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Transdisciplinary academic-NGO collaborations for the resilience of food, energy, and water: a case study on the INFEWS-ER experience in post-disaster Puerto Rico

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The communities of Puerto Rico are highly vulnerable to climate change as the archipelago has experienced a multitude of compounding crises and extreme weather events in recent years. To address these issues, the research, analysis, and design of grand challenge solutions for disaster-prone regions like Puerto Rico can utilize collaborative transdisciplinary efforts. Local non-governmental and community-based organizations have a pivotal role in the reconstruction processes and the building of community and environmental resilience in underserved communities. This paper contributes an empirical case study of an online transdisciplinary collaboration between a group of academics and a Puerto Rican non-governmental organization, Caras con Causa. From participant observation, it includes a document analysis of meeting notes with cohort members who were involved in a collaborative National Science Foundation Project, The INFEWS-ER: A Virtual Resource Center Enabling Graduate Innovations at the Nexus of Food, Energy, and Water Systems, with Caras con Causa between October 2020 and April 2021. Caras con Causa focuses on uplifting Puerto Ricans by creating and administering environmental, educational, economic, and community programs, highlighting disaster relief and resilience to help Puerto Rican food, energy, and water systems. Eight key discussion themes emerged from the document analysis: team organization, collaboration with Caras con Causa, deliverables, team contributions, context understanding, participation outcomes, technology setup, and lessons learned. We analyze each of the emerging themes to explain how academics may use transdisciplinary skill sets in addition to standard disciplinary-based approaches or techniques to enhance the institutional capacity of a non-governmental organization doing community resilience work to benefit local food, energy, and water systems. While the learned lessons in this non-governmental organization-academic collaboration may be context-specific, we provide

insights that may be generalizable to collaborations in comparable transdisciplinary settings.

KEYWORDS

FEWS, transdisciplinary research, team organization, knowledge co-production, disaster preparedness, virtual collaboration, service-learning project, hurricane relief

1 Introduction

Puerto Rico has become emblematic of regions suffering many compounding crises in recent years (Soto, 2020; Stablein et al., 2022), including major economic policy shifts (Falcón, 1991; Cabán, 2018), demographic changes (Hinojosa et al., 2019; Matos-Moreno et al., 2022), natural disasters such as hurricanes and earthquakes (Zorrilla, 2017; Kishore et al., 2018; Mitsova et al., 2021; Vičić et al., 2022), the COVID-19 pandemic (Garriga-López, 2020), and consequent economic downturns (Lloréns, 2018). These crises have highlighted the vulnerability of Puerto Rico's communities and food, energy, and water systems (FEWS) to climate change and extreme events (Santiago L. et al., 2020; Welton et al., 2020; Bennett et al., 2021) relative to other regions (Rafael et al., 2021). This unfortunate new reality of dealing with repeated, compounding disasters is likely to continue due to the effects of climate change, especially in tropical regions (Gould et al., 2018; Zscheischler et al., 2018; Stablein et al., 2022). As a result, disaster risk reduction (DRR) becomes crucial in addressing these crises (Wisner et al., 2012; Twigg, 2015), as DRR aims to reduce exposure to hazards and vulnerabilities and to decrease risk while ultimately strengthening resilience (Manyena, 2006; UNISDR, 2011; 2012).

The increasing frequency of disasters calls for a greater need for resilience, or the capacity of the system to absorb shock or disturbance while retaining its function and structure (Walker et al., 2004; UNISDR, 2009; Stablein et al., 2022). Resilience highlights the ability of a social system to respond and recover from disasters by allowing the system to absorb impacts and cope with disaster and post-disaster recovery (Cutter et al., 2008; UNISDR, 2009). Resilience is especially critical in Puerto Rico due to frequent power outages (Santiago R. et al., 2020), lack of recovery times between frequent disasters (Johnson and Olshansky, 2016; Yabe et al., 2021), and lack of trust in government and institutions (Petrun Sayers et al., 2023). In addition, Puerto Rico's sociopolitical factors, such as its commonwealth status and complex federal laws, have hindered effective response to disasters and reconstruction efforts (García-López, 2018; Rodríguez-Díaz, 2018; Colón-Morera and Cordero-Nieves, 2023). For instance, the U.S. government's response to Hurricane Maria was insufficient for the level of severity and local needs compared to the response to similar situations in Texas and Florida (Willison et al., 2019), and three years after the hurricane, the allocated funds for disaster recovery were underutilized with only 29% spent (Marxuach, 2021).

Prior to Hurricane Maria, Puerto Rico was already facing rapid financial deterioration because of significant borrowing, inadequate fiscal management, and limited options to renegotiate its debt with institutional investors due to the territory's legal status, which prevented Puerto Rico from utilizing the U.S. Bankruptcy Code (Meng, 2019). After the U.S. Supreme Court rejected the

archipelago's own attempt to create a restructuring process, the U.S. Congress passed the Puerto Rico Oversight, Management, and Economic Stability Act (PROMESA) in 2016, further constraining Puerto Rico's ability to manage its fiscal crisis. While PROMESA established a Financial Oversight and Management Board for Puerto Rico to help achieve fiscal responsibility and access to capital markets (Cabán, 2018), the law imposes limitations on how the Puerto Rican government can harness local resources to address crises, ultimately resulting in a curtailed ability to respond to disasters (Rodríguez-Díaz, 2018).

Furthermore, the Merchant Marine Act of 1920, known as the Jones Act, poses additional challenges to Puerto Rico's ability to provide disaster response. The Jones Act was originally established to enhance national defense by ensuring the availability of vessels during times of national emergency and to stimulate domestic commerce (Rivera, 2018). The Jones Act mandates the use of American merchant ships for all imports to and exports from Puerto Rico, making it the most costly option in the world; as a result, food prices increase by 25%–30%, which is particularly hard on people living in poverty who may already struggle with food insecurity and lack of food storage due to financial constraints (García-López, 2018; Straub, 2021). This sole dependency on the U.S. merchant marine also puts the supply chain at risk, eliminating the possibility of negotiating prices with other merchant marines.

Navigating the vulnerabilities of the FEWS and the challenges posed by compounding human-made crises and climate change requires a comprehensive approach. This approach should integrate DRR, community-based solutions, and collaborative efforts among various stakeholders, including non-governmental organizations (NGOs), civil society, and academics (López-Cepero et al., 2021; Sheppard, 2022). Local NGOs and community-based organizations play a pivotal role in disaster relief and recovery processes, building both community and environmental resilience in underserved communities (Fitzpatrick and Molloy, 2014; Hayward et al., 2019). Civil society plays a key role, as effective DRR is only achieved with active participation from the local community (UNICEF, 2014; Seddiky et al., 2020). Partnerships between NGOs, academics, and other stakeholders facilitate the effective interplay between practice-based data and theory, often leading to knowledge creation. It is important to note that the motivations for collaboration may differ among the NGOs, community members, and academics (Harris and Lyon, 2013), but they share a common need to demonstrate impact (Aniekwe et al., 2012; Stevens et al., 2013). For instance, NGOs may be motivated by funding access and addressing community issues that span multiple disciplines, while academics are interested in tackling complex FEWS issues and collaborating with NGOs to gain context-sensitive experiences (Harris and Lyon, 2013). Such collaborations bring benefits for all participants (Roper, 2002; Zscheischler et al., 2018), and transdisciplinary research has the inherent ability to enhance

both human (O'Donovan et al., 2022) and social capital (Gray, 2008).

