Scientific Discourse of Citizen Scientists: A Collaborative Modeling as a Boundary Object

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Abstract: In this study, we examine participants' practices in two citizen science projects in order to explore the use of scientific knowledge and practices as they engage in collaborative modeling. They use the Mental Modeler, an online resource to facilitate science engagement and collaboration. This paper applies an analytical approach that uses visual representations to understand the shifts in scientific discourse and interpret complex interaction patterns between participants and facilitators in two citizen science projects. The findings suggest that the Mental Modeler serves as a boundary object that allows participants and facilitators to collaboratively engage with scientific topics and practices through the development of scientific discourse and learning.

Keywords: citizen science, collaborative learning, scientific practices, engagement

Introduction

Citizen science refers to partnerships between scientists and the public in scientific research in which real data are collected and analyzed (Jordan, Ballard, & Phillips, 2012). Citizen science can provide opportunities for informal learning as citizen volunteers are engaged in scientific practices, including modeling, gathering evidence, and evaluating arguments. Most citizen science projects are contributory in which scientists design the project and include the public in data collection (e.g., Nicosia et al., 2014). Participation tends to only involve data collection rather than engaging in a full range of science practices. However, collaborative and co-created projects have great potential benefits to maintain participants' engagement and closely address stakeholders' interests and concerns (Jordan et al., 2016). In addition, collaborative science projects can enhance public engagement where researchers and citizen scientists collect new information and learn from each other in relation to the local environmental issues. The processes of collaborative decision-making and project planning may increase the capacity of scientific discourse and practices of both researchers and scientists. This study included two collaborative projects in order to examine the processes of project planning, modeling, and collaborative learning of citizen scientists.

Although collaborative learning has been emphasized in science learning (e.g., Cornelius et al., 2013), it is only recently that informal online collaborative tools have been designed and used to facilitate learning and engagement in scientific practices among citizen scientists. The purpose of this study is to apply an analytical approach to investigate participants' scientific knowledge, practices, and engagement with the use of online collaborative tools. In addition, the analytical approach provides visual representations to better understand the shifts in scientific discourse and aid in interpretation of complex patterns between participants and facilitators of citizen science projects.

Theoretical framework

Public engagement with science (PES) refers to an avenue for collaborative discourse in informal settings in which individuals with varied life experiences and scientific expertise participate and engage with scientific activities or events (McCallie et al., 2009). During the process, they are able to share and articulate their perspective, ideas, and knowledge within the scientific community of practice. However, although practices of scientific argumentation have been considered a necessity in terms of learning and doing science, they are rarely taught in formal education settings (Duschl et al. 2007). This study aims to illustrate and examine a designated online resource to better understand scientific discourse and engagement among citizen scientists.

Collaborative Science (http://www.collaborativescience.org) includes a set of online resources such as videos, scenario modeling tools, and supporting education materials on ecosystem functions, which are designed to scaffold the process of collaboration between researchers and citizen scientists. The resources provide a framework for engaging in environmental management projects through adaptive management and a modeling tool, Mental Modeler (www.mentalmodeler.org) (Gray et al., 2013, 2013). Mental Modeler enables analysis of representative shifts in participants' individual and collective knowledge of their management problem. Mental Modeler, shown in Figure 1 is based on Fuzzy Cognitive Mapping (FCM) which provides functionality for users to develop concept mapping in terms of the variety and the impact strength of environmental and social factors influencing their driving environmental problems (Kosko, 1986; Özesmi & Özesmi, 2004; Gray et al., 201). MentalModeler (Gray et al., 2013) can help participants track, monitor, and manage the processes of addressing ecological concerns or issues related to their local environments. The practice of modeling continually challenges participants to reflect on and revise their ideas based on observations, serving as a working artifact to collect and drive individual and collaborative knowledge development within a community (Wartofsky, 2012). In addition, boundary objects refer to artifacts or media, which serve as a bridging function for citizen scientists and facilitators to communicate with each other across contexts and environments. These mental models can also serve as a boundary object facilitating communication between the community and partners, particularly those in scientific communities (i.e. land managers, professional researchers), by providing opportunities for more specific presentation of their concept development and feedback about their planning (Akkerman & Bakker, 2011; Hmelo-Silver, 2003). Although the Mental Modeler serves as a boundary object, we argue that the interactions between citizen scientists and facilitators across sites affect not only individuals but also the different social and scientific practices at large. In this study, we aim to examine participants' uses of scientific practices as well as scientific knowledge through the development of concept mapping with the use of Mental Modeler. In this study, we address the following research questions: (1) How does the opportunity to engage in a collaboratively created citizen science project afford engagement in scientific practices?; (2) How does a collaborative modeling tool serve as a boundary object that supports social practices of science that involve generating conjectures, constructing and evaluating models, and application of science knowledge?; (3) What is the role of a more knowledgeable facilitator in supporting these practices?

