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Learning for collaborative action: learning domains and processes in place-based climate adaptation workshops

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Communities facing complex social and environmental challenges may benefit from opportunities for collaborative learning. Place-based climate adaptation workshops, which help stakeholders to incorporate climate projections into site-specific adaptation strategies, are one space where learning can occur. We studied learning in eight facilitated climate adaptation workshops held in-person ($n = 2$) and online ($n = 6$) in the United States between 2021 and 2023. Workshops averaged 24 participants and included state and local government employees, representatives from non-governmental organizations, interested citizens, academics, and others. We examined declarative, procedural, and relational learning and the processes through which knowledge was created and shared. We found evidence for learning across domains. Participants linked learning to a range of workshop elements, including collaborative workbooks, plenary presentations, and handouts. We found no meaningful differences between online and in-person workshops, suggesting that a range of workshop formats support meaningful learning. We discuss the theoretical and practical implications for understanding and fostering learning.

Keywords: climate change adaptation; learning; workshop; SECI cycle

1. Introduction

Learning is important for communities coping with the wicked complexity of contemporary environmental management challenges (Plummer *et al*. 2017; Rittel and Webber 1973; Suškevičs *et al*. 2018). It can drive changes to resource management approaches, to policies and institutions, and ultimately to environmental conditions (e.g. Armitage, de Loë, and Plummer 2012; Borrini-Feyerabend, Johnston, and Pansky 2006; Koontz and Thomas 2006; Plummer and Armitage 2007). Consequently, scholars of natural resource management have increasingly directed their attention to the process by which scientific and other forms of knowledge are collaboratively created, shared, and acted upon, especially in complex and wicked contexts such as climate change adaptation (Beier *et al*. 2017; Gerlak and Heikkila 2019; Vinke-de Kruijf and Pahl-Wostl 2016). However, learning can be challenging to define and measure, and our understanding of the factors that shape learning remains underdeveloped

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(Armitage, Marschke, and Plummer 2008; Crona and Parker 2012; Suškevičs, Hahn, and Rodela 2019).

One wicked problem set where learning may help accelerate positive change is the challenge of preparing for and dealing with the effects of anthropogenic climate change (Vinke-de Kruijf and Pahl-Wostl 2016). This effort is known as climate change adaptation, or "the process of adjustment to actual or expected climate and its effects in order to moderate harm or take advantage of beneficial opportunities" (Van Valkengoed and Steg 2019, 158). Effective climate adaptation relies upon accessing and using insights from a range of knowledge systems, including scientific and traditional ecological knowledge (Moller *et al.* 2004). Despite the proliferation of climate information over the past several decades, a gap remains between the information available and its uptake by potential users, which has been termed the climate information usability gap (Lemos, Kirchhoff, and Ramprasad 2012).

On a local level, groups have increasingly turned to educational and capacity-building events, such as place-based climate adaptation workshops, to foster learning and advance climate adaptation (Biagini *et al.* 2014). Here, we define place-based climate adaptation workshops as *convenings or series of convenings designed to help multiple stakeholders develop strategies for adapting to climate change in a specific place* (O'Brien *et al.* 2024). These workshops commonly involve sharing climate science data with participants, collectively analyzing the vulnerability of focal systems, and developing and prioritizing potential solutions.

This paper hypothesizes and tests a framework to characterize learning in collaborative contexts. We examine how our framework interacts with processes of knowledge creation in the context of climate change adaptation workshops, and we explore the practical and theoretical implications of this approach to learning. Although adaptation workshops are often designed to achieve outcomes in addition to learning, action outcomes are beyond the scope of this paper.

2. Perspectives on learning

Learning may be thought of as both an outcome and a process (Gerlak and Heikkila 2019). As an outcome, learning can refer to newly acquired knowledge or changes to beliefs in individuals and groups (Leach *et al.* 2014). As a process, learning may refer to how information is acquired, interpreted, reconfigured, vetted, and shared among stakeholders (Heikkila and Gerlak 2013). We describe a typology of learning domains that categorizes meaningful learning outcomes for climate adaptation and related processes. We then describe Nonaka's Theory of Organizational Knowledge Creation, which details how knowledge may be developed, combined, and disseminated within a collective group (Nonaka, Takeuchi, and Umemoto 1996). We explore these elements in the context of place-based climate adaptation workshops.

2.1. Learning outcomes

We conceptualize learning outcomes as occurring within *declarative, procedural*, and *relational* domains. This framework draws upon previous efforts to articulate forms of learning relevant to climate adaptation and related contexts (e.g. Baird *et al*. 2014; Huitema, Cornelisse, and Ottow 2010). *Declarative* learning is learning related to understanding concepts, facts, and other information and the ways those elements relate to each other, such as learning about projected shifts in temperature and rainfall patterns (Baird *et al*. 2014; Krathwohl 2002). *Procedural* learning involves understanding and gaining capacity to undertake processes, procedures, and techniques, such as learning how to use a planning workbook or use a different method of irrigation (Krathwohl 2002). These categories are roughly analogous to distinctions between "know-what" knowledge and "know-how" knowledge, or Bloom's factual/conceptual and procedural dimensions of knowledge (Anderson and Krathwohl 2001). *Relational* learning involves gaining understanding of the mindsets and priorities of other actors within a network and of the broader social network's structure and dynamics, such as knowing who within a group is skeptical of climate change or who could most effectively recruit a new member (Suškevičs *et al*. 2018). It is akin to "know-who" knowledge.

Learning could help to foster the conditions that contribute to successful collective action by enhancing the combined abilities of groups to effectively solve problems over the long term (Ryan and Urgenson 2019). For processes such as climate change adaptation and other attempts to address environmental challenges, collaborative, collective learning can help groups to address conflict and navigate participatory decision making (Daniels and Walker 2001). Such processes have been found to enhance learning in a range of contexts, such as collaborative efforts to manage sea level rise, enhance rural climate resilience, and to foster more resilient coastal social-ecological systems by linking decision makers to rural churches in Maryland (Johnson, Feurt, and Paolisso 2018; Miller Hesed, Van Dolah, and Paolisso 2020; Teodoro, Prell, and Sun 2021).

2.2. Learning processes: Nonaka's Theory of Organizational Knowledge Creation

Learning unfolds at multiple levels in collective contexts (i.e. within individuals, within groups, and within networks). These levels are bridged by "dynamic social processes of producing and sharing knowledge" (Heikkila and Gerlak 2013, 486). Nonaka's Theory of Organizational Knowledge Creation offers a framework to explain the processes through which learning occurs across scales in collaborative contexts.