1.1 Related work

Academic-NGO collaborations bring numerous benefits, such as improved academic and practical project outcomes and the ability to tackle real-world problems and ignite innovation (Aniekwe et al., 2012). For example, working with NGOs hones academics' applied expertise and provides opportunities to refine theories through access to empirical evidence (Aniekwe et al., 2012). Further, working with stakeholders who may live in areas that often face disasters is a way to develop DRR solutions, empower communities, and control crises (Beaven et al., 2016). For NGOs, academics provide sufficient additional perspective and analytical capacity, which are sometimes unavailable to the NGO's team (Roper, 2002).

While there are benefits to these types of collaborations, they also come with their own set of challenges. Collaborations between academic institutions and NGOs can be challenging due to issues such as institutional politics, differing timeframes and philosophies, and varying expectations and requirements for outcomes; prior investigators suggest having a better understanding of how these collaborations can improve development interventions, programs, and projects and highlight how effective communication and open dialogue are crucial when collaborating with academics, affiliated organizations, and NGO practitioners (Aniekwe et al., 2012). Similarly, Lokot and Wake (2021) emphasize the importance of recognizing power imbalances and addressing challenges that come with traditional research partnerships in humanitarian contexts. Roper (2002) examined the reasons why academic-practitioner collaborations often fail; one reason is that some projects can be difficult for practitioners to comprehend and are overly complex.

Previous literature highlights how NGOs and community-based organizations can collaborate with academics to enhance FEWS and disaster resilience. Regarding FEWS, Dentoni and Bitzer (2015) note how projects with multiple stakeholders (i.e., NGOs and academics) can be utilized to deal with problems in the global food system. Similarly, Bolaños-Palmieri et al., (2021) state how multi-stakeholder collaborations are essential for reducing food loss and waste. In Malaysia, a similar collaboration helped to implement sustainable food waste practices (Chan et al., 2022). Further, a study in Bangladesh analyzed how academics and NGOs collaborate to support climate change adaptation and disaster resilience in coastal communities in the Bagerhat District; the study aimed to create a visual representation of the disaster risk and resilience system by illustrating relationships among different groups involved, such as NGOs, government, academic and research institutions, private sector, and community-based organizations (Bollettino and Ferguson, 2020).

Considering that disasters represent inherent failures in the ability of communities to supply FEWS, building bridges between science and practice would seem a viable pathway to address these real-world problems (Marshall et al., 2018). Notably, energy (Shinozuka and Chang, 2004; Tormos-Aponte et al., 2021) and water (Blake et al., 2012; See et al., 2017) are often absent or limited in availability around times of crisis. Depending on the structure of a local supply chain, food may quickly become limiting (Nozhati et al.,

2019), contingent upon local approaches to disaster preparedness (Das, 2018). To our knowledge, there remains a gap in the literature on the transdisciplinary interface of academic-NGO collaborations, the FEWS nexus, and the resilience to disaster-related events (Gaillard and Mercer, 2013; Gall et al., 2015; Bendito and Barrios, 2016; Thompson et al., 2017).

1.2 Addressing the research gap

To address this gap, this case study describes a collaboration between an INFEWS-ER (Innovations at the Nexus of Food, Energy, and Water Systems Educational Resources) cohort of graduate students, mentors, and advisors and a Puerto Rican NGO, Caras con Causa (CCC), to improve community DRR as it relates to FEWS. The purpose of this study is to analyze a transdisciplinary academic-NGO collaboration from October 2020 to April 2021, helping to foster the resiliency of communities during post-disaster reconstruction processes in Puerto Rico and increase their disaster resilience capacity (Chen et al., 2008; Hudec et al., 2018). Working with CCC, this cohort identified a common goal and sought to reflectively co-design context-sensitive solutions spanning the boundaries of natural sciences, engineering, and social sciences (Lang et al., 2012; Gaillard and Mercer, 2013; Bendito and Barrios, 2016; Thompson et al., 2017; Matsuura and Razak, 2019; Lawrence et al., 2022). In this case, the cohort created a literature database and funding opportunities document to support CCC's community-based programs. Considering the symbiotic relationship that defines academia and external stakeholder collaboration, this study addresses how a group of academics and an NGO collaborate to advance community resilience, how different academic backgrounds influence academic-NGO outcomes, and the practices to include and avoid in academic-NGO collaborations. Lessons learned are expected to be useful for academics (students and faculty), NGOs, and those who want to participate in academic-NGO collaborations.

2 Methods

To understand this transdisciplinary collaboration, we describe our case study (Yin, 2018) and focus on our local collaborator, CCC, and the INFEWS-ER cohort in detail. Document analysis (Bowen, 2009) on meeting notes taken from participant observation (Jerolmack and Khan, 2017) from the academic year 2020–2021 describes how the collaboration evolved over time and how cohort participants from diverse disciplines shaped the results and deliverables.

2.1 Case description

National Science Foundation project, The INFEWS-ER (Innovations at the Nexus of Food, Energy, and Water Systems Educational Resources), is an international training program for graduate students that focuses on challenges within the nexus of FEWS (Koelsch et al., 2019; Rodríguez et al., 2019; 2023; INFEWS-ER, 2022; Marshall et al., 2022). Participation in this program is

voluntary. Graduate training modules, topics, and webinars include stakeholder engagement, social justice, cultural intelligence, systems thinking and modeling, communication in transdisciplinary environments, analytics, and high-performance teaming, all of which aim to teach graduate students how to tackle complex or wicked FEWS problems. Generally, cohorts of graduate students are asked to target significant grand challenge scale problems of the day. Graduate students that participate in the INFEWS-ER have weekly meetings with advisors and mentors and are provided a basic guideline regarding project milestones. Within the “Disaster Relief and Resilience” INFEWS-ER cohort, described here, a group of graduate students collaborated with a Puerto Rican NGO, Caras con Causa (CCC), or “Faces with a Cause”; thus, participants of the graduate INFEWS-ER cohort and CCC are co-authors on this paper. From 26 October 2020, to 23 April 2021, our cohort developed a literature database and a list of funding opportunities to support CCC’s environmental citizen science and science, technology, education, art, and math (STEAM) education programs. Approximately midway through this program, cohorts participate in a reflection exercise with other cohorts participating in the INFEWS-ER at that time. This allows cohort members to gauge their progress and lessons learned in the execution of transdisciplinary research efforts and to identify methods that might be useful. It is the intention of this design of cohort experiences that participants observe their development of transdisciplinary skill sets while delivering products to their stakeholder communities. Observations regarding the process of developing transdisciplinary skills for this cohort later became the subject of this study.

CCC works with several disadvantaged communities within the municipalities of Cataño and Guaynabo, Puerto Rico. CCC aims to uplift these neighborhoods by working with local youth to create educational, environmental, and economic opportunities. Through their two main programs, “Community Laboratory” and “Urban Roots,” CCC creates environmental opportunities for communities to better their local ecosystems and generate meaningful environmental data through citizen science. Urban Roots is a horticultural reforestation initiative to cultivate mangroves to sustainably restore local ecosystems. For example, within the Urban Roots program, CCC helps community members participate in educational plantings, allowing students to rehabilitate local reserves that have been negatively affected by urban development (Caras con Causa, 2022). The Community Laboratory (LabCom) initiative gives students access to laboratory equipment to conduct science activities and exercises outside of school, many of which relate to FEWS. These programs provide extracurricular activities for students who may not have access to similar exercises in their school. For instance, public schools in the areas utilize the LabCom facilities “as an annex, having innovative educational experiences and alternatives that meet the academic requirements of the Department of Education” (Caras con Causa, 2022). Puerto Rico’s public schools lost approximately 18,000 students per year due to the economic crises from 2006–2017 (Hinojosa et al., 2019). Since 2016, hundreds of schools have been closed across the archipelago due to disasters, neglect, and poor governance (Katz, 2019). CCC’s programs improve student engagement, foster environmental

stewardship, and build community and environmental resilience against future disasters.