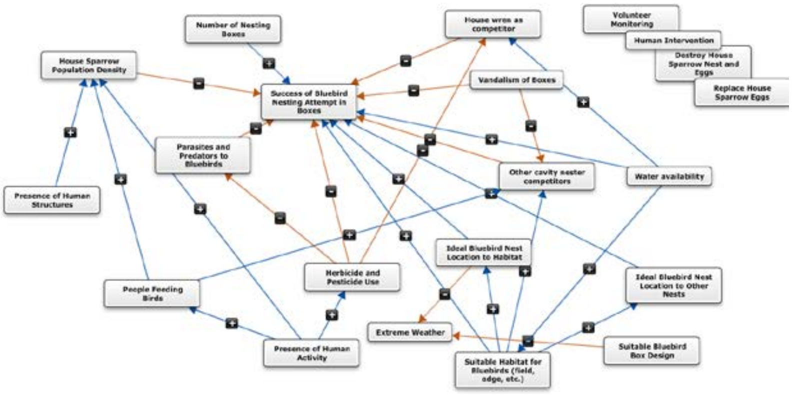

Figure 1. The Sparrow Swap Group Model.

Methods

Two groups of participants were included in the study. Participants from each group were engaged in two one-hour webinar discussions. Participants had developed individual mental models before the webinars, and the goal of the webinar discussions is to develop consensus based group models. The first webinar section was about model construction, and the second one focused on model refinement. The first group was called Sparrow Swap, which had ten participants. A citizen scientist contacted the research team to share this project idea, which was then shared with the Virginia Master Naturalist (VMN) volunteers via email. Participants joined the project voluntarily based on their interest. The primary goal of the Sparrow Swap project was to test the effectiveness of replacing house sparrow eggs with artificial eggs as a technique to decrease competition with between native bluebirds and non-native house sparrows at nesting sites. The house sparrow eggs that were removed were sent to researchers for curation at the North Carolina Museum of Natural History and for testing of contaminants in the eggs to determine levels of certain pollutants in the environment. Participants used the Mental Modeler to collectively develop their understanding of the key factors contributing to the complex issue of house sparrow competition on native songbirds.

The second group was the Booker T. Washington Native Plantings Experiment (BOWA). Participants were recruited via the Virginia Master Naturalists email list serve and during a presentation to the VMN chapter closest to the Booker T. Washington National Monument. The group had 12 members and the purpose of this project was to measure the success of native grass restoration following the removal of an invasive grass species (Johnson grass). Mental Modeler was used to help participants identify the relationships between various native species and exotic Johnson grass in order to promote the success of native seed planting.

During the discussion, participants from both groups developed and refined their group models. Facilitators from the research team helped guide the group discussion with the use of Mental Modeler. In this way, participants and the facilitator could reason collaboratively and make decisions about what research questions they were addressing, add, changing, or revising variables, and developing a data collection plan.

In order to create the initial consensus-based group models, it required two discussion sessions per group. Thus, the data sources were drawn from four webinars of the two groups, Sparrow Swap and BOWA, which were recorded and transcribed. Each webinar was about 72 minutes long, totaling 288 minutes, and with 7-12 participants and 1-5 facilitators. Two coders scored a shared 20% of the data set, achieving a substantial level of interrater reliability, kappa = 0.84. One researcher coded the rest of the data. The videos were coded through the qualitative coding scheme presented in Table 1. The coding scheme was modified from Hmelo-Silver's (2003) study, originally developed for an analysis of cognitive and social processes involved in the construction of a joint problem space in collaborative inquiry with a simulation. The coding scheme was adapted in order to capture the representations of participants' use of scientific knowledge and practices and group dynamics and interactions and differentiate facilitators' actions in terms of monitoring, explaining concepts, and providing research instructions during the discussions (Hmelo et al., 2000, Hmelo-Silver et al., 2002). The coding scheme included 6 major categories and 24 subcategories. The first part of the coding scheme focused on the individual level, including Knowledge used in the discussion (K1-K4), Scientific Practices related to modeling (S1-S2), and Metacognition (M1-M4). The second part of coding scheme focused on the social interaction, including Questioning (Q1-Q5), Responses (R1-R6), and Facilitator(s) Input (F1-F5). Data were coded at the unit of the conversational turn by speakers or were parsed when ideas or topics changed. Turns could be coded on multiple dimensions. The total numbers of turns for the first webinar of the Sparrow Swap group was 325, and the second one was 208. In addition, the total turn numbers of initial discussion for the BOWA group was 211, and 264 for the second group discussion.

