FACETS
a multidisciplinary open access science journal

RESEARCH ARTICLE

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Place and transformative learning in climate change focused community science

Mark Groulx[a*], Amanda Winegardner[b], Marie Claire Brisbois[c], Lee Ann Fishback[b], Rachelle Linde[d], Kristin Levy[e], and Annie Booth[e]

[a]School of Planning and Sustainability, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9, Canada; [b]Churchill Northern Studies Centre, P.O. Box 610, Churchill, MB R0B 0E0, Canada; [c]Science Policy Research Unit, Business School, University of Sussex, Jubilee Building, Falmer Brighton, BN1 9SL, United Kingdom; [d]Natural Resources and Environmental Studies, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9, Canada; [e]School of Planning and Sustainability, University of Northern British Columbia, 3333 University Way, Prince George, BC V2N 4Z9, Canada

*mark.groulx@unbc.ca

Abstract

Community science involves the co-creation of scientific pursuits, learning, and outcomes and is presented as a transformative practice for community engagement and environmental governance. Emphasizing critical reflection, this study adopts Mezirow's conception of transformative learning to theorize the transformative capacity of community science. Findings from interviews with participants in a community science program reveal critical reflection, although instances acknowledging attitudes and beliefs without challenging personal assumptions were more common. Program elements most likely to prompt participants to identify beliefs, values, and assumptions include data collection and interaction in team dynamics, whereas data collection in a novel environment was most likely to prompt participants to challenge their beliefs, values, and assumptions. A review of 71 climate change focused programs further demonstrates the extent that program designs support transformative learning. Key features of the community science landscape like the broad inclusion of stated learning objectives offer a constructive starting point for deepening transformative capacity, while the dominance of contributory program designs stands as a likely roadblock. Overall, this study contributes by applying a developed field to theorize transformation in relation to community science and by highlighting where facilitators should focus program design efforts to better promote transformation toward environmental sustainability.

Key words: community science, citizen science, climate change, transformative learning, place

OPEN ACCESS

Citation: Groulx M, Winegardner A, Brisbois MC, Fishback LA, Linde R, Levy K, and Booth A. 2021. Place and transformative learning in climate change focused community science. FACETS 6: 1773–1794. doi:10.1139/facets-2021-0003

Handling Editor: Jeff C. Clements

Received: January 21, 2021

Accepted: August 9, 2021

Published: October 28, 2021

Copyright: © 2021 Groulx et al. This work is licensed under a Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and source are credited.

Published by: Canadian Science Publishing

1. Introduction

As the extent and intensity of climate change related impacts increase, widespread social shifts in perceptions and behaviours are needed to promote community resilience and mitigate greenhouse gas (GHGs) emissions. Canada's current emissions target, for instance, calls for a reduction of GHGs to levels 40%–45% below those of 2005 by 2030 (Government of Canada 2021), necessitating a drastic change in energy systems, patterns of energy consumption, and ultimately human behaviour (Rosenbloom 2018). Approaches to promoting the types of shifts in public consciousness that are required to build political will for such change have often espoused some version of the information deficit model. The information deficit model focuses on the knowledge gaps that actors in society may have (e.g., related to the scientific consensus around climate change) and an assumption that desired actions or behaviours can be effectively promoted by filling such gaps through "one-way communication" that conveys expert knowledge about a subject (Hochachka 2021; Suldovsky 2017).

As an alternative to the information deficit model, fields like planning and environmental governance often examine whether and how behaviour change is prompted by ongoing transactions within a social–ecological system, with transactions often prompted by participation in learning, decision-making, or planning forums. Whether at the scale of an organization, a community, or a watershed, scholars identify the need for learning processes that recognize context and place, promote active engagement, and respect multiple ways of knowing (Armitage et al. 2011; Norström et al. 2020). As a way to structure an understanding of such learning processes, a body of theory and empirical research on transformative learning (TL) (e.g., Mezirow 1978) emphasizes critical reflection and the re-examination of our underlying biases and assumptions that can be promoted by instrumental and communicative learning. Mezirow (2000) identifies instrumental learning with an emphasis on prediction and performance attained through environmental manipulation. He distinguishes this from communicative learning, which emphasizes capacity to understand the meaning someone is trying to covey to you, along with the assumptions and intentions such meaning is anchored in.

Community science, or citizen science as it is commonly referred to, often involves not just the conveyance of expert knowledge, but a transaction among participants and others in a process of knowledge co-construction within a defined social–ecological system (Eitzel et al. 2017). Community science can refer to a face-to-face project involving a single scientific lead and a small group of participants (see Ruiz-Mallén et al. 2016), a wholly community-driven scientific inquiry (see Charles et al. 2020), or a virtually connected network of collaborators using emerging technologies and digital platforms to coordinate a research process (see Cox et al. 2015). As community science projects often involve environmental manipulation that supports prediction of environmental outcomes, typically embedded within a complex network of communicative exchanges (e.g., between project leads and participants), community science projects have the potential to support TL around environmental issues (Groulx et al. 2017).

Following Jordan et al. (2012, p. 307), we focus on community science as "partnerships between scientists and non-scientists in which authentic data are collected, shared, and analyzed". Our starting point within this definition is partnerships, but we agree with Jordan et al. (2012) that rigorous and direct engagement in the scientific process is what distinguishes community science from other informal learning experiences that might involve scientific knowledge. We also see community science through the lens of its ambition to push beyond ideas of interdisciplinarity to include nonspecialists in a transdisciplinary scientific practice, through for instance, its role as a tool for public engagement (Jordan et al. 2012; Roger and Klistorner 2016). Ultimately, we see community science as being highly relevant to identifying and creating new pathways for multi-level and multi-actor collaboration aimed at addressing complex and increasingly pressing environmental challenges like climate change, biodiversity loss, and species extirpation and (or) extinctions.

As a transdisciplinary practice, community science is associated with the potential to facilitate TL in support of environmental action, but theoretically guided examinations of this potential are lacking (Bela et al. 2016). Deeper examination of the transformative potential of community science is needed, as despite considerable excitement, good intentions, and extensive knowledge dissemination through academic channels, the impact of community science in the realms of policy and practice has been described as limited (Newman et al. 2017). To address the current empirical gap in what is known about community science and TL, we adopted Mezirow's (2000) TL theory, which situates

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

critical reflection as an engine for the TL process. We used TL theory to operationalize aspects of our research design as we pursued the following objectives: (1) examine whether participants' experiences in a community science program include evidence of critical reflection, (2) determine what aspects of the community science experience prompt critical reflection when it is present, and (3) explore the extent to which the structure/function of community science programs in Canada are designed in a fashion that creates an experience conducive to facilitating critical reflection.

TL is an important focus for climate action scholarship (and practice) because carbon-intensive Western economies like that of Canada are perpetuated by a collective suite of consumptive lifestyle choices rooted in often unexamined beliefs, assumptions, and values (Poortinga et al. 2011; Bentz et al. 2019). We addressed objectives 1 and 2 above through semi-structured interviews that enabled an examination of critical reflection among participants in the Climate Change at the Arctic's Edge (CCAE) community science program, as well as an examination of what aspects of the community science experience prompted any moments of critical reflection. To address objective 3, we systematically documented the structure and function of 71 community science programs as they relate to participant experiences, linking this national snapshot to findings garnered from participant interviews.

2. Research context

2.1. Community science and transformative learning

As Miller-Rushing et al. (2012) acknowledged, the professionalization of science is a comparatively recent phenomenon, and the deeper involvement of "amateur"[1] scientists in scientific pursuits through community science is as much a return to the past as a leap into the future. Nonetheless, community science is enjoying a recent surge in popularity as individuals and organizations express greater agency around scientific goals linked to their "innate interest in particular topics or questions" (Miller-Rushing et al. 2012, p. 285). Such goals may include collecting data from a large geographic area or continuously through time (e.g., CoCoRaHS; cocorahs.org/), promoting Arctic science across schools in Canada (e.g., Schools on Board; umanitoba.ca/faculties/environment/departments/ceos/outreach/sonb.html), engaging community members to develop a collective written record of climate driven environmental change (e.g., Climate Diaries; projects.upei.ca/climate/research/), or accessing alternative forms of research funding (Bonney et al. 2009; Jordan et al. 2012; Oberhauser and Lebuhn 2012; Gura 2013).

