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Pathways to engaging in community-centered earthquake science: Lessons learned and tangible tools

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Abstract Although the importance of building meaningful connections between earthquake science research and local communities is widely recognized, the pathways to achieving such collaboration are not always clear, actionable, or well-supported in current dominant scientific culture. We offer strategies and tools to help bridge this gap in earthquake science, drawing on the Collective Impact Model, defined by principles of developing a common agenda, mutually reinforcing activities, centralized support, shared measurement, and continuous communication. We identify lessons learned and offer tangible tools based on the coauthors' collective experience through the primarily U.S.-based Center for Collective Impact in Earthquake Science. We also discuss the unique role of Minority-Serving Institutions (MSIs) in bridging this gap. The five lessons learned include: 1) allocate time; 2) take stock and focus on small, tangible steps; 3) embrace an interdisciplinary and multidisciplinary team and approach; 4) invest in centralized support; 5) be flexible to ensure that community needs guide research directions. The three tangible tools and practices include: 1) an initial project evaluation tool to develop community-engaged earthquake science research projects, 2) a formative collective impact evaluation rubric tailored to natural hazards and earthquake science for evaluating in-progress projects, and 3) practical recommendations for communication practices. Through collective impact, the earthquake science research community can engage in more inclusive research inquiry that is centered on real-world impact for populations at risk from earthquake hazards.

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1 The need for community-centered earthquake science

Exploring the relationship between earthquake science research and local communities where the research is conducted offers an opportunity to innovate and reimagine how science is conducted. Contemporary scientific practices are still largely shaped by inquiry systems developed centuries ago: scientists formulate hypotheses, conduct experiments, and share findings within relatively small–often exclusive–networks of experts. This exclusivity, alongside prevailing values such as individualism, hyper-competition, and productivity-focused metrics, can contribute to a scientific culture that reproduces inequities and limits broader participation (Rayne et al., 2023). By measure of geoscience Ph.D. recipients earned by United States (U.S.) citizens and permanent residents, little progress has been made in terms of diversifying the racial and ethnic makeup in recent decades: from the 1970s to the 2010s, just 6% of geoscience doctorates were awarded to underrepresented minorities (Bernard and Cooperdock, 2018). Within the broader geoscience workforce in the U.S., in 2010, the percentage of non-white geoscientists was 8%, and in 2018, this number was reported at 10% (Velasco and De Velasco, 2010; Wilson, 2019). While there have been gains in the number of undergraduate geoscience degrees awarded to students from marginalized backgrounds—largely thanks to the efforts of Minority-Serving Institutions (MSIs) and demographically targeted programs (e.g., Beane et al., 2021; Carrick et al., 2016)—these advances have not yet been translated into structural change at the highest levels. Consequently, many scholars from underrepresented groups continue to encounter unwelcoming and inequitable academic

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environments across science (Berhe et al., 2022; Rucks-Ahidiana, 2019), including in the geosciences and, more specifically, seismology (Dutt, 2020; Núñez et al., 2020; Velasco et al., 2021).

Additionally, the conduct of scientific inquiry continues to be extractive and exclusive, reinforcing systemic biases and constraining diversity within the research process. For example, the practices of researchers entering a region, collecting and analyzing data, and publishing results with limited engagement from local scientific and practice communities have been rampant in science for generations (e.g., Minasny et al., 2020), including in geoscience (Liboiron, 2021; Núñez et al., 2020). In the United States and Canada, such "helicopter research" practices have frequently characterized work conducted in under-resourced and Native American communities (Adame, 2021; Cherokee Nation Institutional Review Board, 2019; Macaulay, 1994). These approaches not only risk eroding trust in science (Igwe et al., 2022), but they also overlook or dismiss existing place-based and Indigenous knowledge systems—such as the seismological traditions of Indigenous communities in the Cascadia region, which were long marginalized until their recognition in the 1990s (Thrush and Ludwin, 2007). In communities that are easily accessed and frequently studied, these practices can lead to narrowly informed or redundant science (Zill, 2022), underscoring the need to reimagine scientific approaches that account for and address these long-standing biases. Calls for ethical standards in disaster research have pointed to the need for local representation, collaborative and coordinated data methods, and a deeper commitment to beneficence within the research community (Gaillard and Peek, 2019). Embracing these principles offers a path toward more just and inclusive scientific inquiry.

The importance of building meaningful connections between earthquake science researchers and local communities where the research is conducted is clear. However, the pathways to achieving such collaboration are not always obvious or well-supported, especially in the context of the prevailing scientific inquiry system. In this paper, we offer concrete strategies to help bridge this gap towards more just and inclusive earthquake science. We draw on the Collective Impact Model (Kania and Kramer, 2011) as one approach to fostering sustained, community-engaged partnerships in earthquake science. We first describe our implementation of the Collective Impact Model through the Center for Collective Impact in Earthquake Science (Section 2), from which we draw the major findings of this paper. We then present five lessons learned (Section 3) from this center, and share three tangible tools (Section 4) that can be readily applied within an earthquake science context.