To study how the conversation unfolded, we conducted a temporal analysis. The data were analyzed and represented via Chronologically-Ordered Representation of Discourse and Tool-Related Activity (CORDTRA) diagrams. CORDTRA diagrams provide visual representations, which can help in interpreting complex patterns and analyzing collaborative learning processes in CSCL (Computer-Supported Collaborative Learning) environments. In addition, CORDTRA analysis includes the analysis of coding schemes that quantify different types of discourse moves which occurred in the discussion and a chronological picture in which multiple process are represented in parallel on one timeline (Hmelo-Silver et al., 2011).

Table 1: Qualitative Coding Scheme

Category	**Code**	**Subcategory**	**Definition**
Knowledge	**K1**	Conceptual Knowledge	Knowledge expressed with justification/explanation (based on scientific practices).
	K2	Conceptual Conjecture	Knowledge expressed without justification/explanation.
	K3	Anecdotal/Pattern of Experience	Experience related as a one-time occurrence or story from another person/Experience based on a regular observation or occurrence.
	K4	Research Experience	Experience related as part of previous regular field work.
Scientific practice	**S1**	Top-down modeling/planning	Representing conceptual knowledge or learning more about their management problem/ Practical concerns.
	S2	Bottom-up Modeling/planning	Adding removing components, low-level modeling and planning
Metacognition	**M1**	Monitoring	Checking group progress, model components, planning concepts, or asking for other explanations.
	M2	Evaluation /Reflection	Thinking about specific actions and their outcomes.
	M3	External resources	Seeking expertise/resources outside of the group.
	M4	Stakeholder Concerns	Consideration of how external social factors impact participants' planning.
Questioning	**Q1**	Tool-related	Questions or issues pertaining to tool-use
	Q2	Explanation related	Questions about causal antecedents, consequents, enabling conditions; tend to get

			at how and why.
	Q3	Definitional	Participant asks definition for their ideas, or specific values related to the project.
	Q4	Clarification	Participant seeks verification for their ideas, or specific values related to the project.
	Q5	Meta question	Range of metacognitive questions to elicit meta responses, support group dynamics or progress, self-regulated learning.
Responses	**R1**	Agreement with facilitator	When participants show agreement to the views of the facilitator(s), coded in context of facilitator(s) statement.
	R2	Agreement with group member	Participant agrees with view of their group member.
	R3	Brief answer	Answers to general questions that do not include any explanation
	R4	Minimal justification	Answers that include a reason or justification.
	R5	Elaborate justification	Answers that include a detailed explanation to justify one's beliefs or share one's knowledge.
	R6	Conceptual conflicts	Acknowledge or express different opinions through interaction/ over a component of model or broader concepts involved in the project.
Facilitator(s) input	**F1**	Monitoring	Facilitator check-in/monitor progress, and encourages participation.
	F2	Explaining concepts	Addresses higher-level concepts that might help build the model.
	F3	Research Instructions	Facilitators giving explicit guidance about research interventions.

Results

For the CORDTRA diagrams (Figure 2), discourse codes were arranged in chronological order on the horizontal axis (turn numbers). The vertical axis shows the categories of the qualitative coding scheme, from the top to the bottom, K1 to F5. Each point refers to what code(s) was/were coded at specific turn by speakers. CORDTRA diagrams help distinguish the group dynamics and collaborative activity between two webinar sections. The results were also interpreted based on the percentages and frequencies of each code (Table 2). The percentage and frequency can help us to explain how cognitive engagement and communications may be different across the two groups.