These programs led by CCC increase FEWS resiliency in the communities in which they operate through the rehabilitation of the local nature reserves. Mangroves and other trees planted through the Urban Roots program are directly beneficial to disaster resiliency and water quality. Urban forests have been found to provide stormwater management benefits due to evapotranspiration and roots stabilizing nearby soil, reducing runoff and subsequent soil erosion and transport into waterways (Taguchi et al., 2020). In addition, urban forests can help combat the urban heat island (UHI) effect, reducing energy needs for cooling during warmer seasons (Manning, 2008; Livesley et al., 2016; Marando et al., 2019). Mangrove forests, in particular, have been found to offer some protection against storm surges from tropical hurricanes (Dahdouh-Guebas et al., 2005). Through the implementation of the Urban Roots program, CCC is able to improve water resources in the surrounding communities, supporting improved water resource management. Additionally, with their reduction in the UHI effect, urban forests planted by CCC can help reduce the energy needs of the surrounding communities, further contributing to an increase in their FEWS capacity.

Moreover, in relation to FEWS, CCC has a nursery, Vivero Antillano, where they grow native trees and shrubs (endangered and endemic) (Caras con Causa, 2022). The nursery serves as a tool for students and community members to learn more about the environment. From the nursery, CCC plants thousands of trees and plants them within Natural Reserve Las Cucharillas, a nature reserve near San Juan. This nursery serves as an example of what can be achieved in other areas where food and horticultural products are in demand within local communities. There are several other regions around the archipelago where mangroves are to be restored, such as in nurseries from COPI in Piñones (COPI, 2022) and Para la Naturaleza in multiple Puerto Rican cities (Para la Naturaleza, 2022). These nurseries are designed as integrated systems to enhance resilience, collecting and storing rainwater to supplement irrigation systems. A renewable solar power system is currently being designed and developed to drive the irrigation system. Subsystems like these are essential for a reliable system, given the fragility of municipal power and water delivery systems, while providing a learning opportunity for local schools participating in LabCom.

The University of Illinois Urbana-Champaign began working with CCC in 2018 after Hurricane Maria and has a continued, long-term relationship with the NGO. From this relationship, the university created two engineering for disaster resilience courses where students learn stakeholder engagement and engineering techniques to advance FEWS in Puerto Rico. With the help of CCC, the students from these courses can participate in short study abroad programs in the archipelago, implementing engineering systems they created in the course, working on service-learning projects, and helping CCC with their environmental programs. Additionally, the University of Illinois Urbana-Champaign, along with CCC and the University of Puerto Rico at Mayagüez, has led Research Experiences for Undergraduates (REU) projects both in Illinois and Puerto Rico for students to learn qualitative and quantitative engineering skills related to Puerto Rico’s FEWS (Disaster Relief and Resilience, 2022). Moreover, this relationship

has been vital for the INFEWS-ER program and its cohorts. For instance, from 2019–2020, another INFEWS-ER cohort (with members and advisors from the University of Illinois Urbana-Champaign) collaborated with CCC (Stablein et al., 2022).

This work effectively utilized the expertise of both the current cohort and CCC; it used the academic resources and diverse research skills of graduate students, mentors, and advisors along with the citizen science, education, and ecological work of the NGO. The 2020–2021 disaster relief and resilience *team* consisted of 11 graduate students of various academic backgrounds and universities in the United States who completed the INFEWS-ER program. It should be noted that 17 total participants initiated the program. Disciplines represented on the team encompass both the social sciences and STEM fields, with majors including chemistry, water resources science, economics, physics and geophysics, social work, agricultural communications, agricultural and biological engineering, consumer economics, informatics, and sustainability. In addition to the team of graduate students, the *cohort* also includes five *mentors*, who were 2019–2020 INFEWS-ER cohort participants (Stablein et al., 2022), and three *advisors*, providing feedback and guidance during the INFEWS-ER cohort challenge. These terms will be referred to throughout to describe the participation of specific groups within our team.

As the outcome of the collaboration, our cohort produced an academic literature database and a list of funding opportunities to assist CCC with its programs and future funding efforts. CCC specifically requested these deliverables, as they explained to us that they often seek external funding that requires evidence-based literature to back up the claims of the organization. To assist with this, we utilized Zotero (Zotero, 2022) to collect and store literature that supports Urban Roots and LabCom, such as papers regarding STEAM education, citizen science, and environmental science. We taught members of CCC how to use Zotero, and we created a how-to document for them to use the database independently. We also created a list of abstracts of each of the papers we found for CCC, making the material easy to understand and inclusive for non-academics. Furthermore, we created a list of grants and funding opportunities applicable to CCC, highlighting due dates and application requirements for each opportunity. To split up the work based on our interests and backgrounds, three subgroups were made, where five team members worked on finding literature for LabCom, four team members worked on finding literature for Urban Roots, and two team members, our Knowledge Brokers, helped create the funding opportunities list.

Cohort communication and content management included both guided structure and the autonomy for team members to develop their own systems. At the beginning of the cohort, the advisors set up a cohort course website, established a meeting structure with rotating roles of facilitator, notetaker, and timekeeper during meetings, and organized informational sessions on topics and learning modules along with a preliminary meeting with CCC. The cohort was left to figure out the need for and implementation of out-of-meeting communication, team-building activities, and accountability methods. Weekly cohort meetings involved the cohort participants and advisors but not CCC. With the exception of the introductory meeting with CCC, meetings that included CCC were scheduled outside of normal weekly meetings and occurred on three occasions, following the availability of the CCC representatives.

2.2 Research design and analysis

To gain a better understanding of the behavior and decision-making of the cohort during an academic-NGO collaboration, we relied on participant observation for this empirical case study (Jerolmack and Khan, 2017; Yin, 2018). We observed our interactions, decisions, and behavior during the cohort challenge and collected data in the form of meeting minutes. These minutes provided a detailed record of the group's discussions, decisions, and actions. A set of meeting minutes was taken by a rotating notetaker from the team during every meeting of the collaboration after the initial orientation took place at the end of October 2020. By the end of the project, every team member was a notetaker at least once. As the notetaker role shifted throughout the collaboration, the quality and detail in notes varied. Each notetaker used a default base template to structure the notes. The base template included a space to add the meeting's purpose, attendance, the identity of that week's rotating meeting facilitator, notetaker, and time manager, activities and actions conducted during the meeting, and the next steps to focus on. The base template structure was structured according to the P.L.A.N. Collaborative Project Management Framework (The P.L.A.N. Collaborative Project Management Framework, 2020).

In total, 44 individual meeting-minute documents were created from November 2020 to April 2021. Meeting minutes were imported into both NVivo™ (NVivo, 2022) and MAXQDA (MAXQDA, 2020), where two coders conducted document analysis (Bowen, 2009; Frey, 2018) in each program individually. Within these programs, meeting notes were organized into four categories that represent when these were generated: 1) general INFEWS-ER cohort meetings, 2) team meetings with CCC, and team meetings with 3) LabCom and 4) Urban Roots. Classifying the meeting notes in this way gave context to each meeting note, identified who was present at the time of discussion, and facilitated analysis. One previous study that focuses on academic-NGO collaborations also used document analysis to investigate administrative archives from university administrators, society leaders, and public officials to understand more about these types of collaborations in Ecuador (Appel and Barragán, 2017). In our case, we used this research approach to analyze our own meeting minutes to retroactively evaluate our academic-NGO collaboration and the process behind the collaboration.