Nonaka's theory suggests that knowledge exists along a spectrum from tacit to explicit (Nonaka, Toyama, and Konno 2000; Polanyi 2009). Tacit knowledge is embodied, enacted, and encoded in routines, procedures, values, and emotions. It is difficult to communicate directly to others and is more often indirectly observed, veiled in story, or developed through shared experience. Explicit knowledge can be more easily explained and communicated to others, as it can be shared *via* symbols and is readily processed, stored, and transmitted in conversations, data, formulas, manuals, maps, and other vehicles. Thus, explicit knowledge is more easily transferable within a broad network or across networks (Nonaka, Toyama, and Konno 2000).

Nonaka identifies four stages that comprise a cycle of knowledge conversions, known as the SECI cycle (Socialization, Externalization, Combination, and Internalization). The SECI cycle illustrates the processes by which tacit and explicit knowledge forms are created, transformed, transferred, or combined within organizations: socialization, externalization, combination, and internalization (Figure 1). Nonaka's theory holds that movement through the cycle can shift knowledge from one end to the other of the tacit-explicit spectrum and enable the movement of knowledge between individuals and groups and the melding of disparate knowledge sets (Nonaka, Toyama and Konno 2000).

Movement along the stages of the SECI (Socialization, Externalization, Combination, Internalization) cycle could help to equip groups with a shared corpus of actionable knowledge for tackling complex problems (Stern, Briske, and Meadow

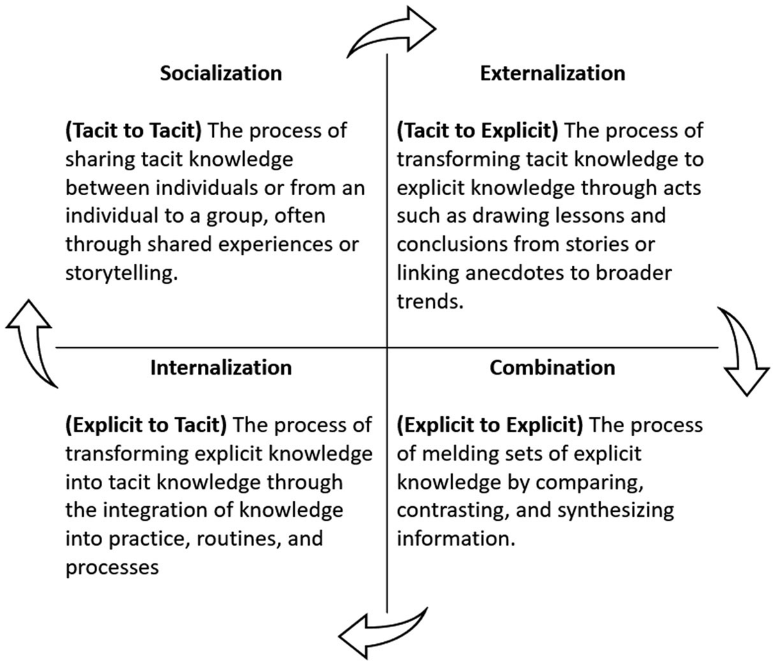

Figure 1. Knowledge conversions in the SECI cycle.

2020). *Socialization* can spread tacit knowledge within a group, potentially helping to align worldviews, strengthening trust among group members, and establishing shared routines and experiences. In *externalization*, individuals' tacit knowledge is transformed into explicit knowledge, which enables insights to be more readily shared among group members. During *combination*, groups engaged in climate adaptation could examine and interrogate explicit knowledge sets, such as climate projections for their region, and integrate them with newly externalized knowledge about factors such as group dynamics, workflows, and local regulations. Finally, as groups engage in the work of planning and implementing climate adaptations, the explicit insights established during combination could become embedded in altered worldviews, trusting relationships, and altered workflows in the process of *internalization*. Attending to these knowledge conversions offers a potential mechanism by which workshop facilitators and others could help groups to overcome the climate information usability gap and make knowledge more readily articulated, vetted, shared, and rendered actionable (Stern, Briske, and Meadow 2020).

From a practical standpoint, movement along the SECI cycle could be enhanced or constrained by the attributes of the learning processes that take place during adaptation workshops, as some formats and activities may lend themselves more readily to specific stages (Nonaka, Toyama, and Konno 2000). For example, *internalization* may be less likely to occur during a plenary presentation, which often involves a one-way sharing of explicit information from a single speaker to a group, because the format does not readily lend itself to practicing or acting upon information. Conversely, *combination* may be more likely to occur during plenary as speakers share data or other information (explicit knowledge) that audience members could integrate with their existing knowledge.

Both virtual and in-person learning spaces can accommodate movement along the SECI cycle, although they may be more- or less-well suited to a specific stage. For example, virtual conferences may lack networking opportunities such as coffee breaks and happy hours that could allow for informal exchange of tacit knowledge (*socialization*: Bosslet *et al*. 2020). Conversely, technological innovations for virtual gathering such as "chat" features, polling, document sharing, or one-on-one breakouts could enable novel forms of interactions that facilitate *combination* (Lawton, Harman, and Gupta 2020). Making gatherings more accessible to non-dominant groups through virtual formats could also add breadth to the range of tacit knowledge that is shared and made explicit in the processes of *socialization* and *externalization.*

2.3. Extending Nonaka: learning processes and outcomes in collaborative contexts

The present study extends Nonaka's theory in two ways. First, we explore its applicability in a collaborative, multi-stakeholder setting that differs from the context in which the theory was initially developed. Past research has examined the SECI cycle in a range of organizations, such as those engaged in manufacturing, trade, transportation, service, finance, disaster risk reduction, and aerospace engineering (Becerra-Fernandez and Sabherwal 2001; Chou and He 2004; Nonaka *et al*. 1994; Oktari *et al*. 2022). However, we are unaware of research that has empirically examined Nonaka's theory within a local collaborative climate change adaptation context.

We are also unaware of other research that links the SECI cycle to learning domains. Declarative, procedural, and relational learning outcomes each exist along a spectrum from tacit to explicit, and we suggest that learning outcomes in and across each domain may arise through movement along the SECI cycle (Table 1). Because effective collaborative climate adaptation requires long-term coordination across a broad range of sectors and disciplines, we suggest that a focus on these learning domains may enrich Nonaka's theory when applied in collaborative, multi-stakeholder settings. Furthermore, Nonaka's theory offers an explanation of a process through which these distinct learning domains may be melded and made actionable.