First, for the Sparrow Swap group, participants shared more anecdotal (K3) and research experiences (K4) in the second group discussion than in the first meeting (Table 2), whereas there were slightly fewer knowledge practices (K1 & K2) shared in the second discussion. Since the first group discussion focused on identifying the variables and defining the relationships between variables, bottom-up modeling (S2) was more prominent in the first discussion. The second group meeting focused more on conceptual knowledge (S1) and practical concerns (M4) for conducting the projects. Top-down modeling/planning was more prominent in the second discussion. The second group discussion also involved more group interactions (Questioning and Responses). The facilitators provided more monitoring for checking group progress and encouraging participants' contributions in the first group meeting. In addition, the CORDTRA diagrams (Figure 2) helps us to zoom in certain time period to examine the interactions between participants and facilitator as well as scientific discourse more closely.

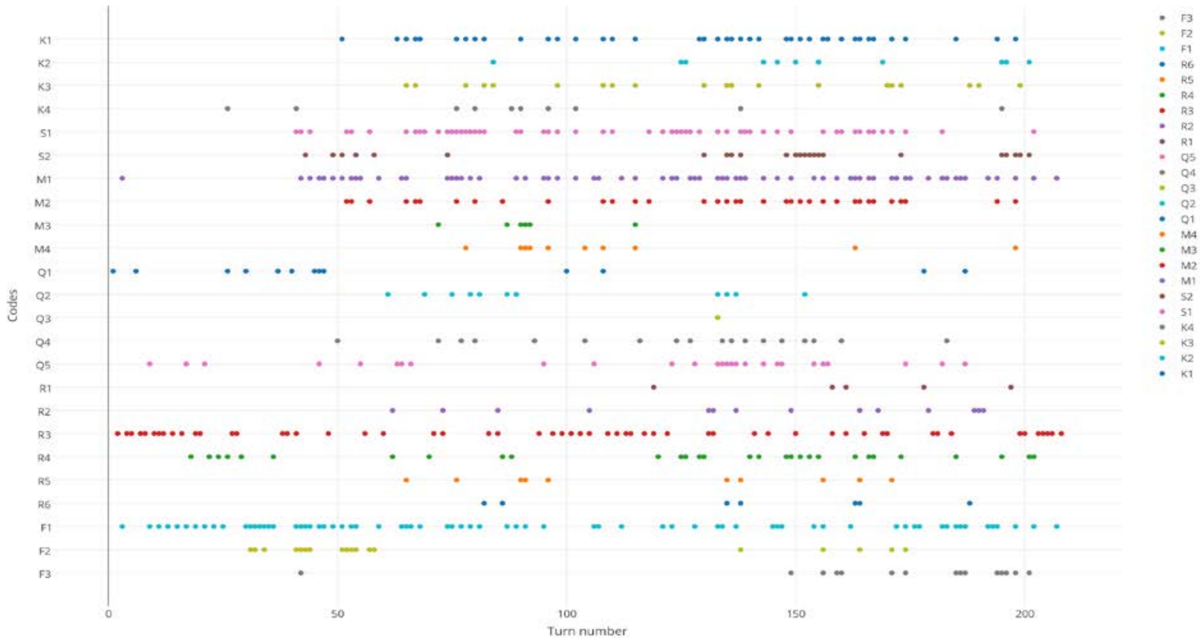

Figure 2. CORDTRA Sparrow Swap Group (Section I).

To better understand the interaction, we provided an excerpt from Sparrow Swap below to illuminate how scientific knowledge and practices are engaged while the group uses Mental Modeler. Additionally, the data supported that the Mental Modeler tool served as a boundary object to help participants collaboratively build the model. In this group, Rena and Sam are the facilitators and the others are citizen scientists. In particular, this excerpt was selected to illustrate how the tool is a dialogical learning resource to help collective knowledge building. This occurred after Amy raised a question about bluebird boxes compared with natural habitats and the facilitator asked the group a meta-level question about what they think they should be talking about:

Rena: Is there a reason to specifically focus on our boxes (*bluebird boxes*)?

Amy: I think so because I mean, maybe this is jumping the gun, but we are talking about
swapping eggs eventually so we are only going to be doing that on a bluebird trail with
bluebird boxes… because bluebird population density. I mean it is going to be different if
we have a natural habitat or just boxes. When we do this diagram. Does that make sense?