Terminology within fields that explore public participation in science has been highly dynamic, reflecting multiple characterizations of community science as a form of research collaboration, a movement to democratize the scientific research process, and a mode of knowledge co-production for informing evidence-based decisions (Eitzel et al. 2017). Recognizing the interdependence of these streams, we view community science as having varying degrees of co-creation in scientific pursuits, learning, and outcomes among a network of "professional" and "amateur" scientists. We use the term community science to refer to what has traditionally been identified as citizen science. Like a number of scholars who have adopted this phrase (see MacPhail et al. 2020 or Nowak et al. 2020), we substituted the term community for citizen to recognize the fact that the term citizen may be viewed as undesirable by many, and to avoid any real or perceived exclusion regarding who should be included in partnerships in developing and conducting scientific studies.

[1] Miller-Rushing et al. (2012) described amateur involvement as the pursuit of science by individuals who were not paid as scientists, rather than by individuals that necessarily lacked a particular body of expertise.

In adopting the term community science to refer to the type of scientific programming described in this paper, we acknowledge that some scholars have adopted this phrase to refer to a broader range of modes through which the public engages with scientific processes. Charles et al. (2020), for instance, recently described citizen science as a form of community science, paying explicit attention to the importance of initiatives that are: (1) community controlled, (2) focused on place-based knowledge and social learning, and (3) normatively directed at improving social–ecological outcomes through transformed governance.

While not reflecting perfectly our view of community science, by linking place, shared learning, and a normative call for transformative change, Charles et al. (2020) identified the importance of explicit political practice in public engagement with science. Their work therefore highlights the need for a clear theory that can bridge the field's emphasis on individual learning and a growing interest in collective environmental action. Here, we focus on TL as one way to explain how members of the public involved in community science might begin the shift from individual participation to broader collective action during or after their experience.

TL is articulated in many conceptual and operational forms and we focus on TL in the tradition of Mezirow's TL theory (Mezirow 2000). TL theory developed out of Mezirow's work to understand barriers that adult learners faced when returning to post-secondary education and particularly from the realization that a personal transformation was part of the journey for many returning students (Kitchenham 2008). No longer focused exclusively on adult learners (Bentz et al. 2019), TL theory examines the context for and process of perspective transformation, with Mezirow (1981, p. 6) describing perspective transformation in early writings as:

> "the emancipatory process of becoming critically aware of how and why the structure of psycho-cultural assumptions has come to constrain the way we see ourselves and our relationships, reconstituting this structure to permit a more inclusive and discriminating integration of experience and acting upon these new understandings".

According to Mezirow's (1978) early conceptualization of TL theory, perspective transformation follows a mutually reinforcing pathway that begins with a disorienting dilemma that is prompted by critical reflection. Critical reflection, in turn, involves intentional scrutiny of the origins and consequences of the habits of mind (beliefs, assumptions, and values) that direct our actions (Mezirow 2000; Taylor 2007). Critical reflection occurs across different levels (Lundgren and Poell 2016; Mezirow 1981), ranging from a state of consciousness that involves simple reflectivity (becoming aware of a habit of mind) to a heightened state of critical consciousness wherein a new awareness of our unexamined cultural or psychological assumptions opens us to engagement with alternative perspectives (Mezirow 1978). **Figure 1** conceptualizes these relationships in a context where place bonding and community science operate as a shared platform for instrumental and communicative learning. The following section discusses this shared platform in greater detail.

2.2. Place as a platform for perspective change through community science

A growing number of studies that focus directly on the learning benefits of community science acknowledge that the research-based nature of the experience creates a unique opportunity to (re)connect people to the environment and develop a deeper sense of place (Haywood et al. 2016; Newman et al. 2017; Wals et al. 2014). This emerging focus is important to understanding the transformative capacity of community science, which often involves hands-on learning in culturally valued natural environments. As a social–psychological construct, sense of place or place bonding has been modelled in myriad ways, but often includes three interrelated processes:

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

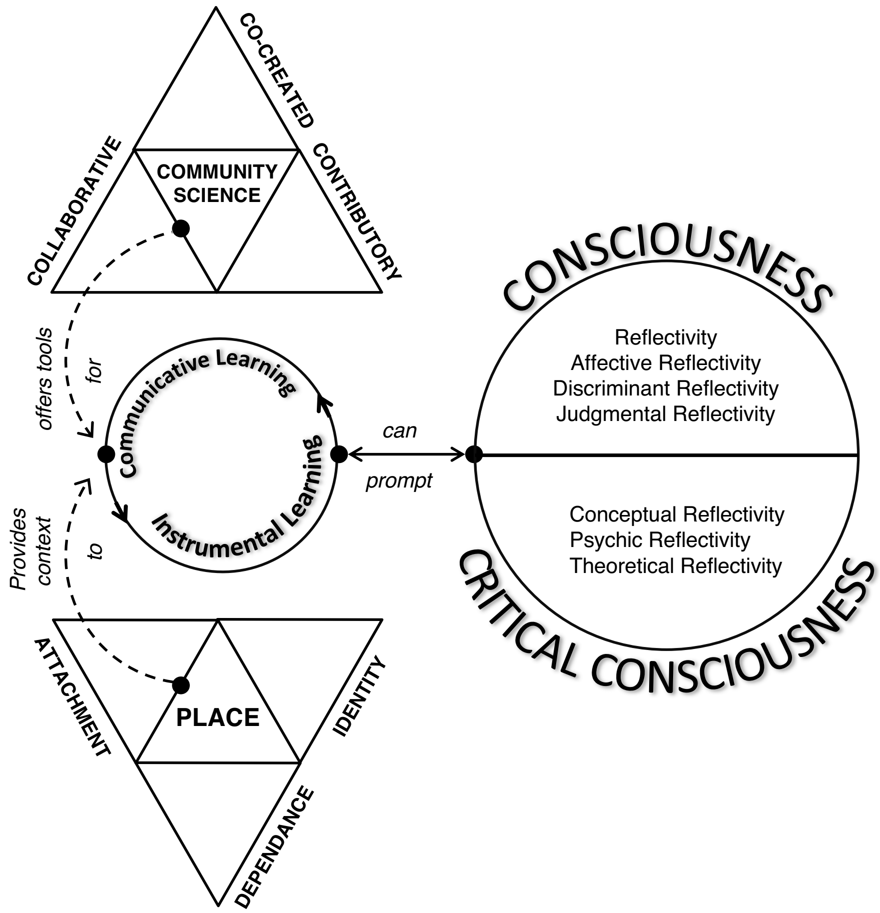

Fig. 1. Conceptual model relating community science, place, and transformative learning.

(1) the construction of place identity, which involves the incorporation of a social–ecological context into one's sense of self; (2) the development of place attachment, or the emotional bond that develops with a social-ecological context; and (3) place dependence, described as the capacity for a social–ecological context to meet a person's functional needs (Jorgensen and Stedman 2006; Scannell and Gifford 2010).

Kudryavtsev et al. (2012) described place-based education as learning that is focused on local environments and facilitated through inquiry and interaction in a particular place. Through an integrated approach where educational programming brings together hands-on experience in a local environment with instruction and interpretation, place-based education can not only deepen participants' sense of connection to a landscape through the above processes, but also make hidden ecological and cultural values visible (Kudryavtsev et al. 2012). Gruenewald (2003, p. 636) agreed presenting place-conscious education as an opportunity to "teach us who, what, and where we are, as well as how we might live our lives".

By definition, place is a negotiated and multifaceted construction of socio-ecological meaning that is tied to a particular social–ecological environment (Relph 1976; Lewicka 2011; Kudryavstev et al. 2012). As the model above conceptualizes, community science programming can offer the motivation and quite literally the tools to work and learn within a particular social–ecological context or place (e.g., a watershed). This programming might vary significantly in the degree to which community is involved through partnership to set priorities for knowledge co-production. Programs could range from contributory designs led by scientists with public involvement limited to data collection, to co-created projects that are a joint initiative including scientists and members of the public, with public leadership at most or all stages (Miller-Rushing et al. 2012).