Adaptation workshops offer a context in which learning processes can be examined and assessed. This research examines the prevalence of learning in each domain and the evidence for SECI-cycle knowledge conversions during climate adaptation workshops. Insights from this area of inquiry could provide lessons for overcoming the climate information usability gap and improving future adaptation workshops, as well as deepening our understanding of how learning may help communities grappling with contemporary wicked problems. We address the following research questions:

1. What kinds of learning result from climate adaptation workshops?
2. What learning processes take place during climate adaptation workshops?
3. What climate adaptation workshop elements are associated with learning?

3. Methods

This manuscript draws upon data gathered before, during, and after eight place-based climate adaptation workshops that took place between January 2021 and April 2023 and which were part of a larger study focusing on these and other research questions (Table 2). Before each workshop, we conducted interviews with the local

Table 1. Tacit and explicit dimensions of declarative, procedural, and relational learning outcome domains.

		Learning outcome domain		
		Declarative (Know-what)	Procedural (Know-how)	Relational (Know-who)
Dimension	Explicit	Facts, figures, concepts	Articulated and shareable processes and protocols	Knowledge of network structure and dynamics, operationalized through—conversations, network maps, organizational charts, and other artifacts
	Tacit	Worldview, mental models, hunches, intuition, implicit rules of thumb	Skills, habits, routines, physical/sensory experiences	Trust, affinity, distrust, unspoken group norms

Table 2. Climate change adaptation workshop details and host community overview.

Workshop	State-level adaptation mandate	Prior climate event	Density	Date	Format	Breakout topics ("focal areas")	Number of participants
Santa Rosa, CA	Yes	Yes: Fire	Urban	January 19, 21, & 27, 2021	Virtual	Land Use & Economic Vitality Housing & Environmental Justice Transportation & Noise and Safety Public Services & Open Space	33
Johnson County, IA	No	Yes: Freshwater flooding	Rural	March 23 & 30, & April 6, 2021	Virtual	Land Use Health and Safety Transit Facilities and Public Services	28
Indian River County, FL	Yes	Yes: Hurricane and erosion	Rural	October 26, & 28, & November 3, 2021	Virtual	Utilities Transportation Conservation Lands and Parks	16
Kalamazoo, MI	No	No	Urban	February 8, 10, & 14, 2022	Virtual	Connected Communities Habitat Conservation and Biodiversity Food Security and Agriculture	27
Butte Silver-Bow, MT	No	No	Rural	June 8-9, 2022	In-person	Public Health Water Resources Contaminated Sites Protection and Redevelopment	26
Chattanooga, TN	No	Yes: Tornado, drought, wildfire	Urban	October 3, 4, & 6, 2022	Virtual	Housing Transportation Natural Resources	27
Canton/ Potsdam, NY	Yes	No	Urban	March 7, 9 & 14, 2023	Virtual	Housing Utilities Agriculture and Food Security	19
Salisbury, MD	Yes	No	Urban	April 24-25, 2023	In-person	Transit/housing Open Spaces	13

convener(s)—individuals who helped to organize the workshop—to gain a deeper understanding of the community context and their goals for the workshop. Insights from these interviews were used to develop breakout topics, identify potential invitees, and identify relevant examples to present during the workshop. All workshop participants completed an online survey that also served as a registration form for the workshop using QuestionPro or Qualtrics survey software. At the end of each workshop, participants completed a second survey about their experience. Survey measures relevant to this study are described further below. While all workshops were originally planned to take place in person, the COVID-19 pandemic shifted six of them to an online format. This post-workshop survey was administered online for virtual workshops ($n = 6$) and on paper for in-person workshops ($n = 2$). All protocols were approved by the Virginia Tech Institutional Review Board. All subjects provided written or verbal informed consent as appropriate before participating in surveys and interviews.

3.1. Case selection and workshop format

We sent out a call for applications to host a climate adaptation workshop through a variety of professional networks, including the Climate Adaptation Knowledge Exchange (http://www.cakex.org/) and the American Society of Adaptation Professionals (https://adaptationprofessionals.org/). We received more than 90 applications from community representatives, such as members of local governments and those from non-governmental organizations. We selected a total of eight communities based upon four factors. First, we sought communities wherein local planning processes were already underway or in preparation, because literature suggests that incorporating climate adaptation into ongoing efforts can help to advance sustainable change (e.g. Runhaar *et al.* 2018). Next, we sought places that varied along two dimensions: the presence or absence of climate adaptation planning mandates and the occurrence or absence of extreme weather events during the previous five years that the applicants linked to climate change (Table 2). By selecting communities according to the presence or absence of mandates and extreme events, we sought to include cases that varied systematically along dimensions that prior research suggests can influence learning within collective adaptation processes (Carmichael, Brulle, and Huxster 2017; Egan and Mullin 2017; Mackay *et al.* 2021). Workshops were also selected to ensure diversity in geographical spread across the US and for each site's urban/rural character. We consider areas with population densities less than 500 people per square mile or fewer than 2,500 people as rural, and areas with higher densities or populations as urban (USDA ERS n.d.).

Once a community was selected, we worked with the applicant to organize the workshop. In instances where the original applicant was no longer available due to retirement or other factors, we identified a local convener to help organize the workshop. This process included selecting workshop dates and a venue (if in-person), identifying and inviting participants, and selecting focal topics for deeper exploration during the workshop. Participants were invited in accordance with the local convener's goals for the workshop and with input from the facilitating organization about important stakeholder groups to include in the process. These groups included government representatives, community groups, academics, and the private sector. Invitations came from the local partners or community leaders and were distributed to specific individuals identified within each stakeholder group. Although the specific language varied somewhat between workshops, the invitations and other workshop materials informed prospective participants that the workshop was designed "to aid local planning about key areas that are tied to our future community climate resilience," and "focuses on understanding community vulnerabilities to climate change and then developing adaptation strategies to address those vulnerabilities. Participants will also learn how to use some tools that are available for communities to enable climate savvy decision making into the future." The workshops in Butte-Silver Bow, Montana, and Salisbury, Maryland took place in person because transmission rates at the time of the workshop were at a level deemed acceptable by organizers and the host community.

3.2. Workshop overview

Each workshop focused on understanding community vulnerabilities to climate change in that location and then developing adaptation strategies to address those vulnerabilities. Participants also gained experience with the decision-support tools used during the workshop. As place-based workshops, the climate data, participant list, resources, and discussions were tailored as narrowly as possible to the focal locations, which were at the scale of individual cities, counties, or closely associated communities (such as Canton and Potsdam). Both in-person and virtual versions of the workshop covered essentially the same material, and the basic structure of the event remained largely consistent between workshops. In-person workshops took place over two consecutive days, whereas virtual workshops took place over three half-day sessions spread over one or two weeks.