2 Implementation of the Collective Impact Model

Our contribution through this paper reflects the coauthors' direct experiences applying the collective impact approach within the earthquake science community and through our work with the Center for Collective Impact in Earthquake Science (C-CIES, NSF Award #2225395, 2022–2025). The Collective Impact Model (Kania and Kramer, 2011) specifically develops a network of community members, organizations, and institutions through the framework of a common agenda, centralized support, continuous communication, mutually reinforcing activities, and shared measurement. Figure 1 provides a non-exhaustive description of ways we designed activities in C-CIES around these five conditions of collective impact. Due to more recent trends, such as the application of the Collective Impact Model to large-scale alliances designed to broaden participation in science through the U.S. National Science Foundation's Inclusion across the Nation of Communities of Learners of Underrepresented Discoverers in Engineering and Science (NSF INCLUDES) program (Payton and Gates, 2023; Villa et al., 2020), there is a growing movement to adapt this as a framework for community science in the U.S. (e.g., Derrien et al., 2024). Collective impact's application in community-engaged geoscience education suggests promising potential through available conference abstracts (e.g., McGill et al., 2017; Tesser et al., 2021). However, to the authors' knowledge and at the time of writing, detailed accounts of collective impact within geoscience in peer-reviewed literature is not yet available, and the Collective Impact Model has not previously been formally implemented within an earthquake science context. We acknowledge that this is not the only framework available—important work on community-engaged natural hazards research, particularly within the social sciences, has laid valuable groundwork (Kelman et al., 2011; Mercer et al., 2008). With some exceptions, (e.g., McGill et al., 2017; Tesser et al., 2021; Villa et al., 2020), collective impact has seen limited application in the context of scientific research and practice.

C-CIES was established with a distinctive and ambitious approach in response to persistent challenges within the scientific community, such as hypercompetition, unwelcoming work environments for individuals from marginalized groups, and limited reciprocal engagement with communities. Our two-year catalyst center spanned 6 non-profit organizations, 6 governmental agencies, 1 industry partner, and over a dozen universities (see Table S1 for partner organizations and see author affiliations for university affiliations). The center's four core goals were to: 1) advance interdisciplinary and convergent research in earthquake science and engineering; 2) recruit, retain, and train a new generation of diverse, interdisciplinary Earth scientists and leaders; 3) build capacity and strengthen communication between geohazard scientists and partner communities to support value-driven research that responds to evolving community needs; and 4) develop a collective impact management structure with coordinated, reinforcing activities to help translate scientific discovery into actionable strategies that enhance resilience and reduce geohazard risks.

The National Academies of Sciences, Engineering, and Medicine identify Minority-Serving Institutions (MSIs) as an underutilized resource for strengthen-