For this analysis, two coders separately analyzed the documents by reviewing and interpreting the text to gain empirical knowledge and generating a set of codes (or themes). As the codes (or themes) emerged from the text, these codes were applied deductively to all the meeting notes. As an iterative process, the analysis included inductive and deductive analysis of the text content (Bowen, 2009). To strengthen the reliability of data analysis of meeting notes, the two coders compared the emerged codes and agreed on how to code the text content. Afterward, we adjusted the codes based on the agreed coding technique (changing codes from our new shared understanding of how to code) and created the final codebook, highlighting the main themes and noting the number of occurrences for each (Table 1).

TABLE 1 Themes and sub-themes established via document analysis. Each theme was identified to have occurred with frequency as listed under Number of Occurrences.

Themes	Sub-themes	Description	Number of occurrences
1: Team Organization	Distribution of Work, Background and Skills, Participant Expectations	How the challenge and team were organized	90
2: Collaboration with CCC	Learning from CCC, Questions for/from CCC, Communication with CCC, Documents from CCC	Collaboration between the team and CCC	39
3: Deliverables	Timeline, Goals, Discussion of Findings	Outcomes of the collaborative experience handed over to CCC	30
4: Team Contributions	Skills Utilized, Personal Contributions	Cohort members' skills and contributions	16
5: Context Understanding	Understanding of Project/Material, Uncertainty of Project/Material, Translation	Participant interest in learning more about the context of the project and Puerto Rico	12
6: Participation Outcomes	Career Outcomes, Skills Gained	Training, skills, and competencies acquired through the INFEWS-ER experience	12
7: Technology Setup	Zotero Database, Technology for Communication	Decision-making process for technology use	12
8: Lessons Learned	Advice Given	Knowledge derived from the INFEWS-ER experience	6

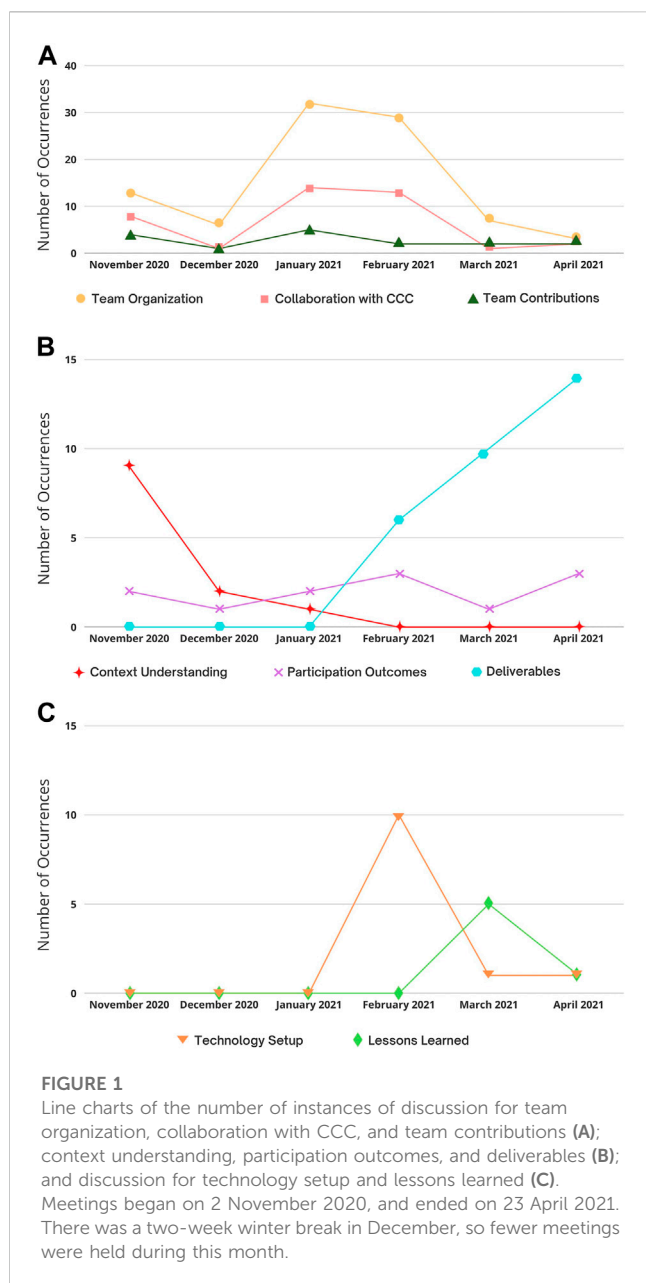
TABLE 2 Examples of each theme taken from the meeting minutes. For some themes, multiple examples are utilized to highlight the meaning and topics discussed that match the theme.

Themes	Example (taken from meeting minutes)
1: Team Organization	<i>"Discussion about skill sets and how to incorporate this into the literature review, matching everyone's skill sets"</i>
	<i>"Discuss splitting up groups and people who will connect the groups (LabCom vs Urban Roots)"</i>
2: Collaboration with CCC	<i>"I think that's something really important to talk to Caras about. If they don't want new projects or things for them to implement, we should do things that they want us to do and what will be helpful for them. We should do things we want to do as a group but also take into account that our stakeholders are going to be doing the actual implementation of these things."</i>
3: Deliverables	<i>"Many articles fit for both groups (Urban Roots and LabCom), we can use the tags for both Urban Roots and LabCom -- this might make things easier for Caras if they want to focus on specific areas."</i>
	<i>"We should decide on similar formats for everything."</i>
4: Team Contributions	<i>"Initially, seemed like 'I didn't have anything to contribute,' but learned that every individual has something to contribute. I am a piece of this puzzle, but everyone else is too."</i>
	<i>"Discussion about skill sets and how to incorporate this into the literature review, matching everyone's skill sets."</i>
5: Context Understanding	<i>"Purpose: Learn more about the history, policy, and political climate in Puerto Rico and how that impacts the ability of local communities to prepare for, respond and recover from disasters"</i>
6: Participation Outcomes	<i>"Important that we have a product to show. Think about how we're going to use this to market ourselves as well -- something we can be proud of."</i>
	<i>"Marketing your experience for career next steps"</i>
7: Technology Setup	<i>"Zotero has a certain amount of storage capacity to save the documents. Do you think we should still complete the abstract document?"</i>
	<i>"Create a keyword/journal search document as a Google Sheet"</i>
8: Lessons Learned	<i>"The cohort should move at a faster pace and get more work done during the first semester. We could potentially reduce the number of webinars to make more time to do work during our formal meetings. We could potentially work on fewer platforms. We can work on understanding what our stakeholders want quicker. We can do more team-building exercises or try to get to know each other better earlier on."</i>

3 Results

Analysis of the meeting minutes taken during the academic-NGO collaboration revealed eight key discussion themes: team

organization, collaboration with CCC, deliverables, team contributions, context understanding, participation outcomes, technology setup, and lessons learned (Table 1). Each will be discussed in turn.