The arc of each workshop followed the steps described in the Rapid Vulnerability and Adaptation Tool (RVAT), a workbook designed to usher users through four consecutive steps: project scoping, vulnerability assessment, adaptation strategy development, and adaptation implementation planning (EcoAdapt 2024). During in-person workshops, the first day focused on exploring local climate impacts and assessing vulnerability, and the second day focused on developing adaptation strategies. For virtual workshops, the first session focused on understanding climate impacts, the second on assessing vulnerability, and the third on developing adaptation strategies.

All workshops followed the same basic format. After welcoming remarks, facilitators led participants through an icebreaker about whether participants thought of themselves as optimists, pessimists, or pragmatists, both in their daily lives and in terms of how they think about climate change. In virtual workshops, participants then spent five minutes in breakout groups with two other workshop participants for small-group introductions. During in-person workshops, facilitators asked participants to line up according to the extent of their experience with climate change adaptation (from those new to the work to more seasoned adaptation practitioners), and then led a discussion with participants across the spectrum.

Facilitators gave an overview of the workshop agenda and presented on the steps involved in adaptation planning. Participants then worked individually to complete the opening steps of the Climate Change Adaptation Certification Tool (CCAC), a workbook designed to assess the climate readiness of specific projects and policies (EcoAdapt 2024). The CCAC process helps users identify climate change risk factors relevant to the project, evaluate climate impacts on their project, and determine whether to approve the project. After completing the first step of the CCAC,

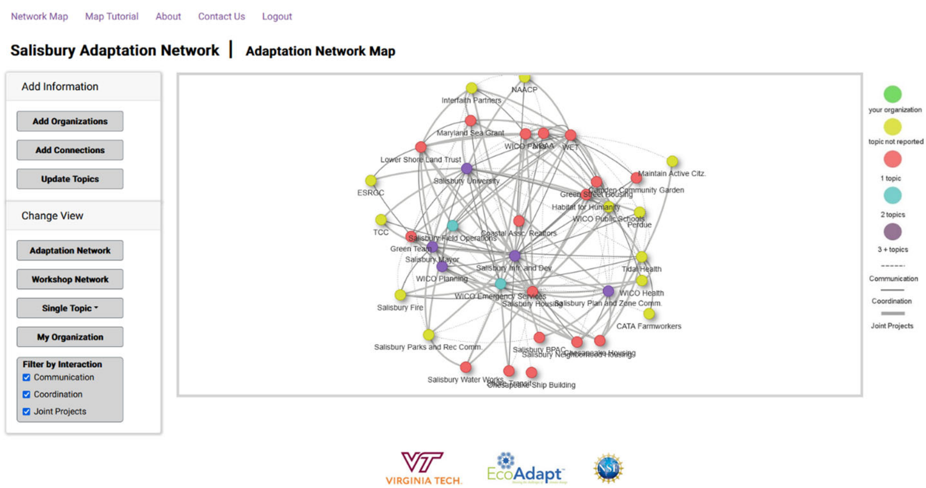

Figure 2. Virtual climate adaptation network mapping tool.

participants were asked to finish the CCAC as a homework assignment outside workshop hours.

During plenary presentations, facilitators next introduced climate change impacts and vulnerability assessments, including a summary of projected changes to climate (such as temperature, precipitation, and seasonality) and impacts for the local area, where to find data, and how to use it. The workshop then shifted to breakout groups, wherein each group worked through the first two steps of the RVAT. Breakout group themes and members were determined in advance in collaboration with local organizers to address topics of interest to the community. Each workshop's breakout groups are described in Table 2.

In breakouts, facilitators led each group through a process of identifying and prioritizing pre-existing conditions—or current non-climate stressors already impacting their community—as well as climate stressors (i.e. RVAT Step 1: Project scoping). Each breakout group then worked through RVAT Step 2 and conducted a vulnerability assessment by exploring the intersection of each priority pre-existing condition and climate stressor to identify probable impacts of greatest concern for their focal topic. For each impact of greatest concern, the group then assessed the likelihood of the impact occurring, the resulting risk, and the community's adaptive capacity to cope with the impact in order to develop a holistic assessment of the community's vulnerability to each impact. Participants returned to plenary to share their findings with the group, and facilitators presented an introduction to adaptation strategies. Adaptation strategies are actions that aim to reduce the impacts of climate change or increase the climate resilience of human, built, and natural systems (EcoAdapt 2024).

On the second day (and, for virtual workshops, the third session), facilitators shared examples of successful climate adaptation initiatives from other communities in plenary before participants returned to breakout groups and completed the final two steps of the RVAT: developing adaptation strategies to reduce vulnerabilities and identifying how to implement preferred strategies. During this stage, participants drew upon a customizable network mapping tool that organizers had developed based upon input gathered from participants during the workshop registration survey (Figure 2). In virtual workshops, the tool was shared as an interactive website that depicted the kinds of connections (communication, collaboration, and joint projects) among the entities that workshop participants identified as being relevant for climate change adaptation. For in-person workshops, the network maps were shared as large posters that participants could modify using markers and sticky notes.

To develop adaptation strategies (i.e. RVAT Step 3), facilitators led the breakouts through a process of considering each impact of greatest concern and brainstorming possible adaptation strategies to reduce vulnerability by reducing risk or enhancing adaptive capacity. Participants explored the possibility of co-benefits and unintended consequences that might accompany each adaptation strategy. Each group then selected their preferred strategies and developed a plan for implementation, including identifying leads, partners, and necessary resources; assessing resources and barriers to implementation; and determining the efficacy and feasibility of each action (i.e. RVAT Step 4). Breakout groups identified up to five preferred strategies to consider for implementation.

The workshop concluded with participants from each breakout group sharing their preferred strategies in a plenary session and closing remarks from the facilitators, followed by administration of the post-workshop survey. After the workshop, the facilitating team compiled the workshop outputs into a synthesis report, which was shared with all participants. The final workshop reports, presentations, resources, and tools were also made available online (EcoAdapt 2024).