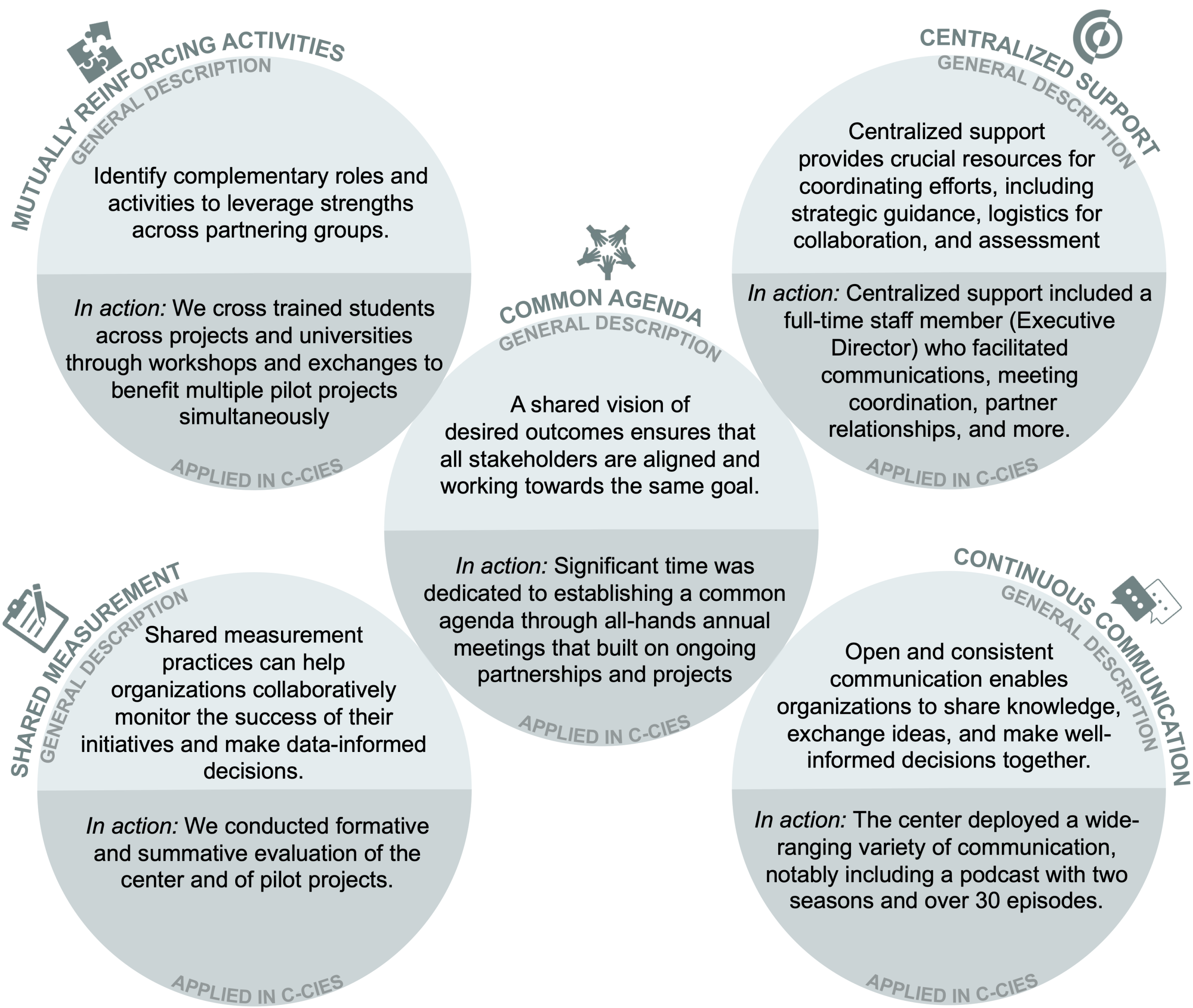

Figure 1 Description of necessary conditions and core principles of the Collective Impact Model (Kania and Kramer, 2011) and examples of how these conditions were implemented within the Center for Collective Impact in Earthquake Science (2023-2025).

ing the Science, Technology, Engineering, and Mathematics (STEM) workforce, and recommend stronger partnerships between MSIs and non-MSIs for stronger STEM attainment (National Academies of Sciences, Engineering, and Medicine, 2019). "MSI" is an umbrella term to describe institutions that serve specific groups of students, and have earned specific designations (including but not limited to "Hispanic-Serving Institution" and "Historically Black Colleges and Universities") through enrollment and/or expenditure thresholds (National Academies of Sciences, Engineering, and Medicine, 2019). Hispanic-Serving Institutions (HSI), which constitute the majority of Minority-Serving Institutions, can serve as a link between the "traditional" non-Minority-Serving Institution R1 schools and the engagement of both diverse scholars and communities, where R1 indicates the Carnegie Foundation-designated classification for the highest level of research spending and doctorate production for U.S. universities (Carnegie Foundation & American Council on Education., 2025; National Academies of Sciences, Engineering, and Medicine, 2019).

In the U.S., the HSIs have missions that focus on lifting up their local communities and serving their regions (Crisp et al., 2021), and are therefore well-positioned to lead community-engaged work. HSIs graduate disproportionately high numbers and shares of low-income and minoritized students in science fields, including specific science fields that see among the lowest representations of these students, like the geosciences (National Academies of Sciences, Engineering, and Medicine, 2019). MSIs and HSIs have led U.S. higher education institutions in developing and implementing innovative educational strategies to serve students from communities that have historically been underserved in higher education (National Academies of Sciences, Engineering, and Medicine, 2019; Núñez, 2022; Núñez et al., 2021). In addition, many MSIs have internal infrastructure that supports community engagement, since many support the local student population. UTEP (The University of Texas at El Paso), for example, has the Center for Community Engagement, and UNM has a similar center (Center of Community Engagement). Since these types of institutions serve local communities, it makes engagement with the community much easier and valued within the institution.

The centralized support of C-CIES included a full time staff member who served as the executive director of the center, and 5 lead faculty members across three broad-access HSI universities. Broad-access institutions are defined as those that have missions to provide a variety of communities, including those from low-income and minoritized backgrounds, with access to postsecondary education (Crisp et al., 2021). Within this core team, four researchers (coauthors Alvillar, Velasco, Karplus, Weidner) were based at the University of Texas at El Paso, one at the New Mexico Institute of Mining and Technology (coauthor Bilek), and one at the University of New Mexico (coauthor Lin). The fact that each leading institution is a broad-access Hispanic-Serving Institution was not an accident, but rather an embodiment of C-CIES's values. Additionally, the pilot project leads also represented a number of additional MSIs (e.g., University of Puerto Rico at Mayagüez) and Primarily Undergraduate Institutions, which focus on undergraduate education and have minimal or no graduate student enrollment (e.g., College of Charleston), adding to the diversity and richness of C-CIES' leadership.

To demonstrate collective impact's practical utility, C-CIES piloted examples of collective impact-driven projects in geographically diverse communities in the United States that may experience high consequence, low frequency of incidence (HiC-LoFI) earthquakes. These regions include Puerto Rico (a complex plate boundary), the Intermountain West (a transitional region between intraplate and plate boundary), and the Central and Eastern U.S. (an intraplate region) (see Supplemental Materials, Table S.1). Earthquake awareness tends to be low in places where HiC-LoFI earthquakes generally occur–for example, where infrastructure is not designed for earthquakes, away from plate boundaries and where spatiotemporal patterns of earthquake occurrence are not well understood (Liu and Stein, 2016). It is difficult to determine how communities with low earthquake awareness will respond to an earthquake and how increased awareness would change their response (Khajehei and Chandrasekhar, 2021). For example, the City of Montreal has been shown to have the highest seismic risk of all municipalities in Canada (Hobbs et al., 2023). Several studies have used earthquake scenarios to demonstrate the potential impacts on Montreal buildings, critical facilities and residents (e.g., Ghofrani et al., 2015; Goda et al., 2023; Lessault et al., 2025; Tamima and Chouinard, 2016), but without community engagement and increased awareness, the insurance penetration, preparedness, and perceptions of risk are far lower than in the more tectonically active western Canada (Goda et al., 2020). Furthermore, HiC-LoFI earthquakes can cause significant damage in local communities. The 2011 M_w 5.8 Mineral Wells, Virginia earthquake and the 2020 M_w 5.7 Magna, Utah earthquake, produced \$200 – \$300 million and over \$150 million in damage, respectively (Horton Jr. et al., 2015; Pankow et al., 2020). By studying HiC-LoFI earthquakes and conducting inclusive community-centered science through the Collective Impact Model, earthquake scientists and engineers can better develop strategies for identifying, quantifying, and communicating seismic hazards, while also engaging the public about other aspects of fundamental earthquake science.