3.1 Team organization, collaboration with CCC, and team contributions

“Team organization” was the most common theme. Discussion on this topic was broad, and there were frequent conversations on how the team and collaboration were organized. Team members would talk about their roles, the project itself, the organization of the challenge and collaboration, how team members wanted to split up into smaller groups, the rescheduling of meetings and absences of team members, the distribution of work, and what it means to be a high-performing team (Tables 1, 2: Team Organization).

The discussion on team organization occurred throughout the project, peaking as the cohort was starting work on the deliverables in earnest in January and February and toward the cohort’s formation, documented by the meeting minutes (Figure 1A). The

number of occurrences for team organization followed similar patterns to discussions on how the team collaborated with CCC and the contributions of the team.

The “collaboration with CCC” was the second most common theme. On November 2nd, team members were introduced to previous projects with CCC, and discussions about their own projects with CCC began on November 16th in a meeting with CCC (Figure 1A). Cohort members discussed the project goals and clarification of the project, ideas for the project, tasks to do before directly meeting with CCC, information requests from CCC, and questions for CCC. As with the discussion on team organization, the discussion of collaboration with CCC was greatest toward the cohort meeting minutes commencement (November 2020) and during project commencement (Figure 1A: January and February 2021).

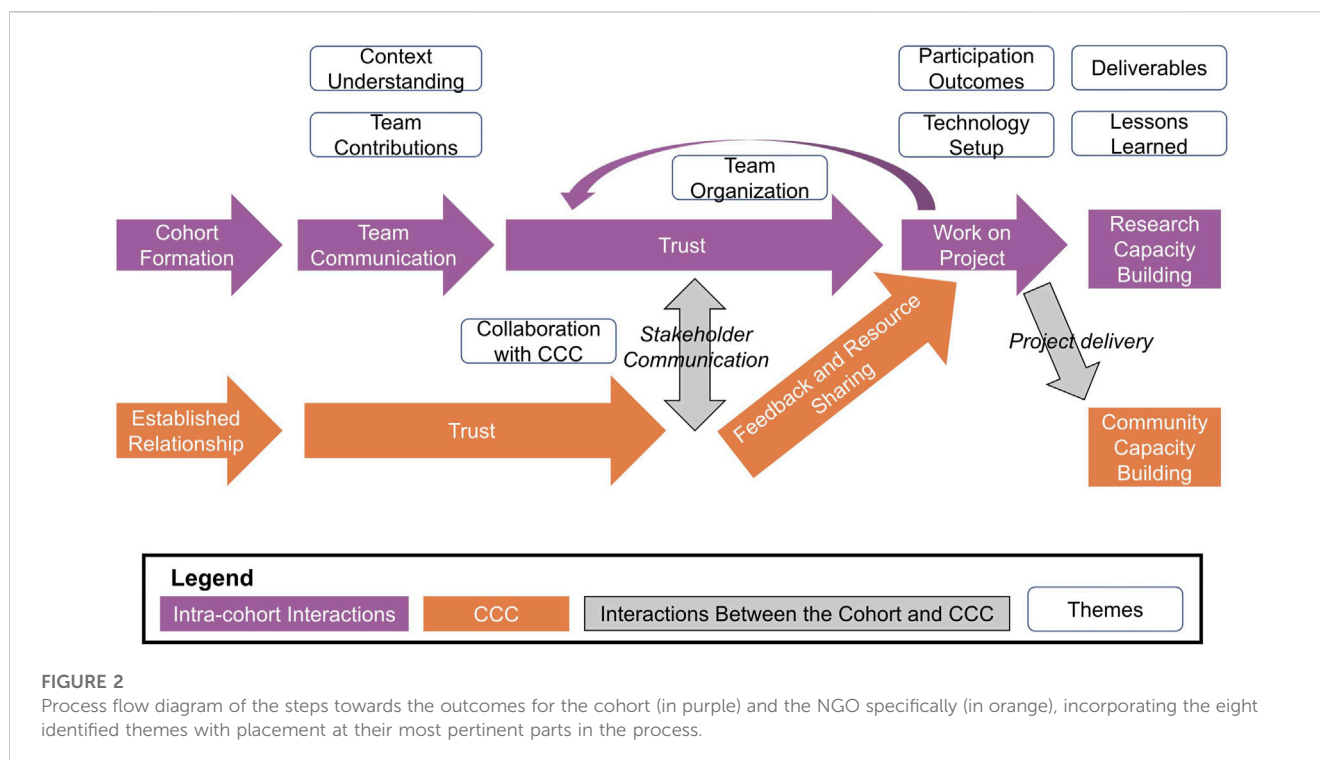
“Team contributions” was one of the most uniformly discussed themes throughout the project, occurring a total of 16 times with a similar occurrence pattern to team organization and collaboration with CCC. The discussion on team contributions peaked in January 2021, similar to team organization and collaboration with CCC (Figure 1A). Team members discussed their different backgrounds, shared skills, how to match students’ skills to the project, and the strengths members brought to the project. Participants also discussed disagreements and the contribution of each team member. These discussions were a formative part of building the transdisciplinary research capacity of the graduate students (Figure 2) as they reflected on how they could best contribute to the group and the value of a transdisciplinary team (Table 2; Theme 4: Team Contributions).

3.2 Context understanding, participation outcomes, and deliverables

For “context understanding,” cohort members talked about Puerto Rico (its culture, history, and political climate), the communities with whom CCC works, how disasters have affected Puerto Rico, governmental corruption across the archipelago, and the importance of context in engineering and community-engaged projects. Most of these discussions occurred in November during the introductory portion of the challenge, where the meetings were structured around learning modules set forth by the advisors, with discussion on the topic ending by February 2021.

Like “context understanding,” “participation outcomes,” was also discussed 12 times, though at different points during the project (Figure 1B). Participation outcome discussions concerned high-performing teams, marketing the cohort challenge experience, the measurements of success, and how to align the project with cohort members’ interests. These discussions occurred throughout the project (Figure 1B), instead of primarily at the beginning as context understanding was.

The third most frequent theme was the “deliverables” of the project to CCC. Cohort members discussed the deliverables’ status, their accessibility and inclusivity, how to define collaborative success, and the ways in which the deliverables should be organized and created (e.g., the ways the deliverables could be easily displayed and handed over to CCC). Conversations on deliverables did not start until after January 2021 as work on the project began, and discussion increased in frequency until the end of



the project (Figure 1B). These discussions occurred in an opposite frequency to context understanding, which was heavily talked about early on in the collaboration and decreased halfway through.

3.3 Technology setup and lessons learned

Furthermore, “technology setup” had equal discussion with context understanding and participation outcomes (12 occurrences). For the technology setup, cohort members discussed what technology they were going to use to create the literature database for CCC, online polls to figure out when to schedule meetings, and different means of online communication (e.g., Slack), most discussion of which occurred in February 2021 as the cohort was figuring out how to make the deliverables accessible to CCC.

The occurrence pattern for “lessons learned” was similar to the technology setup, although the lessons learned lagged by a month. It was the least frequently discussed theme; all related discussions were lengthy and detailed (six total occurrences). Cohort members discussed ways to improve future cohort challenges, how to better start the process of working on the project, and their experiences working with the NGO. Discussion on lessons learned (mainly March 2021; Figure 1C) revealed that the cohort was engaging in co-reflection on its own in addition to the scheduled reflection in January built into the cohort challenge. Since the January reflection was mid-way through the project and constructive for moving forward, discussions from this meeting were classified under themes other than “lessons learned.” Co-reflection, such as discussing lessons learned, is considered an integral part of transdisciplinary research (Roux et al., 2010).