Minor changes were made between workshops to improve presentations and increase the efficiency of the tools used during the workshop. For example, the first four workshops included a step designed to assess the adaptive capacity of individual organizations within each sector. Participants struggled to critique each other's capacity in small groups, and subsequent workshops skipped this step. Instead, each breakout group conducted a more holistic assessment of their collective adaptive capacity in response to specific climate-related impacts. This reluctance or inability to evaluate individual organizations' might have stemmed from reticence about criticizing participants' own institutions or those of their peers. Also, assessing each organization within a sector required far more time than a single holistic assessment of the sector. Evaluating organizations ahead of time *via* the registration survey might have enabled participants to offer more honest assessments and saved time during the workshop. After the first workshop in Santa Rosa, facilitators also limited the breakout topics to one per group to ensure they had enough time to work through the RVAT steps for each topic. After the workshop in Kalamazoo, organizers expanded a presentation on vulnerability assessments to include more explicit examples relating to equity aspects of the process.

3.3. Assessment of learning outcomes

To evaluate the domains in which learning took place during the workshops, we drew upon closed and open-ended survey items. Participants responded to an identical battery of survey items in the pre-and post-workshop survey to evaluate their own levels of knowledge in domains corresponding to declarative, procedural, and relational adaptation knowledge (Table 3). We consider differences in scores from pre- to post-workshop as evidence of self-assessed learning.

We conducted confirmatory factor analyses (CFA) and reliability analyses using R to examine relationships among items and underlying latent factors. CFA tests hypothesized measurement models and identifies model revisions to improve fit with the data (Bandalos 2018). We tested a range of models, including a one-dimensional

Table 3. Survey items associated with Declarative, Procedural and Relational knowledge.

Domain	Survey item (7-pt scale: Strongly disagree to Strongly Agree)
Declarative	D1: I understand the causes of climate change.
	D2: I understand the impact of climate change in my region.
	D3: I feel I have a good understanding of the concept of climate adaptation.
Procedural	P1: I know how to plan for meaningful climate adaptation in my region.
	P2: I know how to implement climate adaptation strategies.
	P3: I know how to identify which climate adaptation strategies are likely to be most successful.
Relational	R1: I understand the relationships among the people and groups working on climate adaptation in my location.
	R2: I understand the priorities of others engaged in climate adaptation work in my region.
	R3: I see how my work can fit with the work of others in climate adaptation efforts in my region.

model to explicitly test the null hypothesis that the forms of knowledge in our typology were indistinguishable. We next tested a three-dimensional model to evaluate our originally hypothesized three-domain model. We also tested a two-dimensional model that combined procedural and relational knowledge. In each case, we followed Andersen and Gerbing's (1988) approach to model testing by evaluating the loadings of indicators within each independent measurement model and sequentially removing indicators with latent-variable loadings below 0.5. We examined indicators of model fit including the Robust Comparative Fit Index (CFI), Standardized Root Mean Square Residual (SRMR) the Robust Root Mean Square Error of Approximation (RMSEA), the Akaike information criterion (AIC), and the Bayesian information criterion (BIC) to identify the best-fitting model (Brown 2015; Byrne 2013). Values for the CFI should be greater than 0.9, for the SRMR should be less than 0.09, and for the RMSEA should be below 0.06 for acceptable models (Bandalos 2018; Hu and Bentler 1998). For AIC and BIC, smaller values are indicative of better fitting models (Burnham and Anderson 2004).

After identifying the best-fitting measurement model, we created composite indices for each learning dimension by weighting each item equally and averaging all items within the index. We also calculated Cronbach's alpha scores for all resulting indices. Cronbach's alpha measures an index's internal consistency on a scale ranging from 0 to 1, with higher scores representing greater internal consistency. Scores above 0.7 are considered acceptable for index development (DeVellis 2003).

We performed a range of tests to examine each research question. We performed paired sample t-tests to examine the impact of participating in an adaptation workshop on respondents' self-assessed knowledge by comparing mean knowledge scores before and after participation in the workshop. We also examined differences between individual workshops, between those that happened in-person vs. those online, and between those that happened before and after minor adjustments were made to the workshop design using independent sample *t*-tests and ANOVA to compare across workshops. We calculated Cohen's *d* for each of the statistically significant results. Cohen's *d* assesses the effect size of statistically significant associations. A score of 0.2 is considered small, 0.5 is considered medium, and 0.8 or higher is considered a large effect size (Cohen 1988).

3.4. Assessment of SECI cycles and workshop components' contributions to learning

We posit that the knowledge conversions of the SECI cycle may manifest as "ah-ha" moments, or instances of sudden realization, insight, or comprehension that contribute to long-term learning (Topolinski and Reber 2010). We analyzed participants' self-reported "ah-ha" moments to establish linkages among the kinds of insights reported by workshop participants, the stages of the SECI cycle, and the workshop context in which they occurred. We drew upon the following open-ended question: "Did you have any "ah-ha" or "light-bulb" moments during the workshop? If so, please describe them and explain how the workshop contributed." The lead author coded write-in responses through an iterative sequence of identifying themes then refining and adding additional codes in subsequent coding efforts to accommodate additional concepts and insights (Bailey 2017). Codes and examples were regularly discussed with the second author to enhance validity. We classified "ah-ha" moments as declarative, procedural, and relational learning, as well as within other emergent codes. We further classified respondents' "ah-ha" moments within the SECI cycle. However, because *internalization* is a gradual process that likely extends beyond the timeframe of the workshop, we could only code "ah-ha" moments of anticipating, planning, or preparing to act in a manner consistent with internalization. We labeled these instances *potential internalization.* Finally, we categorized respondents' explanations of which workshop elements most contributed to their insight according to the workshop agenda and other emergent codes (Appendix 1 [online supplementary material]). Following Eisenhardt (1989), we compared the emergent themes with existing literature and enfolded additional concepts to refine our constructs and boost generalizability. We then cross tabulated learning domains and stages of the SECI cycle to examine associations between them. We also cross tabulated each domain with the workshop elements identified by participants as contributing to their key insights.

4. Results

A total of 248 people registered for the eight adaptation workshops, and 189 attended at least a portion of the workshop for which they had registered. Workshop participants represented a range of sectors, including local governments (49%), non-profits (20%), academic institutions (9%), community organizations and interested citizens (7%), private sector organizations (7%), state and regional governments (5%), utilities (2%), and the federal government (1%). We collected both pre-and post-workshop surveys from a total of 151 participants, yielding a response rate of 80%. Most (27) of those who did not complete the post-workshop survey did not attend the workshop conclusion, during which we provided time for participants to complete the survey. Due to a survey formatting error, we were unable to use quantitative post-workshop knowledge scores for participants from one workshop (Chattanooga). While those data have been excluded from quantitative analyses, we do include the open-ended responses from Chattanooga participants in our analysis of "ah-ha" moments. This leaves an effective sample size of 138 for quantitative analyses and 151 for qualitative analyses.