The pilot projects ranged from exploring novel methods of earthquake scenario development to using citizen science, low-cost seismographs, and crowdsourcing techniques for earthquake risk and vulnerability assessment in under-resourced communities. The projects were designed around four elements: (1) a basic science question that aligns with the research themes discussed above; (2) use-inspired research which can be directly translated into practical solutions for the community; (3) significant social impact; and (4) robust community engagement. Pilot projects also aimed to include an element of workforce development, particularly among communities historically under-represented in geosciences. Projects were asked to articulate their contributions towards promoting interdisciplinary research or practice. One way that projects promoted interdisciplinary research was through funded students (graduate and undergraduate) who were cross-trained between projects, disciplines, and institutions.

We share our experiences through C-CIES below to provide an illustrative example for how the Collective Impact Model can be applied to real earthquake science projects. We believe this paper provides one of the first examples of applying the Collective Impact Model in the peer-reviewed geosciences literature. This paper also contributes to the limited but growing literature on implementations of mutually beneficial partnerships between MSIs and non-MSIs (National Academies of Sciences, Engineering, and Medicine, 2019).

3 Lessons Learned in Implementing Collective Impact for Earthquake Science

A primary challenge to implementing collective impact for community-centered earthquake science is the lack of capacity within the scientific community to actually conduct research in this community-engaged way. Knowing and reading about the five conditions for the Collective Impact Model is only the first step: implementing those five conditions is not trivial.

To address this challenge, we share five "lessons learned" that are based on our two-year catalyst center and other related experiences of the coauthors. These "lessons learned" are intended to support other earthquake scientists interested in engaging in community-centered research.

For this paper, we applied a self-reflexive method (e.g., Arnold et al., 2023) to identify the lessons learned. First, each center member and co-author was invited to identify their top three lessons learned and examples of each lesson in action through an online survey towards the end of the center's funded award period. The individually contributed lessons learned were then sorted and grouped into these resulting five overarching lessons learned by the lead author. We also drew from notes, presentations, and center resources to corroborate the identified lessons learned. Because of the structure of C-CIES described in Section 2, some examples focus on the ”pilot project” scale, whereas other examples below focus on the overall center.

3.1 Lesson 1: Collective impact needs time

Collective impact requires time: time to learn about collective impact in order to apply it; time to develop trust and a shared understanding of each other's interests, skills, and needs within the project; time to develop trust with community partners; and time to engage in additional collective impact activities, which by definition requires slower, more deliberate decision making for coordinated and collaborative actions compared to a traditional research model.

A potential collaborator is more likely to invest their limited time if the invitation to collaborate is built on a foundation of trust, which may come from previous partnerships based in years-long (or even decades-long) relationships between the participating individuals and/or organizations. This includes relationships between researchers, as well as relationships between researchers and community partners. Trust and familiarity may also be built through visibility of earthquake scientists as subject matter experts sharing earthquake-related information publicly through local news, social media, or community events (e.g., co-author Velasco quoted in O'Regan (2024); co-author Ebel quoted in O'Laughlin (2024)). Because the UTEP researchers had spent years building trust and familiarity in their community of El Paso, TX, the local office of emergency management and a local hospital reached out to the UTEP researchers after instances of felt earthquakes in the area. We built on this community-driven interest to develop strong partnerships where we shared information about earthquake hazards, and this planted the seed for Pilot Project C. As part of this partnership, we attended the local Office of Emergency Management meetings and facilitated meetings with local hospitals. We also worked with the Office of Emergency Management to develop tabletop exercises for a realistic earthquake scenario that the Office of Emergency Management has since secured funding from the U.S. Federal Emergency Management Agency (FEMA) to conduct.

A few actions early on can help. Scheduling time to ensure that everyone involved in the project has the information to understand what collective impact is and *how it works* is key. Time to align and articulate the values of the group is also critical as a guiding framework for decision making: setting the common agenda, allocating available funds and human-power, and prioritizing action items for moving forward. Budgeting time to meet as a group, in-person, as early and often as possible can help to build (or continue building) relationships and trust within the team. Additionally, individuals or organizations may require compensation for their time (e.g., through supplemental income or gift cards for relevant outlets) or may need time-bound outcomes that are a mandatory part of their career progression (e.g., publications for students and junior faculty, or professional conference presentations for partners). Taking the time to understand individual goals and contexts across diverse partners can help groups facilitate a sustainable path forward for mutually beneficial collaboration. Similarly, making time during meetings to articulate shared values across the group, respecting the knowledge that each stakeholder brings, creating space for all stakeholders to speak, and demonstrating reciprocity, in some cases showing that a partner will invest time to do something “without expecting anything in return” also enhances the collective impact of such an effort (Núñez et al., 2021).

This lesson is corroborated by other research on collective impact in computer science, which has identified *time invested in relationships* as essential to building trust, or *confianza*, in the case of the Hispanic community largely served by these HSIs (Núñez et al., 2021). This is particularly important when there are power differentials between partners, whether it be between community members and universities, or between more well-resourced and less well-resourced universities, such as HSIs and MSIs (National Academies of Sciences, Engineering, and Medicine, 2019).

