergraduate student who was identified as "pro-justified" and completed the modified version of the intervention. After completing the survey pretest, the participant was thinking aloud when she read the instructions to an item, "Of 195 countries in the world how many are committed to climate action." then noted that she was "gonna round down to 194." When prompted by the researcher to explain why, she said,

> I [rounded to] 194 because [halving] 195 will result in a point five calculation and there's not really half a country, so I just rounded down because, you know, down is less... Half of 194 is 97, but I'm going to put 42 countries because it's less than half of 195. [*She then enters 42 and clicks to show the scientifically accepted answer, revealing that 175 of 195 countries are committed to climate action.*] No! I mean, yes! But no, I mean yes! So that's more than half. That's significantly more than half. Wow, that genuinely surprises me a lot, I did not know that. I really thought that a lot of the countries were not committed to climate action, this is a good statistic. I'm happy with this. I mean, I'm sad that I'm wrong, but I'm happy that I'm wrong at the same time.

This excerpt illustrates the flexible approach to working with imperfect calculations that were characteristic of pro-justified participants. Notably, this student drew from her expectation that the world is not very supportive of climate action and performed a few casual "back of the envelope" computations using the given number (i.e., rounding to an even number to ease halving, and then going much lower again). These casual arithmetic manipulations seemed to support students in making meaning of the numbers. When shown the true value, this student noted that, though she was not particularly happy to learn that her estimate was inaccurate, the meaning of the scientifically accepted value was most salient. In contrast, students categorized as pro-unjustified were generally less willing to manipulate given numbers and attended more to the accuracy of their estimate when compared with the meaning associated with the true value.

Conclusion

We sought to explore what prior skills and knowledge support the learning that occurs from an intervention that involves numerical estimation of climate change data. We found that students with higher prior knowledge were more tolerant of error, willing to make informal calculations, and make meaning of feedback compared with individuals with lower prior knowledge. Instructors who wish to support science learning through casual estimates of real-world quantities might assure students that, when estimating, it is okay to tolerate some error in computations. They may also provide feedback that de-emphasizes performance outcomes and highlights meaning. Future research stemming from this project will more closely examine mathematical reasoning that supports the interpretation of scientific meaning and investigate how learners with negative climate change attitudes interact with the intervention.

References

Anderson, T., & Shattuck, J. (2012). Design-based research: A decade of progress in education research?. *Educational researcher*, *41*(1), 16-25.

Bright, G. W. (1976). Estimation as part of learning to measure. In D. Nelson & R. E. Reys (Eds.), *Measurement in School Mathematics: 1976 Yearbook* (pp. 87–104). Reston, VA: NCTM.

Brown, N. R., & Siegler, R. (2001). Seeds aren't anchors. *Memory & Cognition*, *29*(3), 405–412.

Corbin, J., & Strauss, A. (2014). *Basics of qualitative research: Techniques and procedures for developing grounded theory.* Sage publications.

Desimone, L M., & Le Floch, K. C. (2004). Are we asking the right questions? Using cognitive interviews to improve surveys in education research. *Educational Evaluation and Policy Analysis, 26*(1), 1-22.

Dowker, A. (2005). A good guess: Estimation and individual differences: Implications for psychology, neuroscience and education. In *Individual differences in arithmetic* (pp. 132–151). Psychology Press.

Joram, E., Subrahmanyam, K., & Gelman, R. (1998). Measurement estimation: Learning to map the route from number to quantity and back. *Review of Educational Research*, *68*(4), 413–449.

Lombardi, D., Nussbaum, E. M., & Sinatra, G. M. (2016). Plausibility judgments in conceptual change and epistemic cognition. *Educational Psychologist*, *51*(1), 35–56.

Lombardi, D., & Sinatra, G. M. (2012). College students' perceptions about the plausibility of human-induced climate change. *Research in Science Education*, *42*(2), 201–217.

Lombardi, D., Sinatra, G. M., & Nussbaum, E. M. (2013). Plausibility reappraisals and shifts in middle school students' climate change conceptions. *Learning and Instruction*, *27*, 50–62.

Marlon, J., Howe, P., Mildenberger, M., & Leiserowitz, A. (2020). Yale climate opinion maps–US 2016. *Yale Program on Climate Change Communication*. Retrieved from https://climatecommunication.yale.edu/visualizations-data/ycom-us/

Ranney, M., & Clark, D. (2016). Climate change conceptual change: Scientific information can transform attitudes. *Topics in Cognitive Science*, *8*(1), 49–75.

Reys, R. E., & Reys, B. J. (2004). Estimation in the mathematics curriculum: A progress report. *Beyond Written Computation*, *29*, 101–112.

Reys, R. E., Rybold, J. F., & Bestgen, B. J. (1982). Processes used by good computational estimators. *Journal for Research in Mathematics Education*, *13*(3), 183–201.

Richter, T., & Maier, J. (2017). Comprehension of multiple documents with conflicting information: A two-step model of validation. *Educational Psychologist, 52*(3), 148-166.

Rinne, L. F., Ranney, M. a, & Lurie, N. H. (2006). *Estimation as a catalyst for numeracy: Micro-interventions that increase the use of numerical information in decision-making.* Proceedings of the Seventh International Conference of the Learning Sciences, 571–577.

Shimizu, K., & Ishida, J. (1994). The cognitive processes and use of strategies of good Japanese estimators. In R. E. Reys & N. Nohda (Eds.), Computational Alternatives for the twenty-first century: Cross-cultural perspectives from Japan and the United States (pp. 161-178). Reston, VA: National Council of Teachers of Mathematics.

Sinatra, G. M., Kardash, C. M., Taasoobshirazi, G., & Lombardi, D. (2012). Promoting attitude change and expressed willingness to take action toward climate change in college students. *Instructional Science, 40*(1), 1-17.

Sinatra, G., & Seyranian, V. (2016). Warm change about hot topics. In L. Corno & E. Anderman (Eds.), *APA handbook of educational psychology* (pp. 245–256). APA Publications.

Sowder, J. T., & Wheeler, M. M. (1989). The development of concepts and strategies used in computational estimation. *Journal for Research in Mathematics Education*, 130–146.

Thacker, I. (2020). Numerical estimation skills, epistemic cognition, and climate change: Mathematical skills and dispositions that can support science learning. In A.I. Sacristán, J.C. Cortés-Zavala & P.M. Ruiz-Arias, (Eds.). *Mathematics Education Across Cultures: Proceedings of the Forty-Second Annual Meeting of the North-American Chapter of the International Group for the Psychology of Mathematics Education* (pp. 1054-1062). Mazatlán, Sinaloa, Mexico. http://doi.org/10.51272/pmena.42.2020-166

Thacker, I. & Sinatra, G.M. (2019). Visualizing the greenhouse effect: Restructuring mental models of climate change through a guided online simulation. Education Sciences, 9(1), 14. https://doi.org/10.3390/educsci9010014