4.1. Index development: learning domains

While we originally intended to test one- and three-factor models to test the fit of our hypothesized model, we found relatively high covariance between procedural and

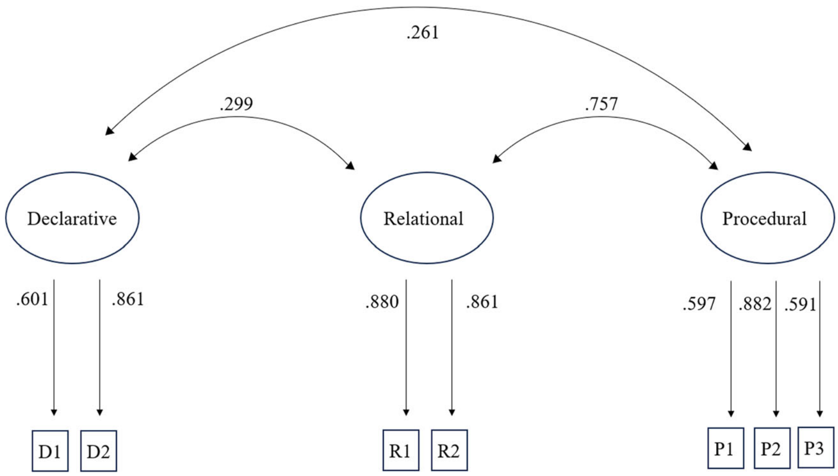

Figure 3. Best fitting model depicting learning domains of participants.

relational knowledge. This prompted us to also consider a two-dimensional model that combined these two types of knowledge into a single factor. We tested each with and without covariance between the factors. Independent measurement models of the three-dimensional model suggested dropping two items due to low factor loadings (< 0.5): "I feel I have a good understanding of the concept of climate adaptation" (declarative) and "I see how my work can fit with the work of others in climate adaptation efforts in my region" (relational).

Fit indices indicated that the three-dimensional model was the best fit (Figure 3). The resulting Cronbach's alpha scores for the declarative (0.839), procedural (0.879), and relational (0.915) knowledge indices were each deemed acceptable. We thus developed indices based on the three initially hypothesized learning domains.

4.2. Workshop learning

We observed statistically significant gains in declarative, procedural, and relational knowledge across all workshops (Table 4). Gains in procedural and relational knowledge exhibited a large effect size, whereas the change in declarative knowledge exhibited a small effect size, likely due to a ceiling effect resulting from high self-reported levels of declarative knowledge prior to the workshops. We found no significant differences between workshops in the learning scores for declarative, procedural, or relational knowledge; between workshops that took place during the first versus the second half of the study (after revisions to the workshop design); or between online and in-person workshops ($p > 0.05$).

4.3. "Ah-ha" moments, learning outcome domains, and workshop elements

One-hundred and four respondents (69% of those who completed post-workshop surveys) indicated that they experienced an "ah-ha" moment during the workshop they attended. The most common "ah-ha" moments were related to procedural learning (47), followed by relational (25) and declarative (24) learning. Some of these "ah-ha" moments encompassed multiple learning domains. Respondents also reported "ah-ha" moments linked to

Table 4. Paired sample t-test and effect sizes for self-assessed declarative, procedural, and relational knowledge indices. Scale is a seven-point bipolar measure.

Item	Pre-mean	Post-mean	SD	T-stat	DF	*p*-value	Cohen's *d*
Declarative knowledge	6.02	6.16	0.68	2.37	123	0.02	0.21
Procedural knowledge	4.29	5.41	1.11	11.18	123	<.01	1.00
Relational knowledge	4.14	5.45	1.31	10.57	125	<.01	0.94

affective states, or insights around feelings, attitudes, and emotions (Marks, Mathieu, and Zaccaro 2001). Through an iterative process of refining codes and consulting the literature to accommodate emergent themes (Eisenhardt 1989), we categorized these affective "ah-ha" moments as insights into efficacy (11) and motivation for climate adaptation (12; Appendix 1 [online supplementary material]). Nine respondents reported general "ah-ha" moments but did not provide sufficient detail to categorize their insight.

Respondents described the context in which an "ah-ha" moment they experienced occurred ($n = 25$; Table 5). These most commonly took place during plenary activities ($n = 12$) or breakout work ($n = 10$). Other participants ($n = 3$) attributed their insights to the interdisciplinary nature of the process overall, hearing the perspectives of other participants, and observations made outside workshop sessions. Five respondents indicated that more than one workshop element generated key insights. Declarative, procedural, and relational "ah-ha" moments took place in both plenary and breakout sessions. No participants linked efficacy-related "ah-ha" moments to specific workshop elements. Some participants described when their "ah-ha" moment occurred during the workshop but did not identify the nature of the insight. These general "ah-ha" moments occurred during breakouts (3) icebreakers (1) and outside the workshop (1).

4.4. "Ah-ha" moments, the SECI cycle, and learning domains

Some "ah-ha" moments were codable as instances of combination (Explicit-explicit, $n = 19$), potential internalization (Explicit-tacit, $n = 16$), and externalization (Tacit-explicit, $n = 8$). For example, one participant described an insight related to combining two elements of explicit knowledge (combination): "The process challenged me to think specifically about the element of long-term change brought on by climate and how that change might influence the work we do." Another participant spoke about how the explicit knowledge they acquired in the workshop could be transformed into tacit knowledge embedded in their workflow (potential internalization): "One of the 'ah-ha' moments for me was thinking through how my office at the state level could apply this information directly. We don't control a lot of physical assets, but we do offer grant funding that results in physical assets. So I did have a bit of a lightbulb moment that attaching some additional requirements to grants could be a good option for furthering adoption of climate smart design/development." A third participant described a process of converting tacit knowledge into a shared explicit understanding (externalization) as their intuitions about the nature of their shared goals were made clear: "We realized that all of the key leaders in sustainability were in the room, but none of us really knew what the City's goals were around certain things like % increase of tree canopy, how many acres of green space, emissions reductions, etc."

We were able to code 43 "ah-ha" moments in terms of both stages of the SECI cycle and learning domains (Table 6). Instances of externalization were primarily

Table 5. Context in which "ah-ha" moments occurred.