4 Discussion

The results provide insights on both advantages and limitations/challenges to the academic-NGO collaborative process, and here we highlight what to include and avoid in these collaborations. Having an established relationship between the cohort leadership and CCC was advantageous, as it enhanced the cohort’s ability to build trust and communication during the collaboration. Further, a structured approach to a transdisciplinary process is especially helpful in FEWS work, as knowledge ordinarily pertaining to many disciplines provides perspectives from both the hard and social sciences, as well as at the community, level. The effectiveness of the collaboration was limited by accountability and motivation within the cohort, communication, and the great investment of time in developing a transdisciplinary process. The size of the team impacted member motivation and caused troubles when distributing work evenly. The cohort experienced communication barriers, and correspondence with CCC was impacted by the ongoing pandemic and related impacts to day-to-day operations. Upon reflection, we discovered that CCC shifted its operations at the beginning of 2021 to prioritize in-person community services and virtual learning in response to the pandemic’s impact on the communities they serve. This coincided with our cohort project and resulted in significant changes to CCC’s availability due to increased workload and longer working hours to meet the population’s needs. For reference, CCC worked with over 380 students in Puerto Rico, 86% of whom lacked access to computers or the Internet, during this time. This posed a significant challenge to ensuring that educational services were consistently and urgently provided through alternative means. As a result, from the perspective of the team, progress was delayed (we later deemed this an inappropriate response, given the reflection on

CCC's situation), and lessons learned only materialized toward the end of the collaboration. As the collaboration took place from 2020–2021, the pandemic was ongoing, and COVID-19 acted as both an asset and a limitation.

4.1 Relationships

The well-founded relationships between advisors and mentors within the cohort (Section 2.1) and CCC at the project's start created the foundation of trust between the two groups (Figure 2). Based on their past experiences in transdisciplinary research and their familiarity with the NGO, our advisors and mentors were able to offer the team their insight into CCC's work and organizational structure or on working in transdisciplinary teams, such as how to organize work for a large group. It was clear that the long-lasting relationship benefitted CCC since its members arrived at the start of the 2020–2021 cohort with a defined scope for deliverables, in contrast to the undefined scope and deliverables at the beginning of the previous cohort's project (Reed, personal communication). This foundation changed and arguably expedited the project definition process for the 2020–2021 cohort.

The existing relationship between the academics and the NGO improved the knowledge and familiarity of one group with the other, facilitating communication and trust between the two groups (Figure 2). As mentioned previously, past participants from the 2019–2020 INFEWS-ER cohort were mentors during the 2020–2021 cohort (Section 2.1). Existing relationships are a common way to build trust in transdisciplinary collaborations through the knowledge that the two groups can work together and through an existing foundation of shared understandings and norms (Harris and Lyon, 2013). The trust foundation from the existing relationship gave both parties confidence that the other would hold up its end in achieving the project outcome.

As seen in the findings, the context of the project was evident from the existing relationship between the cohort and CCC, as much discussion focused on context understanding toward the beginning of the collaboration but went away in three months (Figure 1B; Theme 5: Context Understanding). In general academic-NGO collaborations, it is crucial for both parties to fully understand the project and each other's roles to ensure that all gaps are addressed, and research tasks are complementary (Aniekwe et al., 2012). According to Stokols et al. (2008), having a history of successful partnerships with a particular organization or community in transdisciplinary collaborations is helpful. This fosters trust between coalition partners and strengthens future collaborations. Maintaining strong relationships through regular communication and socialization builds trust and creates a sense of group identity. Throughout the cohort challenge, the collaboration with CCC was solid and sustaining (Figure 1A; Theme 2: Collaboration with CCC). Therefore, trust was readily established because of the long-standing collaboration. One challenge regarding trust for the team was believing that CCC was still on board throughout the project despite occasional lags in communication response time. When reflecting on the

collaboration, we learned that CCC remained committed to the project despite facing operational challenges and resource constraints due to the return to in-person services in 2021 and restrictions imposed by strict COVID-19 protocols. This trust was previously generated by other members of the cohort and enabled the project to move forward, minimizing snags in project completion from issues of lack of knowledge of the other group. Based on prior literature and our own findings, trust is established through knowledge of others, past collaboration, and shared expectations, understanding, and context (Harris and Lyon, 2013).

4.2 Transdisciplinarity

The breadth of disciplinary knowledge and cultural exposure amongst members of the cohort revealed both the disparity in knowledge about the field of CCC's work and the differences in research terminology. This disparity demanded explicit open-mindedness and effective communication (Theme 1: Team Organization), which is beneficial for stakeholder engagement (Milani, 2019). The team responded to this demand by facilitating communication that crossed disciplinary boundaries; the team was able to overcome challenges with inter-team communication that are common with transdisciplinary efforts (Gaziulusoy et al., 2016). Since team members recognized they had such diversity of backgrounds, due in part to framing from the cohort advisors and learning modules, they acknowledged each other's differing expertise and were able to have discussions with respectful debate. For example, in January, based on concern that some team members were not interested in the project that CCC had proposed, there was a debate on whether the cohort could perform a second project. Previous literature mentions how having increased debates is common in high-performing teams (Ocker and Fjermestad, 2008).

In addition to what the cohort learned about the cultural, historical, and economic situation of Puerto Rico (i.e., Theme 5: Context Understanding), cohort members who had at one point been residents of Puerto Rico contributed place-based knowledge that strengthened the understanding of the stakeholders for the group. Tandemly, bilingual cohort members also facilitated conversations with CCC where a mix of English and Spanish was utilized. To effectively contribute to decision-making and provide appropriate solutions, it is essential to have a comprehensive understanding of the situation at hand (Heiden and Saia, 2020). By prioritizing a thorough comprehension of the situation, a meaningful impact can be made on the outcomes of the decision-making process.

The breadth of knowledge present in the graduate student team was beneficial in contributing to the human capital and research capacity of the graduate students. The development of the literature review database relied on “soft” research skills gained by most graduate students during their studies, such as reading literature and synthesizing its information, and less on their technical expertise or expertise in the field in which CCC works. As team members worked outside of their field during the production of the literature review, a deliberate checks and balance system was created, where the team would go over each

research article to determine if it fit the needs of the review. The main difficulty of the project lay in defining the project's organization and how sub-groups within the team would work together, which relied less on discipline and more on collaborative/research experience. Even so, team members were able to split into groups and specialize in topics of interest for the literature review (Section 2.1). Team members commonly discussed how their different disciplines could help: the useful contribution of each member was one of the most common discussion points under Theme 4: Team Contributions. As seen in previous literature, field variety has the potential to enhance scientific creativity (Yong et al., 2014; Lee et al., 2015). While discussion on academic backgrounds was common, true disciplinary understanding, as described by Castán Broto et al. (2009), may not have been achieved, nor may not have been absolutely necessary, in the few months of the cohort challenge. Rather than the specific composition of disciplines (e.g., informatics, social work, engineering, etc.), we posit that it was the range of disciplines and diversity of experience that imparted an open-mindedness among the cohort to different perspectives, possibly aiding the group in both understanding the Puerto Rican NGO and in creating an accessible product.