Rena: It does to me, others?

Anna: I changed it to success of bluebird nesting attempts in boxes specifically.

Rena: And so bluebird population density, how do we want to treat that in this model?

Sam: I have questions about whether or not density is the interesting thing or is it the population
in the area, and I do not know if those are two different things... if these are two different
variables…or just overall population.

Donna: I think the population in the area…and I am thinking that the population density, well the
more bluebirds there are, the more likely one of them is going to choose a box, so...Unless
there is an abundance in the natural habitat...I can't see how there would be a negative
impact on nesting attempts if you have...high population density.

Rena: That makes sense. Do we want to keep both of these in the model (*see Figure 3 below*)?

Sam: I wonder as I hear Donna talking about it is there a feedback relationship between the
density and success from year to year? So the more successful they are the higher the
density, the higher the density, potentially the more success? Or is there kind of an arrow
going one way, and an arrow going the other between these two?

21 Amy: …I think that the more successful attempts you have the greater the population density.

22 Rena: Ok great.

23 Lee: I think it depends more on the population density of house sparrows.

24 Rena: Ok, let's look at our house sparrow population density then. What do we think an
25 arrow…right there? Is that what you are thinking Lee?...

During this five-minute conversation, participants and facilitators applied the tool as a boundary object to discuss the components and the relationships between the components (Figure 3) as they engage in bottom-up and top-down modeling/planning (Line 02-05). This suggests that they were reacting to issues raised in the discussion. Donna applied conceptual knowledge based on her pattern of experiences in Lines 12-15 with justification based on scientific practices to justify the connection between population density and bluebirds' nesting attempts. The process of collaborative decision-making was dynamic and dialogical based on the use of the Mental Modeler (Line 16-25).

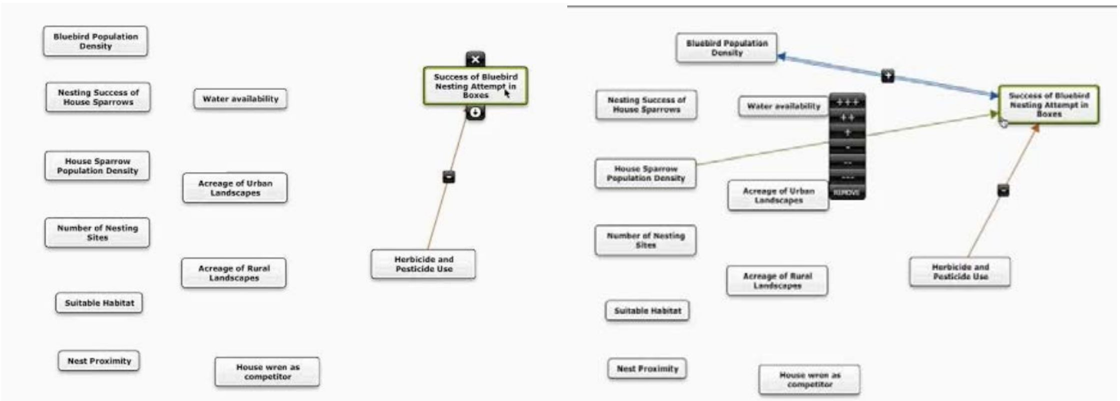

Figure 3. Sparrow Swap model excerpt (Turns 91-105) that focuses on components that participants changed.

For the BOWA group, there are three major findings. First, more frequent and dense conceptual knowledge/conjecture (K1 and K2) was found during the second group meeting (Table 2). In addition, more of the individuals' anecdotal and patterns of experiences (K3) were shared among participants in the second group discussion, which means participants applied the experiences related as an one-time occurrence or based on a regular observation rather than an research experience which involves regular field work. Also, top-down modeling and planning (S1), monitoring (M1), seeking external resources (M3), and stakeholder concerns (M4) also appeared more frequently in the second group discussion. However, there was less facilitator monitoring (F1), explaining concepts (F2), and research instructions (F3) during the second group discussion.