Given the range of community science program designs, ways that place bonding might interact with community science activities to support instrumental and (or) communicative learning, and critical reflection, should be expected to be diverse. Feick and Robertson (2021) offered one opportunity for distilling this complexity in a place-informed discussion of community science that delves deeper into the nature of learning and expertise. Reformulating Collins' (2013) original dimensions of expertise (i.e., esoterocity; contributory; interactional), they identified two facets of place-based expertise related to community science participation. The first is the degree of "locale familiarity", or the extent that accumulated experience in place provides local knowledge about its social–ecological systems. The second is the degree of "place-type" expertise, described as a body of transferable knowledge about a specific class of place (e.g., coral reefs). While the acquisition of both forms of place-based expertise through community science experiences might reinforce conditions conducive to critical reflection, studies have shown that accumulation of local familiarity or local knowledge (in particular) can lead to new relationships to place that facilitate critical reflection (Walker and Moscardo 2016; Simm and Marvell 2015).

Numerous community science studies examining participant learning outcomes have demonstrated a capacity for participation to enrich locale familiarity, and subsequently participant behaviour in relation to that locale. The Neighbourhood Nestwatch program, for instance, sought to enhance place bonding and knowledge of avian ecology by encouraging participants to engage with project materials (e.g., data collection protocol; project website) as they observed and reported on the nesting behaviour and success of eight common backyard bird species. Participants' reflections illustrated new understandings of the ecology in their backyards, and this learning was linked to a change in behaviour within this newly valued habitat (Evans et al. 2005). More recently, studying participant experiences in the Coastal Observation and Seabird Survey Team (COASST) project, Haywood et al. (2016) found that involvement in a program monitoring seabird mortality and marine debris led to an increased sense of attachment to the beaches being monitored, as well as an increased consciousness of coastal phenomena.

The transformative potential of community science is broadly recognized, but research documenting how community science programs might contribute to transformation is limited (Bela et al. 2016). If community science seeks to not only develop connections between person and place, but promote socio–ecological benefits by changing the habits of mind that direct our action in the world, programming efforts must emphasize activities that foster reflection on and motivation for different ways of knowing and doing (Jordan et al. 2012; Wals et al. 2014).

3. Methods

3.1. Mixed-method approach

Mixed-methods research designs are commonly used to address multifaceted research objectives, similar to the ones in this study (Bryman 2006). A hallmark of mixed-methods research is the selection and combination of methods that emerge from a research objective or problem, rather than a commitment to a particular research paradigm or methodological orientation (Greene et al. 1989; Johnson and Onwuegbuzie 2004). The term mixed can refer to integration of research approaches

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

or techniques at different stages of the research design, including mixing of quantitative and qualitative techniques as late as data analysis and reporting or as early as project conceptualization (Bryman 2006).

In this project we adopted two complementary research methods and applied mixing in the interpretation and discussion of our key findings from each method. Specifically, we conducted a matrix review that analyzed 50 variables documenting the design and function of 71 community science programs (Ritchie and Spencer 2002). The purpose of this method, outlined in more detail below, was to survey a broad range of programs to map the context in which community science experiences related to climate change are taking place in a Canadian context. Results from the matrix review do not directly address the question of how participants might experience community science programming or what the impact of these experiences can be with regard to critical reflection. To address this aspect of our research objectives we conducted semi-structured interviews (described in detail below) with participants in one of the programs covered in our matrix review.

3.3. Interviews with participants

To address the question of whether and how community science experiences can prompt critical reflection, we conducted semi-structured interviews with participants in a community science program. Following an extreme case selection approach, we chose the “Climate Change at the Arctic’s Edge” (CCAE) program in Churchill because we believed its distinct environmental context and strong focus on education offered a case where there would be sufficient experiences and thus evidence to examine TL (Patton 1990). Following this case selection logic, we were less interested in generalizing results to all community science programs than establishing a benchmark for what aspects of a program can, but not necessarily will, prompt critical reflection. We were also interested in informing how TL might be conceptualized in the realm of community science (i.e., analytic generalizability) (Onwuegbuzie and Leech 2010).

The CCAE program is hosted at the Churchill Northern Studies Centre (CNSC) in Churchill, Manitoba, Canada, and is facilitated via a partnership between the Earthwatch Institute and researchers at the CNSC. As part of the program, small teams of participants travel to Churchill from around the world to take part in long-term monitoring projects related to climate change. Projects have included snowpack sampling and methane bubble mapping on frozen wetlands and the use of ground penetrating radar to measure permafrost depth, among others. The CCAE program can be described as a contributory design, although it is housed within the CNSC and informed by an organizational culture rooted in the community of Churchill through ongoing community outreach, board representation, and employment of community members on staff.

Participants in the CCAE program are somewhat unique as community science “volunteers” in that they pay to cover costs associated with the administration of the program, although Brosnan et al. (2015) identified community science, including programs ran through EarthWatch, as a growing form of voluntourism. Teams typically participate in the CCAE program for a two-week period, though some shorter excursions occur, and participants are housed at the CNSC in accommodations shared with researchers, school groups, and some tourists. The participants on each team vary and can include youth/student teams, “retail” teams including any member of the public, or corporate teams where participants are generally employed by a single company but join from many locations.

After one or two days of orientation and training, participants take part in full days of fieldwork in various environments and also help sort and process samples. Some projects involve laboratory work, and generally team members are responsible for data entry and management. Evening activities throughout the program include lectures and workshops related to climate change, subarctic ecology, and the scientific method. At the end of the fieldwork, participants receive a summary of their work and how it fits into the larger project.

We connected with 18 participants at the end of their experience in the CCAE program. Semi-structured interviews were solicited as part of a broader study examining participant experiences that also involved participant surveying (we focus only on interview data here as survey data are fully reported elsewhere—see Groulx et al. 2019). Participants were invited to take part in an interview after completing a short (~15 to 20 min) postexperience survey. As participation in the CNSC program involves only a few small teams each year, data collection occurred over an 18-month period, with recruitment coinciding with the timing of program offerings. The opportunity to participate in the study, along with a description of the study's procedures and ethics approval (University of Northern British Columbia REB # E2016.0324.027.00), were provided to each group upon arrival at the CNSC by a member of the research team. Typically, one to three members of each small group (~5–6 participants on average) agreed to participate.

Semi-structured interviews adopted an open format that encouraged the sharing of stories. Conversations covered four broad themes, including: expectations and motivations for participation; self-perceived learning outcomes; potential shifts in thinking about environmental issues; and the possible adoption of new roles, relationships, and actions related to climate change. To ensure consistency in the interview format, a single member of the research team conducted all interviews.[2] For one group, interviews were completed in Churchill on the last day of participants' program experience ($n = 4$), but most interviews were completed by Skype or telephone after participants had returned home ($n = 14$).

All interviews were recorded with the consent of participants and were transcribed for thematic analysis. To enable a theoretically informed analysis, we applied a coding framework based on Mezirow's (1981) description of different levels of reflection. This coding framework was originally developed by Liimatainen et al. (2001). The framework operationalizes Mezirow's seven levels of reflection and was used by Liimatainen et al. (2001) to assess the promotion of critical thinking among nursing students in a clinical training program. Minor adaptations to the code descriptions allowed for an application of the framework to an environmental learning program, as shown in **Table 1**.

Coding of interviews occurred in two stages and involved two independent coders who completed their work using the NVIVO qualitative research software package. During stage one, the critical reflection codes shown in **Table 1** were applied to participant transcripts that had been assigned a pseudonym to identify instances and levels of reflection associated with the community science experience. The two coders met on multiple occasions to discuss and compare their application of the codes to an overlapping set of transcripts. Once agreement on appropriate application was reached, a single coder completed all coding to ensure consistency. To address research objective 2, during a second stage of coding we returned to each coded instance of reflection to examine the context in which that reflection occurred. We were interested in, and using NVIVO's relationship function coded for, elements of participant's community science experience that were evident as a trigger for reflection.

[2]On average, participants in virtual interviews illustrated a somewhat higher number of instances of reflection, suggesting the time between the experience of the program and the interview may have enabled reflection. The sample size and distribution does not allow for robust statistical analysis.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Table 1. Reflection codes and descriptions (adapted from Liimatainen et al. 2001).