Food, energy, and water systems research is inherently transdisciplinary; FEWS stretches across a variety of disciplines, integrating both social and hard sciences into solving problems related to facets of FEWS grand challenges. Transdisciplinary approaches are at the core of the FEWS fields as they are essential for dealing with the scale, complexity, and interconnectedness of issues in FEWS (Munasinghe, 2001). Inherently, what our team added to CCC's effort was transdisciplinary, as not only are both disaster relief and resilience transdisciplinary, it is the resources of food, energy, and water that are most limiting in the immediate aftermath of a disaster. A core component of CCC's mission is to improve community resilience, and these efforts contribute towards this goal. Both transdisciplinary knowledge on how each program will assist the community on a social and economic level, as well as on a natural science and engineering level, were needed in order to better understand and assist with the multitude of benefits these programs bring. The transdisciplinarity aspect of this project is exemplary of the transdisciplinarity in FEWS research, whereas without the diversity of backgrounds the team possessed, this case study would have been significantly less effective and capable of providing our NGO partner with the research and knowledge needed to assist with their issue that our team was charged with. In general, transdisciplinary research involves bringing together individuals from different disciplines and perspectives to collaborate and contribute their ideas. This process of knowledge co-production is essential for effective collaboration (Boon et al., 2014). The CCC project that may emerge later, as a result of the deliverables we created for CCC (e.g., the research database and funding opportunities list), would likely seek to build FEWS-related community resilience either with CCC or in neighboring communities. The provision of community-based, safe, and reliable food, energy, and water are central to resilience.

4.3 Accountability and motivation

The large group size caused some team members to struggle to see how they could contribute and stay motivated (Theme 4: Team Contributions) and caused difficulty in organizing work distribution (Theme 1: Team Organization). Cooke and Hilton (2015) found that within teams, each member may have their own values and motivations, influenced by various factors such as expertise, organizational context, or life experiences. The difficulty in establishing accountability and motivation when participation was voluntary was exacerbated by the project's virtual modality (Armstrong and Jackson-Smith, 2013). Gaziulusoy and their collaborators (2016) argued that geographically separate transdisciplinary teams are less efficient, though Ocker and Fjermestad (2008) showed that virtual teams have the potential to be high-performing. We found that accountability, participation, and enthusiasm were largely self-driven without both the natural pressure and camaraderie that comes from in-person interactions. The heavy reliance on self-driven action over the large volunteer team may help explain team attrition, frustration, and burnout.

Trust is integral to a team as the safety of participants is built on trust—trust promotes creativity and innovation (Ocker and Fjermestad, 2008). Trust in an interdisciplinary team is especially important because as people cross disciplinary boundaries, they become vulnerable (Harris and Lyon, 2013). We found that within the cohort, trust was built over time during online meetings and especially once the team split into smaller groups. Early on, the team had optional “coffee chats” before official meetings as an informal way to get to know each other, and later, some team members added each other on social media as an added way to connect. Additionally, it is important to note that the trust between the cohort and CCC is also critical for their collaboration; we found that the long-lasting relationship between INFEWS-ER and CCC (Sections 2.1, 4.1) was enough to instill trust in the groups despite limited interactions between them (Figure 2).

Other interdisciplinary efforts have been found to suffer from the lack of systemic or institutional support for their time and efforts, making participation by graduate students or junior faculty a risk rather than a reward (Armstrong and Jackson-Smith, 2013). Graduate students in this cohort had competing priorities with their own research and classes, but many students were able to combat this by requesting and receiving class credit for the project from their university (this was not given by default). However, we did observe attrition among the team members.

4.4 Communication

Communication barriers included meeting frequency, the online Zoom platform, lags with communication, and disciplinary differences. Intra-team communication was exclusively virtual due to the cross-university nature of the collaboration. Tools such as Slack, email, and Zoom meetings were used to overcome this barrier, with the bulk of intra-team communication completed during weekly Zoom meetings. Ocker and Fjermestad (2008) showed that it is not the mode nor frequency of communication that contributes to the performance of the team; rather, it is the level of debate among the team members. Since most communication was

completed during weekly Zoom meetings, most progress was completed at the weekly timescale until the team broke into subgroups that met more frequently. In addition, meetings by Zoom limited conversation to primarily one conversation stream in which some team members were more able or comfortable to speak up while others had more trouble making their ideas known. Alternatively, a feature of Zoom meetings unavailable in in-person meetings was the chat feature in which participants could contribute in writing without breaking the flow of oral conversation.

Correspondence with CCC over email involved a communication lag time of up to a week, which was accentuated by scheduling virtual meetings weeks in advance. This reduced the team's ability to exchange information and ask questions of the stakeholders, as well as limited team productivity (e.g., not starting the project until two months after receiving it, see [Section 3](#)); however, we learned after reevaluating our communication with CCC that at the time of the project, CCC was going through a transition after COVID-19, resuming in-person community work despite strict COVID-19 protocols, while also having many employees working remotely. This unexpectedly consumed CCC employees' time and ability to respond in a timely manner as many learned to adjust. As graduate students at major universities in the continental United States, we expected a certain pace for all of our communication given the infrastructure available. When accounting for our stakeholders from a different environment, community, and culture, we realized that our communication expectations were not appropriate when considering the transition period CCC was experiencing. It should also be noted that all communication and discussion regarding key themes ([Figure 1](#)) decreased around the Christmas and New Years holidays, contributing to a delayed start of the project.

Previous research has shown that there can be significant communication challenges among different disciplines in transdisciplinary research both inside ([Harris and Lyon, 2013](#); [Stablein et al., 2022](#)) and outside of FEWS ([Rudhumbu et al., 2017](#)). Although we recognized some communication challenges upon reflecting on the collaboration, actual coded segments of meeting notes did not show evidence of this communication challenge. We hypothesize that communication was smoother than that of the previous cohort ([Stablein et al., 2022](#)) due to mentorship from the previous cohort ([Section 2.1](#)) and a learning module on communication and dialogue in transdisciplinary research in December 2020.

4.5 Obstacles to efficiency

By and large, transdisciplinary learning can be inefficient ([Roux et al., 2010](#); [Gaziulusoy et al., 2016](#)); the cohort experienced this inefficiency with delayed discussion on deliverables and technology setup ([Figures 1B, C](#)). Team members reflected that progress was slow and that more progress could and should have been made in the first months of the project ([Table 2](#); Theme 8: Lessons learned). Consequently, we must ask why the progress was slow based on the perspective of team members, if the delays were necessary, and what factors contributed to the eventual acceleration of progress.

The large group size led to a slow project start, logistical challenges in scheduling meetings, and a lack of clarity

concerning individual roles. Working with such a large team (17 team members at the outset) over a virtual landscape limited individual participation in the early stages of the project until subgroups were created months after the first meeting ([Section 2.1](#)). Two subgroups researched topics relevant to the Urban Roots program (four team members) and the LabCom program (five team members). The third subgroup was Knowledge Brokers (two team members), which originally planned to bridge the other two groups but evolved into identifying possible grants for CCC. Cohort members subdivided themselves into the subgroups depending on interests or perhaps by observing which other team members joined each sub-group. The subgroups were smaller units that allowed for increased accountability, more focused work for each member, and easier meeting scheduling.

Efficient group decision-making was hampered by a combination of large group size and the ambiguous definition of leadership roles. The rotating meeting leadership roles (i.e., facilitator, notetaker, timekeeper) involved all team members, gave each team member leadership experience, and provided accountability. However, the lack of a consistent leadership team slowed group decisions and organization, especially in the project's initial stages. Although CCC introduced the project to the group in November 2020, the team did not begin project work until January 2021, arguably due to a lack of group decision-making derived from the large cohort group size and unclear, rotating leadership structure, as well as the impact of the holidays on communication ([Section 4.4](#)).