Workshop Context (number of associated "ah-ha" moments. Note that not all "ah-ha" moments correspond to a learning domain, and some reflect multiple domains)		Emblematic quotes from workshop participant survey responses (Learning domain of quote)	Learning domains			
			Declarative	Procedural	Relational	Affective
Plenary	Projections (4)	*Definitely hearing about the real scientific numbers for warming, which were dramatically higher than the conservative watered-down numbers you see on the news.* (Declarative)	*4*			*2*
	Network maps (2)	*The network visualization really showed how a lot of different entities were connected when addressing complex issues.* (Relational)		*1*	*2*	
	CCAC tool (2)	*I had this gut dropping feeling that I need to show the… CCAC tool to as many people in leadership positions as possible.* (Motivational)	*1*			*1*
	Ice breakers (2)	*During one of the ice-breaker chats we realized we need to get our sustainability committees working together more, and I met the Climate Smart Communities Regional Coordinator who can help us make that happen.* (Procedural; Relational)		*1*	*1*	
	Report outs (1)	*Hearing the other breakout presentations and seeing large amt of overlap. So much in common*! (Relational)			*1*	
	Presentations (1)	*How affected all sectors of community will be b/c of climate change–CCAC & presentations* (Declarative)	*1*			
Breakout work	RVAT process (5)	*The climate adaptation tool process was an aha moment. Easy way to think about future impact.* (Procedural)		*4*		
	Breakout: General (3)	*I realized during the agriculture breakout session just how many resources ARE already available. As a farmer myself, I made a list of different places to*	*2*	*1*		

		look for grants, support, etc. One of our goals was to broadcast these resources more readily. (Procedural)		
	Developing strategies (1)	*Maybe I strayed a bit from the topic at hand, but discussing strategies helped me brainstorm ideas for how to integrate concepts into work I'm doing now. "People hate native plants that look like weeds." Maybe a native coloring book for local kids to learn about them & to find them in the real world*. (Procedural)	*1*	
	Prioritizing strategies (1)	*Just watching the creative/thoughtful juices flow by end of day 1–follow-up on day II –> solutions* ranking (General)		
Other	Interdisciplinarity of workshop (1)	*I was thinking about natural solutions for climate impacts to [our community], it made me think about how our work in conservation and ecological restoration could help mitigate flooding along the… River with the right resources. It was essentially the interdisciplinary approach of this program that provided the context.* (Procedural)	*1*	
	Other participants sharing (1)	*It was good to hear others share the perspective that housing density is important to climate adaption.* (Relational)		*1*
	Outside the workshop (1)	*As I was walking around my neighborhood, I had new ideas come up.* (General)		

Table 6. Distribution of participants' "ah-ha" moments within the SECI cycle as a function of learning outcome domain.

SECI stage		Learning domain Declarative	Procedural	Relational	Total
Externalization	*N*	2	2	7	11
	%	29%	9%	50%	26%
Combination	*N*	5	7	4	16
	%	71%	32%	29%	37%
Potential Internalization	*N*	0	13	3	16
	%	0%	59%	21%	37%
Total	*N*	7	22	14	43

related to relational learning. Instances of potential internalization were primarily related to procedural learning. Examples of combination were more evenly distributed across learning domains. Three responses were linked to affective "ah-ha" moments and stages of the SECI cycle. Two motivational insights were linked to moments of externalization, and one efficacy insight was linked to potential internalization.

5. Discussion

This study sought to identify how learning happens in climate adaptation workshops. We found that participants across all workshops in our sample reported statistically significant gains in declarative, procedural, and relational learning domain. Our qualitative findings provided evidence that workshop participants experienced key "ah-ha" moments across these learning domains, as well as changes in perceived efficacy and motivation. Key insights experienced by workshop participants aligned with externalization, combination, and potential internalization, but not socialization (although, as discussed below, the absence of socialization-type insights may be an artifact of our methods). Of the responses that were both classifiable within the SECI cycle and linked to learning domains, most were associated with procedural learning, but we also found evidence of knowledge conversions across declarative and relational learning domains. We explore the theoretical and practical implications of these findings below.

5.1. Declarative, procedural, and relational learning

Our findings align with prior research that has sought to disaggregate forms of learning relevant for climate adaptation and related contexts (e.g. Baird *et al*. 2014; Huitema, Cornelisse, and Ottow 2010). Although participants reported learning across all domains, the relatively high covariance between procedural and relational knowledge in our confirmatory factor analysis may indicate a closer relationship between these two forms of learning than between either domain and declarative learning. This suggests that for workshop participants, an understanding of the adaptation network and of the steps, approaches, and processes for enacting adaptation were more strongly associated with one another than with an understanding of relevant facts and concepts. However, the smaller gains we identified in declarative knowledge may be partially due to a ceiling effect (Cramer and Howitt 2004), because participants arrived at the workshop reporting relatively high levels of declarative knowledge. A retrospective assessment, in which participants are asked immediately after the workshop to reflect upon the extent of their learning in each domain, might have yielded a more sensitive measure.

5.2. Knowledge conversions and learning domains: pathways to actionable knowledge

Movement along the SECI cycle from tacit to explicit serves to make knowledge shareable, and therefore more actionable, across a collective (Stern, Briske, and Meadow 2020). Participants reported experiences related to externalization and combination across declarative, procedural, and relational learning domains, which suggests that adaptation workshops can help groups to create a shared body of actionable knowledge by transforming individual, tacit knowledge in each domain into shared explicit knowledge. Once rendered explicit, this knowledge can be combined with knowledge from other domains and enable groups to take more meaningful, informed, and effective action (Mach *et al.* 2020). Indeed, the presence of potential internalization knowledge conversions in our sample suggests that participants anticipated their ability to draw upon shared explicit knowledge and take action.

Socialization was notably absent from our data. Several factors may have contributed to this absence and the limited number of internalization-type "ah-ha" moments. Socialization and internalization stages of the SECI cycle may not have registered as key insights for participants because they involve sharing or forming tacit knowledge, which is, by nature, less readily articulated. The research team observed examples of the sharing of tacit knowledge between parties during in-person workshops. This suggests that observational techniques coupled with qualitative reflection might have been better able to identify socialization than questionnaires about "ah-ha" experiences, and future research could pursue such an approach. Socialization may also be under-represented in our sample due to the prevalence of online workshops in our sample. In-person workshops may lend themselves to socialization more readily than online processes, despite facilitators' efforts to achieve these kinds of interactions.

Alternatively, participants may simply value explicit knowledge more. Other research reflects a distinction between the perceived impact of conversions yielding explicit knowledge and those yielding tacit knowledge. Becerra-Fernandez and Sabherwal (2001) found that knowledge conversions resulting in explicit knowledge (combination and externalization) impacted perceived knowledge satisfaction for study participants, whereas those stages yielding tacit knowledge (socialization and internalization) did not. Because converting knowledge to explicit formats can help render it actionable for a group, externalization and combination may have felt more useful for workshop participants engaged in collective climate action, and therefore been more likely to register as "ah-ha" moments. Still, other studies highlight the importance of tacit knowledge sharing, especially as it relates to the development of trust between parties (Stern, Briske, and Meadow 2020).