Lesson 1 in action: One pilot project (Pilot Project D in Table S1) experienced challenges when their community partner (in this case, an elementary school) did not have the bandwidth to continue the collaboration, despite the partner wanting to do so. The project was initiated towards the end of the summer break. In retrospect, the pilot likely would have been successful if it had been in the academic-year planning pipeline, which typically starts towards the end of the prior year and continues in some form over the summer. This would have required more concentrated meetings and planning over the summer, and regularly scheduled meetings and activities in the school year (estimated 1-2 hours per week). This led to a more limited scope of the project, but ultimately planted a seed of collaboration between the researcher and community partner that has since grown to other long-term efforts that continue to build trust and shared understanding, such as serving on the community partner's board.

Lesson 1 takeaway: Do not expect to see immediate results (scientific, relationship-building, or otherwise) and do not rush this inherently time-consuming process. Collective impact may seem daunting, but it can lead to rewarding science, improved relationships with the community, long term partnerships, and friendships.

3.2 Lesson 2: Take stock and focus on small, tangible steps to initiate and sustain collective impact

Although enlisting individuals as part of the team with collective impact expertise and experience can be useful, as it was for us, each initiative that employs collective impact will also travel its own journey, advancing its own shared values and ways of enacting those values. For researchers and teams that are new to collective impact, we recommend starting with tangible, small actions to start, then building up the capacity of researchers and communities to engage with the framework more fully. In our case, the group had variable previous experience with collective impact, with some introduced to it through this catalyst center, and others who were already leading scholars in this space, but not necessarily in earthquake science.

To start, identify the scope of skills and activities in which you already take part. You are likely already engaging in parts of the Collective Impact Model without realizing it; take stock of your existing partners, communication practices, activities, and agenda-building practices. For example, in developing project goals and plans, are there opportunities for communities to provide formal or informal input? Or, is there a system for communication that everyone has agreed upon, including mode and frequency of communication, as well as the responsibility of managing communication? Tangible Tool 1 and Table 1 provide additional support for these initial conversations. Once a project is underway, an evaluation framework (Tangible Tool 2 and Table 2) can help the team take stock of ongoing activities aligned with collective impact, and identify small, concrete next steps.

Lesson 2 in action: In C-CIES, we applied an evaluation framework (see Table 2 and Tangible Tool 2 in Section 4) about six months into the pilot projects during an in-person, center-wide meeting. Following a clear framework to evaluate–step-by-step–how an earthquake science project was engaging in the elements of collective impact proved instrumental in (1) recognizing areas for growth and (2) filling gaps in project management and execution. For example, reflecting on the common agenda prompted project leadership to consider the connection between research questions and community needs, as well as community involvement and participation in the development of the research questions. In many cases, science proposals may be written without input and participation by the community (in large part, because they are not funded yet). The evaluation framework may assist project teams to recognize gaps in communication and engage the community in these processes at various stages of the project. For all of the elements of collective impact, researchers found it helpful to break down the terminology of the Collective Impact Model into tangible and specific questions about current practices and outcomes. Pilot Project C, for example, identified a tangible, small action as planning a meeting with community partners to revisit the project goals and listen to desired outcomes from a variety of voices. This improvement in communication and understanding between partners helped facilitate improvements in how the research addressed community needs.

Lesson 2 takeaway: The Collective Impact Model is not an all or nothing approach: partial success is still progress in the right direction. Taking stock of where you are starting and how you are progressing can help initiate and sustain effort towards more meaningful research through collective impact.

3.3 Lesson 3: Embrace an interdisciplinary and multidisciplinary team and approach

One of the strengths of the C-CIES research team was the breadth of disciplines that came together to investigate the challenges of HiC-LoFI earthquakes. Researchers in multiple subdisciplines of geoscience, social science, and engineering joined this effort. Collectively, we represent many disciplines: seismology, geology, structural engineering, geography, urban planning, history, public health, and education, with many individuals on the team identifying as interdisciplinary (or transdisciplinary, or convergent) scholars. A multi- and interdisciplinary approach enabled the center as a whole, and teams within each pilot project, to investigate a shared research topic and identify questions that are not obvious from a single disciplinary perspective. The group was also able to benefit from the multiple methods that are common in some disciplines, but not necessarily common in earthquake science. For example, we were also able to use a mix of qualitative and quantitative research methods to more holistically investigate earthquake science research questions (e.g., Pilot Project A in Table S.1).

Including social scientists who have expertise in organizations, education, and community-based approaches has been recognized as an effective strategy by the National Science Foundation to advance more community-engaged geoscience research, education, and practice (Posselt et al., 2019). Because C-CIES included several social scientists with extensive experience in collective impact work (e.g., Núñez et al., 2021; Villa et al., 2020) and in efforts to advance more inclusive geoscience (Núñez et al., 2020; Posselt et al., 2019), our group was able to consider how lessons from other disciplines could be adapted to research and community-engaged geoscience, and earthquake science in particular. Strengths from our social science researchers in evaluation and qualitative methods also enabled the development of a useful evaluation framework (Table 2) to assess the status of each pilot project. In addition, engaging social scientists with expertise and experience in collective impact helped sensitize our team to the habits of collaboration and reflection necessary for this effort.

Though support for research that expands beyond a traditional disciplinary boundary for early career faculty and for community-engaged scholarship is growing (e.g., Benson et al., 2016; Noone et al., 2022), junior faculty and others in a similar career stage must consider the realities of their institutional and departmental context and assess whether they will have the bandwidth, support, and incentive structure to support this kind of scholarship at this stage of their career. A collective impact focused team can support these scholars by helping them build a broader network while allowing them to focus on their area of expertise within the project. In addition, more senior and established faculty can advocate for institutions to value community-engaged research and the significant time commitment required for engaging in this type of work, especially in the faculty promotion process.