However, the delayed start on the literature review deliverable may have been a necessary allowance for establishing trust and common language ([Roux et al., 2010](#)) and for building cohesion within the team ([Klein, 2008](#)), the case for which can be made by analyzing the timeline of progress. Because there were no pre-defined group leadership roles, the team had to realize a need for leadership roles, define those roles, and fulfill the roles. This process required establishing trust within the team. After the team designated a communication lead dedicated to communicating with CCC, they were able to schedule a second meeting with CCC, which was one impetus for project commencement. In addition to the January 2021 meeting with CCC, another factor that may have aided in starting the project was a January day of reflection with other graduate cohort groups and the consequent definition of a mission statement.

We posit that while there may have been a "phase of confusion" before the cohort properly organized itself; this was not a waste of time as it helped build the research capacity for the graduate students as they built rapport and learned about working in a team. Indeed, proper team integration cannot be pushed too quickly, or the quality of a group's integration will be shortchanged ([Klein, 2008](#)).

4.6 COVID-19: both an asset and a limitation

While recognizing that COVID-19 has had complex impacts on many aspects of work, including fatigue with virtual environments and effects on mental health ([Elbogen et al., 2022](#)), we found that the COVID-19 pandemic acted as a strength for this cohort as well as a limitation. The cohort started working together on 26 October 2020,

approximately seven months after the start of the COVID-19 pandemic in the United States. At this point, most students were accustomed to online meeting tools such as Zoom while also experiencing fatigue (Nesher Shoshan and Wehrt, 2022) and a desire to connect with other graduate students. Therefore, at this time, participating in a virtual cohort provided a sense of community that was lacking elsewhere. This sense of community may have been strengthened in the COVID-19 setting as opposed to a pre-pandemic setting with many in-person activities competing for the time and interest of graduate students.

Managing burnout from continuously working and learning in a virtual environment became a limitation in our study. Effects of remote work due to COVID-19, such as social isolation and family-work conflict, have been found to significantly affect productivity and engagement with work while also simultaneously increasing work-related stress (Galanti et al., 2021). A previous study investigating burnout from different education levels and durations of the study found the highest burnout in university students with nine hours of online learning per day (Sunawan et al., 2021). Within our study, we saw that team members participating in this project were taking their own disciplinary classes virtually throughout the study's duration and were thus exposed to differing levels of burnout which contributed to losses of productivity, frustration, and in some cases, team attrition, as the team went from 17 to 11 team members (Section 2.1).

4.7 Other limitations of this study

The meeting notes that were coded to form the dataset for this study include inherent biases. For example, since the meeting notetaker was inconsistent during meetings, the material analyzed for this study may not fully capture what occurred during meetings since some notetakers were more thorough than others. Additionally, team members took notes on subjects relating to the work that was being accomplished, not necessarily all topics covered during the meeting. For example, cohort members recalled making small talk before meetings which included a discussion of "Zoom burnout," but no notetaker recorded this discussion in the notes. Therefore, the dataset analyzed for this study is inherently biased toward the work aspects of the project and does not necessarily represent all social aspects of the project.

5 Conclusion

Lessons learned from this case study can help future cohorts or similar academic-NGO collaborations. From this study, investigators, communities, and societies can benefit from learning how transdisciplinary efforts influence academic-NGO outcomes and FEWS projects, practices to include and avoid, and how different cohort members' backgrounds affect collaborations. For example, we observed that it is beneficial to explicitly include the establishment of relationships between stakeholders, a structured approach to transdisciplinary processes, and cohort members from diverse backgrounds and disciplines, as this increases open-mindedness for collaboration. However, it may be important to avoid large cohort sizes, communication lags, and members that may lack accountability or motivation.

One aspect of this study that future researchers can seek to achieve is a focus on an environment that facilitates team building, especially early in the process. The relationship between the NGO partner and the University of Illinois Urbana-Champaign has been long-standing, such that mutual trust and respect were already established (Section 2.1). The 2020–2021 cohort benefited from that previously existing relationship and thus was able to facilitate a rapid integration. We recognize that not all collaborations benefit from this. All collaborations have an origin point. Therefore, deliberate cultivation of the relationship is necessary in all cases. This initial relationship-building is important in these types of collaborations, whether between the stakeholders and researchers or the researchers themselves. Transdisciplinary research brings together a diverse group of academics and stakeholders, which requires a high level of mutual trust, partnership, and collaboration to build a successful, high-performing team. We suggest that future efforts build these types of relationships deliberately within the team and with stakeholders from the outset. With increased effort in team building, communication, and participation can be easier among cohort members.

Future studies can also improve upon our project management style by increasing collaboration between cohort members and leveraging each other's expertise. In our study, we broke the larger team into smaller subgroups to work on our proposed tasks (Sections 2.1, 4.5). With this style of project management, it limited some ability to collaborate across teams or leverage each other's areas of expertise and knowledge. We believe that the small team structure for a research team as large as ours was the best structure to allow for participation and efficiency within the team; however, participants become divided, and this should be taken into consideration for future studies using this structure. Previous research suggests that individuals in smaller teams perform better than those in larger teams (Mueller, 2012). Kameda et al. (1992) note that subgroups of four individuals have the greatest individual performance, and our subgroups ranged from two to five team members. However, large cohorts broken into smaller teams need deliberate infrastructures to check in on one another and leverage their strengths.

Furthermore, studies can benefit from learning about the attrition that occurred during our transdisciplinary collaboration. As our team decreased in size over the course of the collaboration, we learned that it is important to allow for attrition to occur as some team members are not actually willing to invest the time necessary to participate in a transdisciplinary project. The INFEWS-ER experience is solely extracurricular and only available to graduate students who are willing to devote their free time to it, as no course credits or assistantships are awarded by default. An interview or application system to vet whether students had the time available and the requisite motivation would likely lessen the attrition that occurred. We also recommend more frequent cohort meetings and one-on-one meetings when potentially unmotivated team members are identified to avoid problems with accountability.

From this transdisciplinary academic-NGO collaboration, the graduate student team gained skills in stakeholder engagement, large-team project management, and communication across disciplines; these skills helped us develop our human capital. CCC gained resources to enhance its ability to secure grant

funding. From CCC's perspective, the virtual experience highlighted the potential of utilizing graduate students' abilities to tackle organizational and community issues from remote locations. This is especially useful in addressing specific and urgent needs identified by the organization that may not have enough resources to attend to them at the moment. Future projects that emulate our process diagram (Figure 2) can increase the efficiency of academic-NGO partnerships toward capacity building and self-reliance. In addition, CCC increased its capacity building. These efforts provide resources and tools for CCC to act independently (without the cohort), which is beneficial for the development of the local community as well as disaster relief and resiliency. For instance, the resources we created positioned CCC to better compete for larger grants with revised and cited literature which lends further credibility and weight to the projects they are implementing. With access to larger funds, CCC is able to plan for the long term, increasing its chances to make a difference, particularly in environmental and educational areas. Overall, this case study bridges a gap in academic-NGO collaborations at the intersection of the FEWS and disaster resilience, highlighting practices to both emphasize and avoid. These findings should be valuable for students, faculty, NGOs, and others interested in participating in such collaborations.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent from the participants was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

DM led the study and contributed to all sections, including conducting the document analysis with GO. DM, AB, PM, GO, SS, SR, JH, LR, MF, and MR wrote different sections of the

manuscript. DM and AB created the figures. MF, MR, LR, and JH contributed to the conception of the study. LR acquired the funding. DM completed the final edits and formatting. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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