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Innovate to Mitigate: Analysis of student design and rationale in a crowdsourcing competition to mitigate global warming

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Abstract: The Innovate to Mitigate project adapts crowdsourcing to support project-based STEM education, posing design challenges for secondary-school students to design feasible innovative strategies to mitigate CO_2 emissions and thus global warming. The paper presents evidence that the web-mediated communities of practice support learning of STEM concepts and practices and provides an account of how student and scientist discourse support that learning. Productive talk deployed by community members elicited greater levels of reasoning than was originally manifest in student work and resulted in improved student products.

Introduction

Global warming is increasingly seen to affect everyone's lives and many young people are eager to respond (e.g., Thunberg et al. 2020). Engaging the issue constructively ("active hope") can counteract the anxiety and depression such an overwhelming problem elicits (Hayes et al., 2018). The Innovate to Mitigate (I2M) project poses design challenges in climate change mitigation for middle- and high-school students. Our initial research (Puttick & Drayton 2017; Drayton & Puttick, 2018) suggests that an open but well-structured challenge to develop mitigation strategies can galvanize creativity and engagement among young people, and support "3-D learning" (NRC, 2012).

Crowdsourcing for STEM learning

Crowdsourcing and social media are increasingly common media for participation in society (Hossain & Kourainen, 2015; Arelas & Ladrón-de-Guevara, 2011). The crowdsourcing communities in Innovate to Mitigate (I2M) (students, teachers, scientists) are designed as learning environments in which students can collaborate to iteratively improve design ideas and STEM knowledge. Such heterogeneous communities of practice offer a diversity of inputs, including insights about practice from more experienced participants (Wenger, 1998). Dialogic knowledge- construction and design, facilitated by the division of labor within the team (Puttick & Drayton 2017; Drayton &Puttick, 2018), is strengthened by collaboration among competitors in the challenge. This open integrative process is central in our adaptation of crowdsourcing. Students' discourse can provide insight into students' reasoning and understanding of STEM concepts and practices, and evaluation of each other's comments (Ketonen et al., 2020; Samarasekara et al., 2020; Cheng & Tsai, 2012). Other impacts may include growth in quality and depth of student argumentation, and in metacognitive effects such as students' capacity to evaluate their own reasoning and evidence (Anker-Hansen & Andrée, 2019).

Dialectical learning in science education

"Discourse" in science classrooms has taken on great importance under the influence of research in the sociology of science. The Frameworks argue that the true aim of science is to create and critique evidence-based causal accounts of natural phenomena (NRC, 2012). On this view, science moves forward in important measure by its discourse within a community of practitioners. One genre or mode of discourse is “narrative” (Kvernbekk, 2003). A second, strongly advocated approach is “argumentation,” structured around making and defending claims that propose explanations for phenomena (Allchin & Zemplén, 2020; Boğar, 2019).

A further refinement, "productive talk," developed and characterized by learning scientists in recent decades, places a key emphasis on collaborative knowledge building and on the ways that teachers can facilitate (but not direct) the use of "talk moves" that help students make theory- or data-based claims, seek or evaluate evidence for or against the claims, and elaborate the implications of their work. A further intent is the adoption of "talk moves" by students into their dialogue with each other within teams, in large-group critique and collaborative sense-making (Michaels & O'Connor 2021; Resnick et al. 2015).

We conjecture that a collaborative/competitive design challenge such as I2M will not only offer an opportunity for students to engage in STEM practices, but also to engage in sense-making and knowledge-building discourse related to their designs, which will shape how resulting products are reshaped.

In this paper we ask: (i) What evidence is there that crowd sourcing led to changes in students' design artifacts and rationales, generated during an I2M challenge? (ii) How are these changes related to students' science discourse with each other and with scientists giving feedback on the project designs?

Methods

Student teams propose a design abstract, based on a mitigation strategy such as energy conservation, alternative energy generation, or social/behavioral change. Since abstracts scaffold the whole investigation, students are asked to describe their idea, how they consider it an innovation, and how feasible it might be to implement. Teams post their abstract to the project's online page. All students and TERC scientists post questions and comments. After two weeks of discussion, teams post revised abstracts, using comments received. The teams conduct their project over the next 3 months and produce a final paper and a short video presentation.