Lesson 3 in action: Pilot Project A (see Table S.1 in Supplemental Materials) was originally focused on measuring average shear velocity in the upper 30m (Vs30) across multiple sites to develop new earthquake scenarios. Bringing in an additional researcher to this team with a background in human-centered design shifted the focus of this pilot project to include an initial stage of interviews so that the data collection locations and eventual scenarios would align more directly with the concerns and values of local communities. We found that linking the impacts of a potential earthquake to buildings and community locations that support mental health, learning, and economic activity would be critical to developing future earthquake scenarios, and data collection should be focused on these locations (e.g., schools) (Álvarez-Gandía et al., 2026).

Lesson 3 takeaway: Including a wide range of disciplines relevant to earthquake science, especially ones that are not commonly represented in earthquake science (e.g., social scientists, historians), can lead to strengthened research projects, intentional center processes that support collective impact, and can help researchers transition into convergent research.

3.4 Lesson 4: Centralized support is critical

Centralized support is one of the five conditions for collective impact: the importance of this support cannot be emphasized enough. As we mentioned in Lesson 1, collective impact is time- (and by extension, energy-) consuming. Coordinating with many people, across many institutions, organizations, and time zones, is not trivial. By identifying a dedicated person (or team of people) to facilitate the time-consuming elements of coordinating and communicating between group members, the individual researchers and community partners can focus on the needs of the project instead. Dedicated, full time personnel (e.g., a project manager, executive director, communications specialist, etc.) require dedicated budget within the project, but in our experience, this is funding well spent. To best support the key principles of the Collective Impact Model, the person in the centralized support role needs to be an outstanding communicator to facilitate meetings that develop a common agenda and shared measures, keep track of activities, and communicate to all stakeholders in multiple forms. In our case, the Director organized and planned with the PIs all meetings, arranged travel, and communicated with all stakeholders. As an example of her outstanding communication skills, the director also led the creation of a C-CIES podcast to reach non-traditional audiences as a creative form for continuous communication. Identifying clear point-persons for key spheres of decision within the center allowed individuals to act with agency and have ownership over their work, rather than have all of the decision-making power sit with the typical "Principal Investigator." In our case, this approach distributed power and agency across different stakeholders, augmenting the likelihood of authentic reciprocity in community-engaged earthquake science efforts. This arrangement also allowed point-people to handle responsibilities and keep the work going. This included not only the staff personnel, but also faculty who played additional supportive or leadership roles related to research, outreach, education, and specific pilot projects.

Lesson 4 in action: In addition to the logistical challenges of arranging a meeting, especially an in-person meeting with 30-50 attendees, we found that centralized support in the form of a specified meeting facilitator can increase the likelihood of having productive conversations by clearly identifying the purpose and boundaries of conversations. For our last all-hands meeting as a center, we hired a trained facilitator to help keep our meeting from spiraling off-topic. We made this decision after recognizing that this type of intentional meeting planning takes time to think through well before the meeting, and this planning was beyond the bandwidth of the existing centralized support team who were focused on the logistics and content of the meeting. Having a trained facilitator also helped us provide an opportunity for all involved to provide input and support each participant (stakeholder, researcher, or otherwise) in feeling heard. Without dedicated support for facilitation (either internally designated or an external facilitator brought in for this purpose), it is all too easy for someone to dominate the conversation and cause other people to disengage once that happens.

Lesson 4 takeaway: Without dedicated support for the heightened effort needed to keep moving forward, the collective effort and vision required for community-engaged work can easily fall by the wayside. Investing in staff and developing structures for distributed but defined leadership can ensure that efforts are more sustainable for the team.

3.5 Lesson 5: Be flexible to ensure that community needs guide research directions

Collective impact will require flexibility, responsiveness to local conditions, and the engagement of those with diverse roles and backgrounds to ensure that community needs guide research directions. First, it is important to recognize that earthquake events impact different communities in different ways, and it is critical to understand these impacts from the community point of view to develop effective solutions to mitigate risk and increase resilience. The impacts that a researcher identifies may be different from the lived experience of the community members, so it is important to understand what those lived and experienced impacts are to be able to assess and mitigate community risk. Similarly, scientists must recognize that community needs may differ from their own research priorities, and adjust their expectations accordingly. Careful planning and a willingness to adapt one's scientific approach to the specific regional context is essential, and potentially more beneficial, to the scientific outcome.

Lesson 5 in action: Excessive focus on achieving the "perfect" community science seismograph (i.e., Raspberry Shake instrument) site conditions as part of Pilot Project B (see Table S.1 in Supplemental Materials) could have hindered the desired outcome for this pilot project of supporting more scientifically engaged com-

Basic Science Question			
Addresses a fundamental earthquake science issue	Yes	No	
Urgency	High	Moderate	Minimal
Timeliness	High	Moderate	Minimal
Research Plan			
Potential for new insights on earthquake processes or on the built environment exposed to earthquake hazards	High	Moderate	Minimal
Potential to lead to **practical solutions** for the community	High	Moderate	Minimal
Includes activities that **empower community input** on research progress	High	Moderate	Minimal
Outcomes of the Research			
Relevance of scientific impact	High	Moderate	Minimal
Social relevance	High	Moderate	Minimal
Potential to **catalyze substantial changes** of awareness of the importance of earthquake science	High	Moderate	Minimal
Tailored to the community where it is implemented	High	Moderate	Minimal
Portability to other research or communities	High	Moderate	Minimal
Community Engagement			
Potential to lead to a long-lasting, sustainable geoscience learning ecosystem	High	Moderate	Minimal
Potential to motivate long-lasting partnerships between scientific institutions (such as universities) and communities	High	Moderate	Minimal
Potential to transform project team members' communities	High	Moderate	Minimal