Level of reflectivity	Description
Consciousness	
Reflectivity	The participant becomes aware of a specific perception, meaning, or behaviour of their own and they are able to verbalize new experiences and perceptions.
Affective reflectivity	The participant is aware of the way they feel about their perceiving, thinking, or acting in the situation. The participant is aware of other participants' feelings.
Discriminant reflectivity	The participant assesses how they managed in their practice. Assessment of the efficacy of perceptions, thoughts, actions, immediate causes. The participant identifies discrepancy between what is planned and what really happens.
Judgemental reflectivity	The participant becomes aware of value judgements made by them and colleagues as well as the inconsistency this can bring to practice and actions.
Critical consciousness	
Conceptual reflectivity	The participant assesses the adequacy of the concepts they use to understand environmental issues. The participant begins to question whether the concepts they use are adequate for making sound judgements and to identify what else they need to know and learn to understand and act in the situation.
Psychic reflectivity	The participant recognizes the habit of making precipitant judgements about environmental issues based on limited information.
Theoretical reflectivity	The participant becomes aware of why one set of perspectives is more or less adequate to explain personal experience and moves towards those that best fit the situation.

3.2. Matrix review of existing programs

The purpose of the matrix review portion of this study was to perform a cross-sectional examination of Canadian community science programs with a climate change focus. A matrix review is a structured approach to appraising, deconstructing, and organizing descriptive text across a number of similar cases, using a range of data sources and a predefined list of criteria. Climate change focused programs are emphasized because the literature suggests more documentation is needed around the contribution of community science to action on pressing socio-ecological challenges (Bela et al. 2016; Newman et al. 2017). In this review we identified programs and extracted data on their goals, operation, participant involvement, and data products. Our objective was to document high-level factors that indicate the relative presence or absence of circumstances conducive to prompting critical reflection. Projects and programs were considered to have a climate change focus if they: (1) referred to either "climate change" or "global warming" in their research or learning objectives, (2) explicitly tracked climate patterns over the long term or focused on weather anomalies, (3) studied the effects of climate change on organisms or ecosystems, or (4) used organisms or ecosystems as indicators of climate change.

The matrix review relied solely on secondary data sources including program descriptions published in the literature or on program websites, and program documentation provided by various organizations. Following Ritchie and Spencer (2002, p. 3), our matrix review utilized the logic of a contextual policy analysis, wherein the goal was to "identify the form and nature of what exists". Following their FRAMEWORK process, we went through stages of familiarization with program content, development of a thematic matrix, indexing of programs, and the charting of program data. Ultimately, we included programs based on the following parameters:

- The program was based in Canada or had a project scope that includes areas of Canada (e.g., North America as a whole).
- The program collected inquiry-based data.
- The program was focused on climate change (as outlined above).
- The program was documented sufficiently to allow for assessment according to criteria in our matrix review.

Candidate programs were assessed for inclusion in the review through internet-based searches that began with an examination of all the projects posted on the community science database websites[3] CitSci (citsci.org) and SciStarter (scistarter.com/). Information provided in the databases and on external program sites was then used to assess inclusion against the criteria above. Following this we used organizational websites to identify sources of documentation for completing our data matrix. Indexing of our selected programs included documentation of program design characteristics that were relevant to participants' learning experience. Each program was also categorized according to its overall design following the typology presented by Bonney and colleagues (see Section 2.2 above).

The matrix was populated with data on a program-by-program basis and memos were used to ensure data extraction was carried out in a reliable fashion.[4] Here, we report on a subset of the 50 total variables indexed during our review that are most relevant to understanding the community science program design landscape as it relates to conditions for critical reflection. Results for reported variables are shared as simple descriptive statistics, with the exception of the textual data for program learning objectives, which were subjected to a ground up thematic analysis following methods described by Charmaz (2014). Three themes (community science as research utility, community science as collective learning, and community science as collective action) that emerged from this analysis were used to integrate results from our two streams of data collection.

4. Results

Coding of our interview data revealed that reflection among participants was not equally distributed across the levels of the TL coding framework we adopted. As **Table 2** illustrates, all participants demonstrated at least some form of reflection along Mezirow's hierarchy, and all levels of reflection were demonstrated by at least three of the 18 participants that we interviewed. Despite this, the forms of reflection that Mezirow (1978; 1981) associates with consciousness (i.e., an acknowledgement of habits of mind) were more prevalent than forms of reflection that are indicative of critical consciousness (i.e., a challenging of assumptions). More specifically, fewer participants demonstrated instances of conceptual, psychic, or theoretical reflectivity (i.e., critical consciousness), and there were fewer overall instances of these forms of reflection ($n = 43$) compared with forms of reflection illustrating consciousness ($n = 165$). Affective reflectivity, wherein a participant becomes aware of how they feel about their perceptions or behaviour was the most common (48 instances), while psychic reflectivity, wherein a participant illustrates an awareness of making judgements with limited evidence, was the least common (4 instances).

[3]These websites act as both databases for community science projects and a way for organizations to recruit volunteers/participants and in some cases, for participants to submit data.
[4]The final matrix review contains information about the structure and function of 71 community science programs that are/have been active in Canada and that have a climate change focus. Program documentation ranged from 46% to 94% complete, with programs having 75% of variables filled in on average. Rates of missing data were influenced by our choice to use secondary data sources and are shown in full in the **Supplementary Material**.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Table 2. Level of reflection coding results.

Form of reflectivity	Participants/ instances	Example participant comments
Consciousness		
Reflectivity	15/47	I think what surprised me a little bit—I come from . . . a world of words; I'm an attorney. So, you know, my day is trying to avoid numbers. But—try to twist the facts, and all those things. But, interesting to me is that the one set of . . . data that is collected can be utilized and dipped into by so many different projects. And so many different things . . . that might not even be contemplated at the time.—Alex
Affective reflectivity	16/48	Now that I know [what] I'm doing . . . so now I feel I'm, I'm good at it. But it made me good. Because like, one of the last days that we were there, one of the . . . I don't know, she's a student that's up there for the summer that's doing assisting. She was like, 'hey can you come with me and, and help me do this'? And I was like, 'me? Do this? Me?' I was very proud of myself. So it was a neat experience.—Alyana
Discriminant reflectivity	15/40	It really helps me realize that even though I'm just a girl in Springfield, and I'm a history teacher, that I can have an impact? And if I can show other people? That's just as important as me . . . making sure that I don't use too much electricity, making sure that I use my recyclable . . . . That, you know, all the things that I always knew were good for the environment.—Alyana
Judgemental reflectivity	12/30	I guess because of replications, a lot of that will be washed out. But just thinking about how we did some of the things, it wasn't particularly random. Which I think is probably an ideal piece of this puzzle. The sampling of the ponds, sometimes [especially on a long day]: "well, where did you sample? well, where it was convenient." Where muck wasn't going to go up to your knees.—Charlie
Critical consciousness		
Conceptual reflectivity	12/23	It's come up most often in the context of . . . the rebuttal argument that seems to be the most common one that I hear, which is, "we've had these cycles before. They don't mean anything. It's just the cycle." And to be able to say, "you know what? There are a couple of really interesting charts and graphs that I've seen, and that I saw, that will show you maybe why that's . . . not quite case. You're absolutely right—there are cycles." But to take . . . the part of that statement that is true and show how it's still a conclusion that's not what we're in. And be able to back that up with, you know . . . "here's the CO_2 graph. And, and oh let me tell you why you have the cycles—that's because of the tilt, wobble and roll of the earth that we learned about." And taking all those bits and tiny pieces and understanding really how some of that whole system functions.—Navdeep
Psychic reflectivity	3/4	We were expecting, on the end of things [on the end of the research] there will be something tangible behind us saying, "ok, so we now know that tree line is doing this and that because of this and that. And there is an influence here." While in fact actually this is a data collection that actually needs to go for the next 50 years to actually being able to interpret something.—Dae
Theoretical reflectivity	12/16	The fact that the temperatures are rising, the fact . . . that the amount of snow and the amount of ice is decreasing. I think that is undisputable. How we—how this happened? That's one part of the story. What we can do, do to actually slow, to slow the pace . . . I think that's what's' important, right? And I think that's, kind of, what I find most valuable for myself. That I did actually come back and now when we separate our trash—and we put paper on one side and we out plastic on the other side and then kind of take different elements like glass in a different container . . . that is actually now—makes a bit more sense to myself. And this is just a one small tangible example right? I think there are other examples. But it can kind of make sense why we are actually doing this.—Dae

While our matrix review examined a range of program characteristics, we paid particular attention to learning objectives across the 71 programs. Reported learning objectives were stated for the majority of projects (~61%), although learning objectives directly related to climate change were only present in approximately 15% of cases. The remaining balance of learning objectives emphasized the specific knowledge domain of the project, and thus an implicit link to climate learning. Consistent with our mixed-methods approach, we completed a thematic analysis of all available program learning objectives and identified three overarching themes that are used below to integrate findings from our interviews and broader matrix review.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