Participants

For this paper, we analyze the data generated by five I2M teams during the abstract phase of the 2021-2022 competition: Eco Warriors (5 students in 10th grade), Team Imoto (2 in 12th grade), Wolf Pack (2 in 9th grade), Dream Team (2 in 9th and 2 in 11th grade), Carbon Cancelling Cougars (2 in 10th grade).

Data sources and Analysis

The data in this case study include: (i) The teams' initial abstracts, (ii) All discussion posts from students and scientists, and (iii) The revised abstracts.

Data were coded by three researchers to identify technical/science content, proposed design elements, categories of rationale, evidence adduced, and talk moves (Table 1).

Table1. *Coding Scheme*

Code	Description
Say more	Asks for clarification of a statement or claim
Rephrasing	Restatement of what commenter thinks they read
Ask for evidence	Asks for evidence in support of a statement/claim
Ask for reasoning/rationale	Asks for description of thinking about a claim
Rationale: Authority	Explicitly cites an authority, (e.g., teacher, article)
Rationale: Causal	Relies upon an explanatory theory or concept
Rationale: Empirical	Based on empirical data, or absence thereof
Rationale: Factual	Asserts a claim as fact
Rhetorical	Aims to persuade, engage
Challenge/counterexample	Describes an exception to an idea
Agree/disagree (and why)	Asks others to agree/disagree with their point
Add on	Asks others to provide more information
New idea	Provides an additional new idea
Affect	Expresses approval, liking

Coded data were discussed by researchers. After coding was stable, a researcher wrote an interpretive research narrative about each team. Narratives were discussed by the research team to test inferences, identify issues requiring further analysis, and maximize the value of the data. Finally, cases were compared to identify differences and similarities of interest in relation to the research questions.

Results

Three of the five initial abstracts that the teams posted provided a rationale for their proposed designs that relied on statements of fact and unsubstantiated claims. For example, Team Imoto, proposing an innovation related to renewable energy generation, wrote, “Renewable energy can be produced from a multitude of ways, wind, solar, or even something as grand as nuclear. But something overlooked is the use of gravity in generating electricity. Using the force of the Earth’s gravitational pull, we want to create some device that will generate electricity by a turbine that is pushed by a flow of water from a rain gutter.”

In the discussion of abstracts, coding of statements from competition **participants** yielded (a) “Affect,” (b) “Add on,” or “Say More," and (c) “Ask for Evidence” as the most frequent codes. For example, Pranav commented on Team Imoto’s abstract, “Very unique idea. (Affect) 1. What materials will have to go into building this device? How accessible is it for people to obtain said materials?" (Add on, Say more). Ned, commenting on the same abstract, asked, "How would gravity be used to generate electricity? How much would the device cost? Would it be relatively simple? […] How would this collect drinkable water?" (Add on, Ask for Evidence). Commenting on Dream Team's abstract proposing to innovate on textile dyeing, Micah Red asked, "Some of your words are a little hard to understand. Could you please explain what a super-degrading microorganism is? Or give an example?" (Say more).

Scientists, on the other hand, tended to suggest new but related ideas, and to ask for reasoning. For example, Gina commented on Team Imoto's abstract as follows, "I wonder how you're thinking about its possible impact on reducing emissions. Will you measure the current produced, then do a calculation […] to come up with an overall guesstimate of greenhouse gas reduction?" (Add on, New Idea, Ask for Evidence and Reasoning). Commenting on the textile dyeing abstract, Benny asked, "Does it make a difference whether the dyes being used are plant- or mineral-based, as opposed to synthetics? I know weavers and spinners in my area […] believe these dyes are better for the environment. I am not sure it's true, though." (Add on, Ask for Evidence, New Idea, Ask for Reasoning).

Regardless of how probing the comments and questions were, the conversational exchanges between teams and commenters uniformly revealed productive reasoning and development of science practices. For example, the following exchange occurred in discussion of the Carbon Cancelling Cougars design, which was to find, and test overlooked hydrocarbons, e.g., household waste, as biofuels:

Brody: Great idea! Do you have any specific materials in mind for initial testing?