Table 1 Project selection for community-engaged earthquake science research: example rubric. Before use of the rubric, we recommend that the team discuss what "minimal," "moderate," and "high" means in the context of their project(s), as this may be different from one group to another.

munities. In addition to seeking Raspberry Shake sites with ideal geophysical characteristics, it was also important to consider how the site location could enhance community engagement and foster local participation. Particularly in intraplate regions, community science instruments can record earthquakes in places where earthquakes are not typically expected to occur, so community seismographs in "imperfect" site conditions can actually lead to the collection of new data from earthquakes in surprising locations that would not otherwise have been recorded. In this case, our installation of a Raspberry Shake seismograph at the home of an interested and invested community scientist was very near a noisy interstate highway, but that "imperfect" site led to a collaborative effort to create a better and denser network in the area because that homeowner became a great colleague in helping us find additional local sites, including a site at a local library. Even in the absence of recording an earthquake at "imperfect" sites, these flexibly deployed instruments can still contribute valuable seismic data such as ambient-noise measurements, tracking movements of people, vehicles and drones, explosions, and other non-earthquake activity.

Lesson 5 takeaway: Organizational and research flexibility enabled us to take advantage of interest as well as expertise. Rather than framing community needs and scientific discovery as orthogonal, we saw examples where we were ultimately better at supporting our communities while simultaneously supporting research aims.

4 Tangible tools and practices

In this section, we share three examples of tangible tools and practices from C-CIES that can be adopted or adapted by others in earthquake science.

4.1 Tangible tool 1: Project development and selection rubric

Shaping a research project embedded with community engagement and collective impact might be new for many earthquake scientists. This project rubric (see Table 1) was developed to help teams assess their own ideas as ideas are being developed, as well as to assess which projects might be most ready for implementation in the context of a funded center that would select a subset of projects for seed support. The project rubric is split into four sections: assessment of (1) basic science question, (2) the research plan, (3) outcomes of the research for both scientific and social types of outcomes, and (4) potential for quality community engagement. Regularly referring to this project rubric may help facilitate shaping the research project in development.

4.2 Tangible tool 2: Formative evaluation rubric while projects are ongoing

The evaluation questions in Table 2 were developed as a tangible tool to initiate and guide the implementation of collective impact within a research project or collaborative team interested in community-centered earthquake science. The evaluation tool was developed internally based on the Collective Impact Model as described in Kania and Kramer (2011), and from previous experience

I. Instructions

This Collective Impact Evaluation Exercise is intended to be used in-person in a group setting, but can be used online and/or alone if necessary.

1. Ensure that all participants understand the goal of the exercise either through a brief presentation, a discussion, or a careful individual reading of the tool.
2. Identify small groups of relevant participants (if a group exercise) and thoughtfully discuss each CI question (II. Evaluation Rubric in this table).
3. For each question, provide answers, action items, and needs, grouped by CI condition. We suggest recording these answers on large format sticky pads, with one large sheet per CI condition.
4. Reflect on the evaluation through four additional questions on the feasibility, progress, gaps in resources, and concrete next steps that can advance each CI condition (III. Reflection questions of this table).

II. Evaluation Rubric

Develop a common agenda

1. **Use-inspired research:** Is the research addressing a key community need? How?
2. **Community partnerships:** Does the project have community partners? What types? More diversity of background, function, etc. requires more effort at creating a common agenda. What actions were taken to confirm/validate the research questions with the community partners? Were the research questions modified/refined after consultation?
3. **Action plan:** What were activities that contributed to development of commonalities and common agenda?

Establish shared measurement

1. **Measurable progress indicators:** What are the discrete indicators that track its progress over time? What indicators measure scientific progress from a multidisciplinary lens? What indicators measure broader impact on the community over time?
2. **Co-creation of indicators:** What has been the process for developing measures, particularly seeking broad participation? What actions were taken to involve the community partner in developing the indicators? How often are indicators reviewed internally and externally with community partners?
3. **Measures:** Who manages and conducts progress tracking of implementation of projects? What does it look like?
4. **Feedback into research:** Is progress tracking conducted at specific intervals? What is the mechanism to feed results of progress tracking back into project planning?

Foster mutually reinforcing activities

1. **Partner engagement in project activities:** How are community partners involved in data collection, analysis and communication of results–or other project activities?
2. **Project engagement in partner activities:** To what extent are project staff invited to engage with partner's own activities, whether related to the project or otherwise? (Indicative of growing trust relations and relevance of Center expertise)
3. **Cross-use of research products:** To what extent are research findings/outputs being used by community partners in their own disaster-related activities? (Indicates broad impact)
4. **Research collaboration:** How are related research interests and activities being integrated with one another, including across disciplines? What new relationships have been developed?