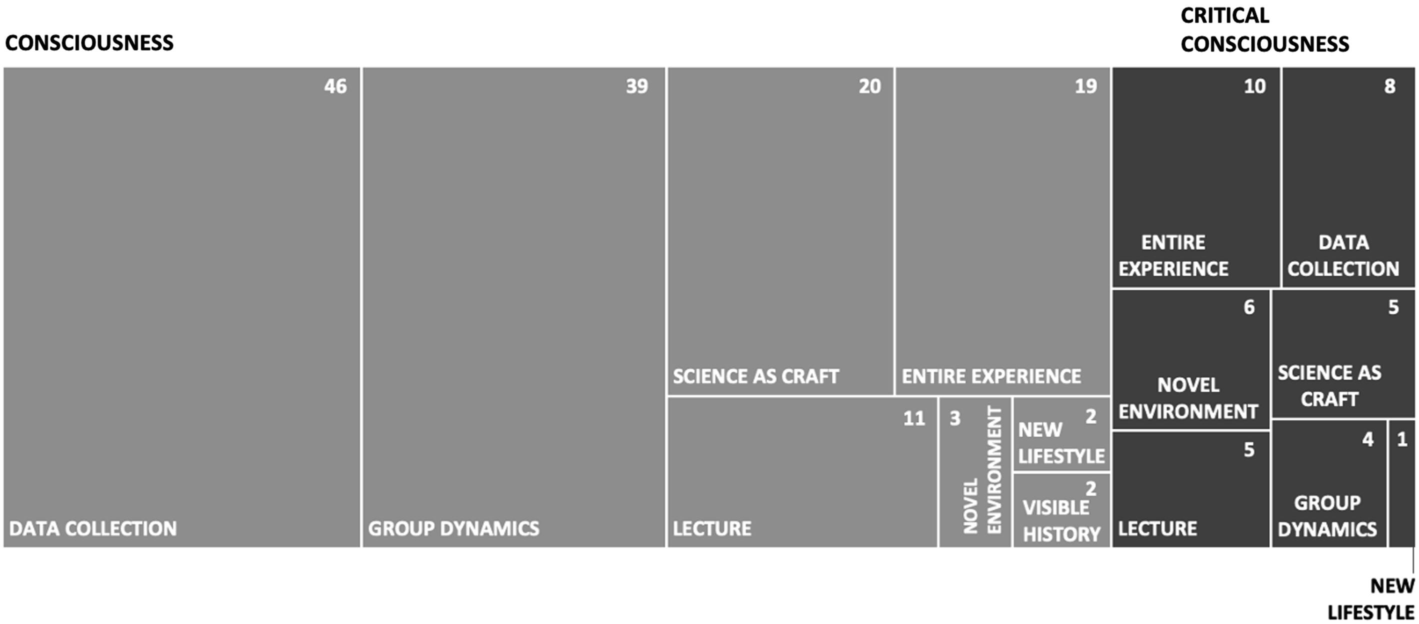

Fig. 2. Triggers of consciousness and critical consciousness in the CCAE program.

4.1. Community science as research utility

As part of our interview analysis, we examined the elements of the community science experience that were evident as a trigger for the levels of reflection that participants illustrated. As Fig. 2 shows, direct engagement in the research process through data collection was the most cited of seven triggers for critical reflection ($n = 54$). This trigger for reflection did not appear to operate entirely independently, and served as a vehicle for another common trigger that we termed "science as craft" ($n = 25$). The notion of science as craft spoke to scientist's willingness to share not just the steps required of a data collection task or the appropriate technical use of instrumentation, but also the embodied experience they had accumulated through a lifetime of enacting rigorous data collection.

Like a person learning to cook with their grandparent, participants appreciated not just being given the recipe and correct kitchen utensils, but having their hands together in the dough with an experienced cook, receiving ongoing instruction, and learning as they go. Indeed, participants discussed several aspects of the CCAE program (e.g., evening lectures) as a source of greater appreciation for climate science, but the caring oversight and close input from trained staff appeared to elevate this appreciation to a deeper level of reflection about actions they could take to become better environmental stewards.

> "Also getting to you know, talk with staff about a lot of the sort of sample and experimental design. Issues that come up and had to be explored. I even wrote in the journal, because I was the journal guy the other day, I said I may just have to go home and start learning more science because I just am not a science guy."—Ted

Interview findings identifying data collection as a key source of reflection for participants closely relate to a prevalent framing of community science that we identified from reported learning objectives. We labelled this framing as "community science as research utility". This title reflects the fact that a majority of learning objectives highlighted participants' role in contributing to a scientific data set and, in doing so, on gaining capacities to independently apply the scientific method. A focus on benefits to the learner was present within this framing, but almost entirely through the promise of filling gaps in their environmental knowledge. This is consistent with the goal of addressing the public's information deficits around science and environmental issues. The Winter Bird Count in the Rouge, for instance, listed the following learning objectives: "(1) To learn and gain an appreciation for the bird diversity within the Rouge; (2) To start learning the basics of bird identification by sight and sound; (3) Teach the public the difference between migrant birds and resident birds."

Findings from the matrix review reveal that the types of data collection that might be tapped to spur critical reflection predominately relate to long-term monitoring designs. Approximately 80% of projects adopted this research design, followed by hypothesis testing (~3%), hybrid project designs (~7%), or other designs (~10%). Across these designs the opportunity to strengthen reflection during data collection through additional training and mentorship was only partially captured. Specifically, only 80% of projects provided readily available data collection protocols while only 70% went beyond a written protocol by including supplementary learning supports like digital videos, a frequently asked questions site, or face to face in class and field instruction.

4.2. Community science as collective learning

Relevant to Mezirow's (1978) description of communicative learning, the second most common trigger for critical reflection was interaction with other community scientists within "group dynamics". As one participant (Alyana) offered in a moment of affective reflectivity, these interactions offered a means to build confidence as a scientist and in her words, to feel "very proud of myself" (see **Table 1** for full quote). In the context of the CCAE program, these dynamics were fostered not just by a project design that involves participants working in teams and alternating roles over the course their involvement in the project, but living with one another in the relatively close quarters of a remote sub-arctic research station.

Co-located amid the tundra landscape over 20 km east of the already remote town of Churchill, for nearly all participants the CNSC was a place to share in the experience a "novel environment". This experience of a new place was a noted trigger that promoted levels of reflection associated with increased consciousness, and was the third most common trigger that promoted levels of reflection associated with increased critical consciousness. Although expressed by just over half ($n = 11$) of participants, the extended time spent together at the CNSC and on the tundra collecting data appeared to reflect the type of disorienting dilemma described by Mezirow (1981) . The source of this dilemma varied according to the particular relationship each participant developed with this new place. In one instance it was the difference between the rhythms and pace of a life in the city and life on the tundra that gave pause for reflection, but in multiple cases it was simply being caught off guard by the awareness of a growing bond to this new natural environment that became a window to different ways of thinking about how to relate to nature.

> "I think definitely it was the relationship. Especially all the beautiful plants out there, the scenery. When we were sampling some ponds, we saw all these flowers and things along the way. It's just really, I think the beauty of the place itself just really throwed me too, and got me thinking about improving."—Jamie

The apparent importance of fostering group dynamics within community science projects was also captured in the second, albeit less prevalent, framing we identified through our thematic analysis of program learning objectives. This framing was learner centred, emphasized "community science as collective learning", and situated relationship building that contributes to knowledge co-creation as a key rationale for community science. ArcticNet's Schools on Board program, for instance, highlights

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

a desire "[t]o encourage and initiate collaboration between students, and with other ArcticNet members".

Despite a recognition of the importance of group dynamics, less than half (48%) of reviewed projects included explicit mechanisms (e.g., team-based data collection) to foster interactions between community scientists. Where collaboration with other participants was planned for, it was either directly built into the design of the project (e.g., participants joining a blitz event at a shared location) or was encouraged through instruction to develop community science teams that support shared research activities.