Ned: one of our chief areas of interest was the "reuse" part of the classic "reduce, reuse, recycle" mantra. This means that instead of disposing of things like cooking grease (often a waste product), one could use that to produce a fuel to use to cut down on gasoline usage. Not only does this reduce carbon emissions, it also cuts down on waste.

Benny: do you have a combustion system […] to test the different fuels with, or will you use a calorimeter and other sensors to evaluate heat output and emissions, or what?

Ned: the calorimeter would be a great tool for testing the output. We'll also be actually testing the different fuels in an engine (not sure of exactly what yet) to test efficiency, as that is also a priority (if the alternative is less efficient than the status quo, it's unlikely to be implemented).

Gina: I'm curious how you plan to do this critical piece of research [ID'ing wasted fuels] before you get to testing the candidates you've chosen. What criteria do you think you will use to make the decision?

Ned: To find such materials, we could ask around and take a survey (perhaps students/teachers/parents of our school?) to find what kinds of products are commonly wasted in everyday life. We would then compare what we know from the EPA of the chemical composition of these products to the goal of what is necessary for a biofuel.

Parag: Do you have an estimate (in pounds/tons) of the amount of greenhouse gas emissions that can be reduced with your idea? Moreover, how will you measure efficiency with regards to biofuels?

Ned: The estimate would be extremely variable based on how large implementation could be, as well as what metric we are going on, e.g., "how much does a gallon of biofuels reduce emissions?" As far as efficiency, what I'm talking about there is how useful the biofuel is compared to conventional sources.

In these exchanges we notice commenters asking for clarification, additional information, evidence, and elaboration of reasoning. Comments in turn elicited a series of elaborated statements that were empirical, causal, rhetorical and authoritative rationales that would contribute to a reshaped design.

The revised abstracts showed quite extensive elaboration of detail and reasoning. For example, the revised abstract from Team Imoto included the same idea of generating "hydro-power" from generators positioned in household gutters but the team elaborated the proposed mechanism thus, "The water will then be stored in a tank and with the help of a small pump, like the one used at UNITEC, will help to generate the electricity. The water can then be used, alongside a pump, to turn a microturbine and generate electricity. The type of generator so far that we are looking at is a cylindrical power generator which we thought about thanks to the idea from Benny." The rationale for their design was buttressed by citing an authority, and an explanatory concept. The team also provided a causal rationale, in connecting their device to mitigation, "Bringing it to a wide scale […] will help people in the fight against climate change because it will bring people energy independence from major fossil fuel companies and in turn reduce greenhouse gas emissions."

Likewise, the revised abstract from the Dream Team remained focused on innovations in textile dyeing but included more depth in detail and reasoning. For example, describing how untreated wastewaters are often dumped into nearby water bodies, the team explained that "Leftover dye water hinders penetration of light into affected bodies of water, impairing photosynthesis rates." Prompted by one commenter, they provided a causal rationale for their design in linking impaired rates of photosynthesis to climate mitigation, "...carbon is sequestered in the world's bodies of water and the lifeforms that live in them such as fish and marine plants.

Therefore, the overall health of these ecosystems is critical to combat climate change."

Discussion and significance

This paper provides preliminary evidence that a crowd-sourced challenge, situated in a heterogeneous community whose conversations are scaffolded by a shared purpose, can enable substantive STEM learning. As the exchanges between commenters and responders show, the abstracts gained empirical and theoretical strength as participants practiced "productive science talk." Research has shown that student uptake of productive talk moves generally only increases after the moves have been modeled in the classroom by a teacher (e.g., Murphy et al., 2018; Sedova et al., 2016), yet this type of discourse emerged without coaching in the I2M community. Furthermore, our findings show that this productivity – in discourse, in reshaped abstracts - was made possible by the diversity in expertise central to learning in a community of practice. Future research will focus on the impact of including additional crowdsourcing opportunities in the course of future competitions and on the microgenesis of concepts and practices in an extended, discourse-mediated design project.

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