More bottom-up modeling/ planning (S2) tasks were observed during the first group meeting for both projects. This finding suggests that participants began with a stage of defining system components and adding or removing variables from the model. Once the variables and their relationships were determined after the first discussion, participants shifted their discussions to top-down modeling/planning (S1), representing conceptual knowledge, and showing practical concerns and management problems. Although space precludes including the CORDTRA diagrams here, our visual inspection shows that how top-down versus bottom-up planning appeared differently throughout the two sections of webinar. Furthermore, the monitoring (M1) and facilitator monitoring (F5) codes were shared among participants and facilitators for most of time across all four webinar sections. In addition, facilitators' inputs (F1-F3) were more frequent in the beginning and close to the end of discussions. Because there was more explaining and guiding during the first group discussion, facilitators' inputs were coded much more frequently in the first than the second group discussion.

Table 2: Frequency and Percentage Results of Sparrow Swap & BOWA Groups

		Sparrow Swap		**BOWA**	
Category	**Codes**	**I (325 Turns)**	**II (208 Turns)**	**I (211 Turns)**	**II (264 Turns)**

		Frequency	%	Frequency	%	Frequency	%	Frequency	%
Knowledge	**K1**	63	19.4	40	19.2	57	27.0	72	27.3
	K2	23	7.1	11	5.3	17	8.1	30	11.4
	K3	27	8.3	20	9.6	10	4.7	19	7.2
	K4	6	1.8	10	4.8	3	1.4	3	1.1
Scientific Practices	**S1**	22	6.8	56	26.9	41	19.4	77	29.2
	S2	143	44.0	24	11.5	52	24.6	53	20.1
Metacognition	**M1**	172	52.9	67	32.2	93	44.1	134	50.8
	M2	16	4.9	35	16.8	38	18.0	33	12.5
	M3	2	0.6	6	2.9	9	4.3	25	9.5
	M4	0	0.0	10	4.8	9	4.3	28	10.6
Questioning	**Q1**	14	4.3	13	6.3	6	2.8	2	0.8
	Q2	17	5.2	11	5.3	11	5.2	16	6.1
	Q3	3	0.9	1	0.5	3	1.4	0	0.0
	Q4	21	6.5	18	8.7	12	5.7	16	6.1
	Q5	52	16.0	27	13.0	46	21.8	38	14.4
Responses	**R1**	14	4.3	5	2.4	13	6.2	17	6.4
	R2	18	5.5	14	6.7	24	11.4	33	12.5
	R3	74	22.8	57	27.4	49	23.2	75	28.4
	R4	27	8.3	30	14.4	29	13.7	26	9.8
	R5	4	1.2	10	4.8	8	3.8	12	4.5
	R6	13	4.0	7	3.4	6	2.8	17	6.4
Facilitator(s) input	**F1**	134	41.2	71	34.1	92	43.6	76	28.8
	F2	10	3.1	18	8.7	18	8.5	11	4.2
	F3	7	2.2	15	7.2	8	3.8	5	1.9

Conclusions and significance

This study investigated changes over time in terms of scientific practices, monitoring, and interactions for two different citizen science projects mediated by group modeling practices. The first webinar section focused on model construction, and the second one was about model refinement. Applying qualitative coding schemes helped us to examine the process of negotiation and group interactions and identify different phases of activity and patterns of action. In particular, the way in which participants applied scientific knowledge and practices in modeling and planning in different phases of group discussion, the overall relation of the discourse between facilitators and participants, and the timing of facilitator input during the discussion suggest that collaborative modeling provides a context for rich discussions with respect to collaborative problem-solving and decision-making. The results suggested that these co-created citizen science projects provided participants with opportunities to work collaboratively and facilitated engagement in scientific practices. Additionally, this supports our conjecture that the models serve as boundary objects for engaging in science practices such as developing and using modeling, clarifying and identifying system components, and constructing solutions. We found there were patterns for group modeling in terms of shifting from bottom-up level to top-down level of discussions. The findings related to the timing of facilitator input suggest that facilitator engagement was strongest in initiating and framing discussions and helping to wrap up the sessions with implications for engagement and ownership of the model as a shared object for negotiation of ideas and knowledge related to the environmental issue that the group was addressing. The facilitators' inputs were less involved in the second sessions for model refinement, which indicated the growth of engagement among participants. This study demonstrates how a collaborative modeling tool can serve as a boundary object that allows citizen scientists and facilitators can engage in meaning making around scientific practices. This suggests that CSCL research and practice can contribute to public engagement in science accessible to a broader citizenry.

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