Matrix review data revealed few relevant insights about how place was leveraged to support collective learning, although some key findings emerged. Geographically, learning objectives were applied across a wide range of scales. Programs covering an international (i.e., multiple counties) scale (~30%) were the most common, followed by programs covering a local/regional (~24%), global (~17%), national (~15%), provincial/territorial (~8%), and inter-provincial/inter-territorial scale (6%). Moreover, some learning objectives sought to build a place-based understanding of community science data, although these two programs were clear outliers. In the All Métis Environmental Monitoring project (scistarter.org/all-metis-settlements-environmental-monitoring), the importance of place was captured by linking land and climate change in "land-based learning activities at the K-9 school [and] facilitating workshops on topics including dendrochronology, climate change, drone flying, rabbit snaring, traditional herbs and even gun safety."

4.3. Community science as collective action

Beyond engaging in collective learning through their community science experience, participants further underscored the importance of group dynamics as a catalyst for reflection by sharing their view that involvement in the CCAE project was itself a practice of collective action. In this case, the opportunity to engage in group dynamics during research activities provided a means to place their individual stewardship efforts in a broader context that revealed the value of collaboration. At the scale of interactions during data collection activities, the ability "to be out and about with other science people" served as an affirmation of beliefs that were not always supported in family, work, or social environments outside of the community science experience. At a more abstract scale, the practice in the CCAE program of plotting data from each team with data from other teams, and visualizing this collective output, prompted an appreciation for how individual efforts can coalesce into something more meaningful and impactful.

> "So the process was basically mass sampling of these wetlands for the majority of what we were doing. And I think you basically feel like a small cog in a big work wheel. A big system. But it's quite an important part to play. It was quite nice at the end when we did the wrap up lecture. We surveyed 3.5 football pitches worth of stuff and had thousands of data points."—Tiffani

In the third framing of community science identified through our thematic analysis of program learning objectives, an explicit intent to support collective action efforts was apparent. Most directly, a small number of programs ($n = 11$) included statements related to collective action intentions, including the Birds Canada's Marsh Monitoring Program, wherein community-collected data are identified as an outcome that is valuable in marshland planning and monitoring efforts. Environment Hamilton's Trees Please project likewise sought to engage neighbourhood residents in tree inventories and air quality monitoring to drive what they refer to as "strategic tree planting" in areas with poor urban tree canopy coverage.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Unlike the theme of collective learning, the theme of collective action explicitly identified ways to mobilize co-created knowledge beyond the programs and spaces where it was created. The Community Collaborative Rain, Hail, and Snow Network (cocorahs.org) sought to create avenues for knowledge to flow through transdisciplinary networks by "participating in social networking experiences", while the CyberTracker project (cybertracker.org) has harnessed community science to help build up the profession of tracking, revive the traditional skill of tracking, and promote "the employment of trackers in education, ecotourism, conservation management, search and rescue, anti-poaching, wildlife monitoring and scientific research". Beyond these few stated objectives, the broader network of community science programs appears to have only partially capitalized on the opportunity for collective action, with a considerable majority of the projects conforming to contributory designs (~77%), followed by co-created (~10%) and collaborative designs (~6) that involve greater public partnerships in setting priorities, carrying out research tasks, and mobilizing knowledge that is created.

5. Discussion

Application of a TL coding framework to interviews about participants' community science experience found that community science programming can be a source of critical reflection for participants, and therefore has the potential to condition the cascade of events that leads to deeper perspective change. In the case of the CCAE program, all participants showed some level of critical reflection, although instances where this reflection challenged previously held assumptions were less common than instances involving a basic recognition of one's views. It is important to highlight that this finding stems from a somewhat distinct travel-based community science program, and that while the group of interviewees was diverse in terms of cultural background, age, and gender, all had the financial means to participate in an Earthwatch program (and (or) were in a position to have an organization sponsor their involvement). Nonetheless, our study is among the first to explicitly use TL theory to examine the extent and source of critical reflection in community science.

As Charles et al. (2020) argued, to move toward a broader positive impact of community science on environmental governance processes, and ideally environmental outcomes, the field needs to create intentional opportunities for knowledge co-creation that are tied to place. Within the environmental governance literature, co-creation or knowledge co-production is explicitly described as a collaborative process involving multiple interacting knowledge frames aimed at solving a complex problem (Armitage et al. 2011). Norström et al. (2020) added that respect for multiple ways of knowing, clearly articulated and shared goals, a process that recognizes context or place, and an environment that enables learning and active engagement are all key to shifting individual capacity and efforts toward a collective pursuit.

Three key findings from our study are relevant to understanding the capacity of community science programming to create the conditions described above. First, for the majority of the participants in the CCAE program, the community science experience created an opportunity to reflect on their system of beliefs, and (or) how these beliefs guided their actions in the world. We cannot state whether a long-term perspective change stemmed from this reflection, but this moment of reflectivity is an important precursor to this outcome. Second, our results show that beyond defined research objectives, a notable majority of programs explicitly articulated learning objectives. Stated learning objectives were not specific to climate change or collective climate action in all cases, but the large proportion of programs that framed participants as learners and not just data collection instruments is a step towards viewing community science as a platform for bridging knowledge networks in support of environmental action (McGreavy et al. 2016).

Third, while our results illustrate critical reflection within a contributory community science program, collaborative and co-created programs offer greater influence to members of the public

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

and might be expected to garner unique opportunities for spurring reflection that were not captured here. Given this, with over three-quarters of reviewed programs following a contributory model, there is arguably space to more fulsomely promote TL through greater collaboration and grassroots leadership within the realm of community science and climate change.

At a point in time where opportunities to conduct science in remote places like Churchill are curtailed due to COVID-19 induced travel restrictions, the benefits of empowering communities to lead scientific pursuits is relevant to maintaining the continuity of scientific discovery. Where communities have long-standing connections to their local environment and strong social ties, community science can also provide a structured means for individuals to organize as a collective. As Haklay (2018, p. 133) noted, a community-driven approach to community science is "a tool of empowerment in the political sense as it provides both 'hard evidence' that emerges from scientific instruments or sensing devices, and methodology which supports a specific narrative that is of importance to the people who put it forward. It becomes an accepted form of evidence-based decision-making."

Just how to design and leverage community science programming in support of TL and collective environmental action is a question of considerable complexity. In the case of this study, higher levels of reflectivity associated with a critical consciousness were linked to all but one of the identified triggers for reflection. Beyond the influence of the experience in its entirety, the data collection process and the experience of a novel environment were noted most often. These two elements are not necessarily synonymous, as participants had opportunities to explore Churchill's tundra landscape outside of program activities (e.g., through guided tours during downtime). That they simultaneously emerge as the most common prompts for deeper levels of critical reflection, however, is unlikely to be a coincidence. Charles et al. (2020) recognized the co-creation of place-based knowledge as a best practice for impactful community science, whereas Newman et al. (2017) argued that strengthening place identification through community science can create special opportunities for new connections and collaborations.

As our findings show, one way to create actors ready for new collaborations may be to catalyze critical reflection by exposing them to deep place learning through scientific data collection in a novel environmental setting. The following quote from Andy, a participant in the CCAE program, speaks to this potential.

> "I tell you this much. I thought you guys were just goofing around over here. You know I'm not, I guess to be candid, before I came here, I was kind of like a climate change, not denier, but very strong sceptic of things. But the way that staff presented the information. I thought it was like, well hell it's not even like whatever theory you want to apply to it, there is change going on, right. It's measurable change, and the numbers are there. And if you are here, all this work is one blip on the graph, and it builds up over thirty or forty years. So you forget the amount of effort that went into every single data point, right? And it just makes it that much more… valid. It really puts it into perspective."—Andy

Although linked less often to heightened levels of critical consciousness, other aspects of the CCAE program experience were noted more often as a catalyst for critical reflection. In support of calls to explicitly foster personal transformation through community science, interactions among participants in the community science team and with project personnel in the detailed application of scientific techniques were the second and third most noted triggers for critical reflection. Prompting greater collective environmental action through community science involves shifting participant learning from an enhanced understanding of environmental issues to an enhanced preparedness to engage with others in developing solutions. Building capacity to communicate ideas, beliefs, values, and feelings (i.e., building capacity for communicative learning) is thus key to fostering this step and

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

requires opportunities for participants to interrogate bedrock assumptions and test new ideas and beliefs through dialectic exchange (Groulx et al. 2017; Taylor 2007).