Encourage continuous communications

1. **Purpose of communication:** What are the main purposes of communication? For communication of results, are appropriate modes being used? For communications for ground-truthing/results validation activities, how are communication outcomes reintegrated into the research?
2. **Frequency and modes of communication:** how often and through what modes are community partners communicated with? Is communication offered in appropriate languages, modes (in person vs phone, group vs home-level), and hours (weekends vs weekdays) to suit the community?
3. **Directionality:** Is communication bi-directional? What is the mechanism for partners to communicate with the project team? Is there a clear point(s) of contact?
4. **Infrastructure:** where needed, is there enough infrastructure provided to meet communication needs of partners? (e.g., Zoom access, computers, etc., but also the effort required to organize communication)

Create strong centralized support

1. **Clear organizational structure:** Is there a clear understanding of roles and responsibilities, points of contact, and relationship between different elements of the organization? Is there appropriate staffing and budget for various activities? Is the organizational structure clear to partners as well as affiliates?
2. **Community involvement in organizational design:** What is the direct involvement of community partners in leadership roles and activities? To what extent are partners consulted during the design of project management activities/budgeting?
3. **Point-persons:** Is there a clear point of contact for community liaisoning?
4. **Organizational evolution:** What is the mechanism to refine/modify/expand/shrink organizational structure? Who can initiate this conversation and how?

III. Reflection questions

1. Can this be done for our project?
2. Are we doing this? What are we missing?
3. What are some concrete actions we can take for each domain in the next few days/weeks/months to fill gaps? When?
4. What resources/help do we need to accomplish this? Where can we obtain those resources, expertise, or assistance?

Table 2 An evaluation rubric and associated reflection questions to make tangible steps towards community-engaged research through collective impact. We developed and applied this collective impact evaluation exercise for an in-person meeting after the four pilot projects had been underway for about six months. We note that this is just one example of how collective impact (CI) evaluation can be implemented, and different teams and different projects may find that this is best implemented for their team in a variety of ways.

in participatory and community-engaged research. After completing the self-evaluation rubric and reflection questions (see Table 2), the intention of this tool is to be able to identify concrete and tangible steps for each collective impact condition, no matter how small. The rubric and self-evaluation process is adaptable to both in-person or online contexts, but due to the nature of the conversations, which can be difficult, open-ended, and complex, we advise taking advantage of in-person opportunities to implement this rubric as a team if engaging in this for the first time. Our group found value in using this evaluation tool once the projects were underway (three to six months since starting), and while there was still plenty of time for feedback and modification (more than a year from the end of the planned project timeline). This evaluation framework can directly support Lesson 2 in creating a step-by-step process to evaluate how an earthquake science project is engaging in each element of collective impact.

4.3 Tangible tool 3: Adaptable communication practices for sustaining collaboration at multiple levels

Identifying clear communication practices for specific contexts and staying agile for communication needs can help sustain collaboration and community over time. Groups (and subgroups) of different sizes and styles may require different platforms, even within the same overarching effort. For example, in C-CIES, the core leadership team relied on quick messages through a dedicated messaging application (e.g., Slack), while center-wide communication was conducted through email. Communication beyond the center was maintained through a website, newsletter, and podcast (Alvillar, 2023). Interestingly, we also saw that the "outward" communication, in particular the podcast, acted as a mutually reinforcing activity for center-internal conversation and connection. A successful communication strategy requires empowering someone to lead, model, and train others in these communication norms. A successful strategy also requires buy-in from the group to then accept, learn, and use these norms.

5 Conclusion

Adopting the Collective Impact Model and its five guiding principles and conditions provides a tangible framework for linking communities and earthquake science. Work on community-engaged science has historically emphasized the social sciences and health fields (Moore, 2014), rather than geosciences or hazards. Our work applies collective impact to broadening the contexts in which earthquake science is examined and in drawing implications and support for communities to prepare for earthquakes, and this paper contributes a detailed account of a Collective Impact Model implementation that has not previously existed in the geosciences or earthquake science literature.

Doing so directly affects our ability to address critical science questions and requires transforming traditional scientific helicopter approaches to become more inclusive of the perspectives of multiple stakeholders, including scientists and the communities they serve. We hope to learn alongside local communities that have been historically marginalized to simultaneously achieve better scientific outcomes, such as in the example of "imperfect sites" of community science seismographs in Lesson 5, and to have a positive impact on communities.

Broadening community engagement and creating shared community resources will greatly improve the potential to respond to the needs of vulnerable populations that have been historically underserved by current science, engineering, and policies, while tackling the fundamental science-policy question of how to characterize and prepare for high impact under-studied events in a world with many competing demands for resources.

We also emphasize the role that MSIs–particularly HSIs, as the largest group of MSIs–can play in supporting both broader community engagement and a more diverse earthquake science research community.

Through the Collective Impact Model, the earthquake science community can help ensure that resources are dedicated to a more complete range of seismic hazards to solve real-world problems that require a coordinated effort beyond our academic silos. One example of this success can be seen in El Paso, TX, where in the last three years, C-CIES was actively working with local El Paso partners, the Office of Emergency Management, and local school districts to support the Great ShakeOut exercise. In 2025, El Paso County had over 83,000 participants–mostly schoolchildren–compared to a total of 89,555 participants from Texas in the Great ShakeOut. The impact of C-CIES on El Paso's participation is evident: In 2024, participation was registered at 14,080; in 2023, it was 3,608; in 2022, it was just 125.

We urge other earthquake science researchers to explore and share both their successes and challenges in engaging in community-engaged earthquake science, whether through the Collective Impact Model or other approaches. There is still a long road ahead towards more equitable and community-engaged earthquake science, and we hope to learn together alongside our community of earthquake hazard researchers–broadly defined–moving forward.

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Data availability

All relevant data are available within the manuscript.

Competing interests

The authors have no known competing interests.

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