5.3. Learning and workshop design

The distribution of learning outcomes across a range of workshop elements in our sample supports prior evidence that diverse formats and opportunities for interchange between participants are important for fostering learning (O'Brien *et al.* 2024). However, we found that more instances of declarative learning occurred in plenary, whereas more instances of procedural learning occurred in breakouts. Thus, certain workshop elements may lend themselves more readily to learning within specific domains. For example, plenary presentations are likely to be effective approaches for disseminating facts and figures one-way, from a presenter to an audience (declarative learning). In contrast, participating in small group discussion could help participants to envision and explain how a new approach could fit into their workflow (procedural learning), while developing a deeper understanding of the individuals and groups in the breakout with whom they might be working to accomplish a task (relational learning). Due to our relatively small sample size, these possibilities should be explored in future research.

We did not identify statistically significant differences in self-reported learning between online and in-person workshops, indicating that meaningful declarative, procedural, and relational learning can take place despite the differences between formats. Workshop organizers adjusted the online workshops' agendas in an effort to achieve the kinds of informal interpersonal interactions that arise naturally during in-person events. We found evidence that these elements contributed to learning in online workshops. For example, one participant reported a key insight arising from the small-group introductions that took place at the beginning of each online workshop session. These small-group discussions may have helped to compensate for the absence of encounters that would have taken place in the interstices of in-person workshops. Our findings differ somewhat from prior research, which indicates that online workshops offer fewer opportunities for valuable social interactions (e.g. Bosslet *et al.* 2020, Rich *et al.* 2020). Alternatively, the absence of meaningful differences between in-person and online workshops may, instead, be indicative of shortcomings in our measurements. Without retrospective or systematic, qualitative observational data, we may have missed opportunities to measure socialization effectively. Future research could seek to identify socialization using these techniques.

Many of the participants in these workshops were specifically invited because their roles aligned with the focal areas explored in each workshop. Also, even though stipends were available, the relatively large time-commitment required to fully participate in addition, many have influenced the individuals who were able to join these gatherings. The workshops described here might have unfolded quite differently with participants who were more representative of the general public. Despite these caveats, we feel that learning domains and processes described here could be adapted by workshop facilitators to a wide range of workshops.

5.4. Implications for practice

From a practical standpoint, our finding of distinct learning domains suggests that facilitators and other practitioners could use these domains when designing and conducting workshops. They could survey participants beforehand to assess trends within each domain, and tailor the workshop accordingly. Absent that level of information beforehand, facilitators could strive to ensure broader learning outcomes by developing workshop agendas that purposefully touch upon each learning domain. Learning within all three domains could contribute to meaningful outcomes by equipping participants with more comprehensive, complementary understandings of the tasks before them:

Declarative learning could result in an enhanced understanding of the situation, procedural learning could yield a deepened understanding of what actions the group could take and how to undertake those actions, and relational learning could result in a stronger understanding of the social landscape in which adaptation could occur. Together, learning within these domains could help to bridge the climate information usability gap (Lemos, Kirchhoff, and Ramprasad 2012).

The SECI cycle offers a pathway for supporting learning within each domain and for helping groups meld disparate knowledge sets into shared corpuses of actionable knowledge. For example, if facilitators sense that participants do not have a firm understanding of what other workshop attendees do, asking participants to pair up and tell stories about their role could contribute to socialization. Then a guided discussion to extract key insights from those conversations could help to achieve externalization of the groups' relational knowledge. Once equipped with explicit relational knowledge, the group may be better able to combine that knowledge with insights from other learning domains to actionable knowledge – in this case, how they might partner to achieve mutual goals. This process of helping participants transform tacit knowledge into explicit knowledge through externalization before engaging in the more familiar process of combination could help to bridge the knowing-doing gap by supporting groups as they articulate, examine, and synthesize shared knowledge[1] (Hulme 2014; Stern, Briske, and Meadow 2020).

In contexts such as climate change adaptation efforts, a presumption can exist that explicit, scientific knowledge forms should drive decisions (Antonello and Howkins 2020). However, decision making in climate adaptation workshops may be even more effective if the process is designed to attend to the full range of learning domains and dimensions. Such an approach could help to generate actionable knowledge and foster more equitable relationships in which non-dominant knowledge holders are better able to introduce and share their knowledge (Mach *et al*. 2020). The approach to learning we describe may be well suited to accommodating complementary knowledge forms such as traditional or local ecological knowledge and scientific knowledge (Reid *et al*. 2021). Broadening the aperture of valued learning domains and dimensions could also benefit collective adaptation efforts in other ways. Although our participants did not report socialization-related insights, the kinds of interactions thought to contribute to socialization can benefit groups by deepening trust and strengthening relationships (Stern, Briske, and Meadow 2020). Conceptualizing climate change adaption as requiring learning within and across three discrete domains could help make a seemingly intractable and politically charged issue more manageable by dividing the challenge into more manageable components. Finally, although internalization is an individual process that primarily occurs after adaptation workshops, by considering the internalization stage of the SECI cycle in workshop design, facilitators could support groups seeking to act upon the shared knowledge they have created. This aligns with findings of other research demonstrating the importance of long-term support for groups working on place-based climate adaptation (Stern *et al*. 2023).

6. Conclusion

This study offers a coarse first attempt at providing evidence for a typology of collaborative learning and examining how the typology meshes with the stages of the SECI cycle in climate change adaptation processes. Our work has both theoretical and practical implications. In terms of theory, this work provides evidence that place-based climate adaptation workshops yield meaningful knowledge conversions for participants. We also link moments of key insight to a range of workshop elements and find that online and in-person workshops can yield comparable self-assessed learning outcomes. Future research could seek to link learning that occurs at one-off workshops and other training to meaningful adaptive actions.

From a practical standpoint, overlaying our learning typology with the SECI cycle provides a scaffolding upon which workshop organizers could develop adaptation workshop agendas and structure collaborative practices to enhance actionable knowledge production. Although our work begins to illuminate the contours of learning domains relevant for climate adaptation and supports the SECI cycle as a mechanism for fueling knowledge conversions across domains, future research could expand upon or challenge our findings. We hope practitioners and scholars continue to explore, critique, and deploy the concepts elaborated upon herein.

Note

1. Additional activities that could support knowledge conversions across domains of learning outcomes are described in Appendix 2 (online supplementary information).

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Supplemental data

Supplemental data for this article can be accessed here.

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