Within the governance and sustainability domains, building competence to recognize and engage with multiple ways of knowing is seen as being so critical to knowledge co-production as to be declared a pillar of the approach (Emerson 2018; Norström et al. 2020). Evidence here suggests that within the realm of community science and climate change, there is already an established foundation for advancing this work. With explicitly stated learning objectives common across well over half of the studies we reviewed, programs interested in advancing collective action should adopt explicit and appropriate learning objectives related to promoting critical reflection and communicative learning and examine what existing or new aspects of their community science experience could support these outcomes. A large majority of reviewed programs already include explicit training protocols to ensure robust data collection. If personal transformation and collective action are valued, training for competencies in teamwork and collaboration should be built into this existing program function.

6. Conclusion

Beyond expanding general acceptance of the scientific reality of climate change, societal efforts that promote climate solution-making are urgently needed. Much of this work within the realms of sustainability and environmental governance is currently framed as a call for intentional knowledge co-production, with a broad recognition that knowledge of place, mobilization of scientific evidence, and collective action will be intimately linked in successful climate solution work (Armitage et al. 2011; Emerson 2018; Norström et al. 2020). As a general field of study and a specific form of designed intervention, community science is attracting growing attention because of its capacity to embody these principles. Indeed, references to the transformative potential of community science are common, despite calls for greater empirical examination into the extent of and source of this capacity (Bela et al. 2016; Groulx et al. 2017).

In this study we drew on Mezirow's (2000) TL theory and examined community science programming as a potential catalyst for critical reflection, and by extension, for the types of perspective change and dialectic exchange that create novel opportunities for authentic collaboration and shared action. Interviews with individuals who travelled from around the world to Churchill, Canada, to take part in the CCAE program showed that community science programming can prompt such reflection, including levels of reflection where individuals challenge their existing beliefs, assumptions, and values (i.e., critical consciousness). A wider review of 71 climate change focused programs suggested some aspects of the community science landscape in Canada, like the extent to which programs have clearly articulated learning objectives, offer an existing foundation for promoting greater transformation. Others, particularly the degree to which programming is led and controlled under a contributory model, represent likely bottlenecks to the journey from individual climate learning to collective participation in ongoing climate action.

The findings from our study should be interpreted in light of several key limitations. First, we relied on secondary data sources to complete our review of community science programs, and due to missing data, were limited in the scope of the findings that we could reliably communicate. Second, we focused only on community science programs with a climate change emphasis and a footprint in Canada, limiting the potential generalizability of our results. Third, our deeper examination of critical reflection included only a single community science program, and while this program was diverse along many lines (e.g., age, gender, nationality), participation was somewhat homogenous in terms of socio-economic status. This latter limitation is an important consideration, as the ability for community science to democratize science as an evidence-based and political tool is well recognized (Haklay 2018; McGreavy et al. 2016), but so too is the potential for community science to reinforce historical patterns wherein certain communities have been excluded along racial and economic lines from these sources of influence (Chesser et al. 2020; Walajahi 2019).

Addressing inequities in community science can be approached as a design challenge to be addressed at the program level by making different choices about program functions to enable access for traditionally excluded populations (i.e., enhance inclusivity), to recognize and respect cultural worldviews (i.e., promote sensitivity), and to create greater benefits for participants themselves (i.e., ensure reciprocity) (Chesser et al. 2020). As a matter of program planning and design, such principles could be embedded at the level of the stated learning objectives, which is an avenue for promoting change that is already available to the majority of programs we reviewed. Importantly, the matter of designing a more diverse network of people interacting and expressing varied worldviews around a shared environmental goal is closely aligned with the goal of promoting TL. Moreover, several avenues and tools for fostering this goal appear to already be at hand with Canada's community science landscape, "baked into" core functions like data collection, interaction with program scientists, and collaboration among fellow participants. Opportunities for change and greater potential impact are thus awaiting the attention and time of creative and innovative program designers.

Acknowledgements

A sincere thank you to all the participants from the Climate Change at the Arctic's Edge program who shared their experience through this research. Thank you also to the University of Northern British Columbia for their financial support of this research.

Author contributions

MG, AW, MCB, LAF, and AB conceived and designed the study. MG, AW, and KL performed the experiments/collected the data. MG, RL, and KL analyzed and interpreted the data. MG and AB contributed resources. MG, AW, MCB, LAF, RL, KL, and AB drafted or revised the manuscript.

Competing interests

Dr. LeeAnn Fishback and Dr. Amanda Winegarder are associated with the Churchill Northern Studies Centre and the Climate Change at the Arctic's Edge program. The potential for their dual role to create a conflict of interest was identified at the study design stage, and actively managed throughout the research process.

Data availability statement

All relevant data are within the paper and in the Supplementary Material.

Supplementary material

The following Supplementary Material is available with the article through the journal website at doi:10.1139/facets-2021-0003.

Supplementary Material 1

References

Armitage D, Berkes F, Dale A, Kocho-Schellenberg E, and Patton E. 2011. Co-management and the co-production of knowledge: Learning to adapt in Canada's Arctic. Global Environmental Change, 21: 995–1004.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Bela G, Peltola T, Young JC, Balázs B, Arpin I, Pataki G, Hauck J, Kelemen E, Kopperoinen L. and Van Herzele A. 2016. Learning and the transformative potential of citizen science. Conservation Biology, 30: 990–999. PMID: 27185104 DOI: 10.1111/cobi.12762

Bentz J, O'Brien K, Iles A, and Milkoreit M. 2019. Art for Change: Transformative learning and youth empowerment in a changing climate. Elementa: Science of the Anthropocene, 7: art 52.

Bonney R, Cooper CB, Dickinson J, Kelling S, Phillips T, Rosenberg KV, and Shirk J. 2009. Citizen science: A developing tool for expanding science knowledge and scientific literacy. BioScience, 59: 977–984. DOI: 10.1525/bio.2009.59.11.9

Brosnan T, Filep S, and Rock J. 2015. Exploring synergies: Hopeful tourism and citizen science. Annals of Tourism Research, 53: 96–98. DOI: 10.1016/j.annals.2015.05.002

Bryman A. 2006. Integrating quantitative and qualitative research: How is it done? Qualitative Research, 6: 97–113. DOI: 10.1177/1468794106058877

Charles A, Loucks L, Berkes F, and Armitage D. 2020. Community science: A typology and its implications for governance of social-ecological systems. Environmental Science & Policy, 106: 77–86. DOI: 10.1016/j.envsci.2020.01.019

Charmaz, K. 2014. Constructing Grounded Theory. SAGE Publications Ltd.

Chesser S, Porter MM, and Tuckett AG. 2020. Cultivating citizen science for all: Ethical considerations for research projects involving diverse and marginalized populations. International Journal of Social Research Methodology, 23: 497–508. DOI: 10.1080/13645579.2019.1704355

Collins H. 2013. Three dimensions of expertise. Phenomenology and the Cognitive Sciences, 12: 253–273. DOI: 10.1007/s11097-011-9203-5

Cox J, Oh EY, Simmons B, Lintott C, Masters K, Greenhill A, Graham G, and Holmes K. 2015. Defining and measuring success in online citizen science: A case study of Zooniverse projects. Computing in Science & Engineering, 17: 28–41. DOI: 10.1109/MCSE.2015.65

Emerson K. 2018. Collaborative governance of public health in low-and middle-income countries: Lessons from research in public administration. BMJ Global Health, 3: e000381. PMID: 30364438 DOI: 10.1136/bmjgh-2017-000381

Eitzel MV, Cappadonna JL, Santos-Lang C, Duerr RE, Virapongse A, West SE, et al. 2017. Citizen science terminology matters: Exploring key terms. Citizen science: Theory and Practice, 2(1).

Evans C, Abrams E, Reitsma R, Roux K, Salmonsen L, and Marra PP. 2005. The neighborhood nestwatch program: Participant outcomes of a citizen-science ecological research project. Conservation Biology, 19: 589–594. DOI: 10.1111/j.1523-1739.2005.00s01.x

Feick R, and Robertson C. 2021. Geographic expertise and citizen science: Planning and co-design implications. *In* Geographic citizen science: No one left behind. *Edited by* A Skarlatidou and M Haklay. UCL Press, London, UK. pp. 107–129.

Government of Canada April 2021. Prime Minister Trudeau announces increased climate ambition. [online]: Available from pm.gc.ca/en/news/news-releases/2021/04/22/prime-minister-trudeau-announces-increased-climate-ambition.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Greene JC, Caracelli VJ, and Graham WF. 1989. Toward a conceptual framework for mixed-method evaluation designs. Educational Evaluation and Policy Analysis, 11: 255–274. DOI: 10.3102/01623737011003255

Groulx M, Brisbois MC, Lemieux CJ, Winegardner A, and Fishback L. 2017. A role for nature-based citizen science in promoting individual and collective climate change action? A systematic review of learning outcomes. Science Communication, 39: 45–76. DOI: 10.1177/1075547016688324

Groulx M, Fishback L, and Winegardner A. 2019. Citizen science and the public nature of climate action. Polar Geography, 42: 176–195. DOI: 10.1080/1088937X.2019.1597396

Gruenewald DA. 2003. The best of both worlds: A critical pedagogy of place. Educational Researcher, 32: 3–12. DOI: 10.3102/0013189X032004003

Gura T. 2013. Citizen science: Amateur experts. Nature, 496: 259–261. PMID: 23586092 DOI: 10.1038/nj7444-259a

Haklay M. 2018. Volunteered geographic information and citizen science. *In* Understanding Spatial Media. *Edited by* R Kitchen, TP Lauriault, and MW Wilson. Sage Publications Ltd, London, UK. pp. 127–135.

Haywood BK, Parrish JK, and Dolliver J. 2016. Place-based and data-rich citizen science as a precursor for conservation action. Conservation Biology, 30: 476–486. PMID: 27110934 DOI: 10.1111/cobi.12702

Hochachka G. 2021. Finding shared meaning in the Anthropocene: Engaging diverse perspectives on climate change. Sustainability Science, 1–21.

Johnson RB, and Onwuegbuzie AJ. 2004. Mixed methods research: A research paradigm whose time has come. Educational Researcher, 33: 14–26. DOI: 10.3102/0013189X033007014

Jordan RC, Ballard HL, and Phillips TB. 2012. Key issues and new approaches for evaluating citizen-science learning outcomes. Frontiers in Ecology and the Environment, 10: 307–309. DOI: 10.1890/110280

Jorgensen B, and Stedman R. 2006. A comparative analysis of predictors of sense of place dimensions: Attachment to, dependence on, and identification with lakeshore properties. Journal of Environmental Management, 79: 316–327. PMID: 16288828 DOI: 10.1016/j.jenvman.2005.08.003

Kitchenham A. 2008. The evolution of John Mezirow's transformative learning theory. Journal of transformative education, 6(2): 104–123. DOI: 10.1177/1541344608322678

Kudryavtsev A, Stedman RC, and Krasny ME. 2012. Sense of place in environmental education. Environmental Education Research, 18: 229–250. DOI: 10.1080/13504622.2011.609615

Lewicka M. 2011. Place attachment: How far have we come in the last 40 years? Journal of Environmental Psychology, 31: 207–230. DOI: 10.1016/j.jenvp.2010.10.001

Liimatainen L, Poskiparta M, Karhila P, and Sjögren A. 2001. The development of reflective learning in the context of health counselling and health promotion during nurse education. Journal of Advanced Nursing, 34: 648–658. PMID: 11380733 DOI: 10.1046/j.1365-2648.2001.01794.x

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Lundgren H and Poell RF 2016. On critical reflection: A review of Mezirow's theory and its operationalization. Human Resource Development Review, 15: 3–28. DOI: 10.1177/1534484315622735

Macphail VJ, Gibson SD, and Colla SR. 2020. Community science participants gain environmental awareness and contribute high quality data but improvements are needed: insights from Bumble Bee Watch. PeerJ, 8: e9141. PMID: 32435544 DOI: 10.7717/peerj.9141

Mcgreavy B, Calhoun AJK, Jansujwicz J and Levesque V. 2016. Citizen science and natural resource governance: Program design for vernal pool policy innovation. Ecology and Society, 21.

Mezirow J. 1978. Perspective transformation. Adult Education, 28: 100–110. DOI: 10.1177/074171367802800202

Mezirow J. 1981. A critical theory of adult learning and education. Adult Education, 32: 3–24. DOI: 10.1177/074171368103200101

Mezirow J. 2000. Learning as Transformation: Critical Perspectives on a Theory in Progress. Jossey-Bass Inc., San Francisco, USA.

Miller-Rushing A, Primack R and Bonney R. 2012. The history of public participation in ecological research. Frontiers in Ecology and the Environment, 10: 285–290. DOI: 10.1890/110278

Newman G, Chandler M, Clyde M, Mcgreavy B, Haklay M, Ballard H, et al. 2017. Leveraging the power of place in citizen science for effective conservation decision making. Biological Conservation, 208: 55–64. DOI: 10.1016/j.biocon.2016.07.019

Norström AV, Cvitanovic C, Löf MF, West S, Wyborn C, Balvanera P, et al. 2020. Principles for knowledge co-production in sustainability research. Nature sustainability, 3: 182–190. DOI: 10.1038/s41893-019-0448-2

Nowak K, Berger J, Panikowski A, Reid DG, Jacob AL, Newman G, et al. 2020. Using community photography to investigate phenology: A case study of coat molt in the mountain goat (Oreamnos americanus) with missing data. Ecology and Evolution, 10: 13488–13499. PMID: 33304554 DOI: 10.1002/ece3.6954

Oberhauser K, and Lebuhn G. 2012. Insects and plants: Engaging undergraduates in authentic research through citizen science. Frontiers in Ecology and the Environment, 10: 318–320. DOI: 10.1890/110274

Onwuegbuzie AJ, and Leech NL 2010. Generalization practices in qualitative research: A mixed methods case study. Quality and Quantity, 44(5): 881–892. DOI: 10.1007/s11135-009-9241-z

Poortinga W, Spence A, Whitmarsh L, Capstick S, and Pidgeon NF. 2011. Uncertain climate: An investigation into public scepticism about anthropogenic climate change. Global Environmental change, 21(3): 1015–1024. DOI: 10.1016/j.gloenvcha.2011.03.001

Relph E. 1976. Place and placelessness. Pion, London, UK.

Ritchie J, and Spencer L. 2002. Qualitative data analysis for applied policy research. *In* The qualitative researcher's companion. *Edited by* AM Huberman and MB Miles. Sage Publications Inc., California, USA. pp. 305–329.

FACETS Downloaded from www.facetsjournal.com by 52.14.1.136 on 05/07/24

Rosenbloom D. 2018. Framing low-carbon pathways: A discursive analysis of contending storylines surrounding the phase-out of coal-fired power in Ontario. Environmental Innovation and Societal Transitions, 27: 129–145. DOI: 10.1016/j.eist.2017.11.003

Roger E, and Klistorner S. 2016. BioBlitzes help science communicators engage local communities in environmental research. Journal of Science Communication, 15: A06. DOI: 10.22323/2.15030206

Ruiz-Mallén I, Riboli-Sasco L, Ribrault C, Heras M, Laguna D, and Perié L. 2016. Citizen science: Toward transformative learning. Science Communication, 38: 523–534. DOI: 10.1177/1075547016642241

Scannell L, and Gifford R. 2010. The relations between natural and civic place attach- ment and pro-environmental behaviour. Journal of Environmental Psychology, 30: 289–297. DOI: 10.1016/j.jenvp.2010.01.010

Patton MQ. 1990. Qualitative Evaluation and Research Methods. Sage Publications Ltd.

Simm D, and Marvell A. 2015. Gaining a "sense of place": Students' affective experiences of place leading to transformative learning on international fieldwork. Journal of Geography in Higher Education, 39(4): 595–616. DOI: 10.1080/03098265.2015.1084608

Suldovsky B. 2017. The information deficit model and climate change communication. Oxford Research Encyclopedia, DOI: 10.1093/acrefore/9780190228620.013.301

Taylor EW. 2007. An update of transformative learning theory: A critical review of the empirical research (1999–2005). International Journal of Lifelong Education, 26: 173–191. DOI: 10.1080/02601370701219475

Walajahi H. 2019. Engaging the "Citizen" in citizen science: Who's Actually Included? The American Journal of Bioethics, 19: 31–33. PMID: 31544650 DOI: 10.1080/15265161.2019.1619868

Walker K, and Moscardo G. 2016. Moving beyond sense of place to care of place: the role of Indigenous values and interpretation in promoting transformative change in tourists' place images and personal values. Journal of Sustainable Tourism, 24(8–9): 1243–1261. DOI: 10.1080/09669582.2016.1177064

Wals AEJ, Brody M, Dillon J, and Stevenson RB. 2014. Convergence between science and environmental education. Science, 344: 583–584. PMID: 24812386 DOI: 10.1126/science.1250515