BUILDING EQUITY AND CAPACITY WITH GEOSCIENCE

For a more inclusive science community and a broader understanding of geohazards to address social justice and equity issues in hazard mitigation

SUMMARY

Early in SZ4D discussions, the community recognized that an initiative of this scale and scope afforded the opportunity to implement a carefully considered slate of activities to ensure the program's long-term "broader impact." Concepts discussed coalesced into two parallel and complementary themes:

1. To better communicate scientific understanding of subduction zones and associated hazards to the public, and
2. To train a new generation of researchers to answer key science questions about subduction processes using interdisciplinary approaches (McGuire et al., 2017).

To develop these themes, in early 2021, SZ4D scientists and specialists in geoscience education, public outreach, diversity, and organizational structures joined to form the Building Equity and Capacity with Geoscience (BECG) integrative group. Since then, BECG has researched a range of programs and activities to consider how SZ4D could be transformative for US students and faculty, international participants, and communities directly affected by subduction hazards. BECG explored topics beyond traditional broader impacts education and outreach efforts, including international capacity building, best practices for conducting interdisciplinary research (Till et al., 2017), and factors that have long undermined belonging, access, justice, equity, diversity, and inclusion

(BAJEDI) in the geosciences (e.g., Bernard and Cooperdock, 2018; Williams-Stroud, 2021; Beane et al., 2021). Additionally, BECG consulted the social science literature and compiled the learned best practices from our community to aid in the development of a list of broader impact activities that support the science goals identified by the other SZ4D working groups and integrative groups. BECG formulated the following six primary areas where SZ4D should concentrate their broader impacts efforts:

1. Building capacity for international collaborative research, training, and data sharing;
2. Promoting hazard equity and social justice;
3. Supporting evidence-based education and training;
4. Increasing effectiveness of public outreach;
5. Strengthening interdisciplinary collaboration; and
6. Improving BAJEDI.

From these six areas (**Figure BECG-1**), BECG developed six research questions to frame its discussions concerning how SZ4D could motivate changes within communities located in subduction zones settings and within the geosciences community, both in the United States and internationally.

In the next sections, we delve into the components of these six research questions, including suggested objectives, primary needs, and potential activities. This text follows our *Traceability Matrices for each of the research questions*. The remaining sections of this chapter propose a framework and an implementation plan for meeting these objectives and needs.

RESEARCH QUESTIONS

International Capacity Building

RESEARCH QUESTION 1: How can we leverage efforts into equitable international capacity-building partnerships that improve capabilities (e.g., skills, data, software, technology, understanding) for all scientists and stakeholders involved? What do we need to build into our programs to make these improvements sustainable?

To address questions associated with international capacity building, a primary objective is to **establish and promote best practices for cooperative international field research**, particularly in the context of SZ4D science. This will entail extensive information gathering and a literature review of sustainable human capacity building and technical infrastructure development in the geosciences. A key principle for effective partnering with scientists, agencies, and universities responsible for subduction zone science and hazard management is establishing the elements of equitable cooperation, such as intellectual property guidelines, cost sharing, field activity plans, and agreement on scientific expectations before work starts. Training of US-based SZ4D participants and close engagement with all international stakeholders (policymakers, scientists, and educators) from the start of the planning process can ensure that we have shared goals and clear plans that will benefit the local communities.

The second objective is to **establish and promote best practices for FAIR (findable, accessible, interoperable, and reusable) data among international researchers** (Wilkinson et al., 2016). SZ4D must ensure its data and data products are openly accessible, but it can also put in place policies that better incentivize data

sharing from other entities to improve the quality of research results and minimize the limitations for access and interpretation (Fecher et al., 2015). This will entail active, organized dialog early on to understand needs and to convey FAIR data practices that have been collectively developed over the last several decades within US and international research communities. The SZ4D Center will be positioned to leverage the experience of its constituent groups to help new partners overcome potential limitations (e.g., infrastructure, human capital) and other challenges (e.g., Boeckhout et al., 2018; Tenopir et al., 2011). Having a clear and sustainable plan for open science is essential for interagency cooperation. It can both impact hazard science and present a unified view to those outside science.

The third objective is to **promote open, effective, bilateral communication and scientific training**. The development of effective multi-language communication and training opportunities is critical for developing and maintaining international partnerships. SZ4D should work with in-country collaborators, existing educational offices, and social scientists to develop appropriate content in effective formats and with careful cultural considerations. This can be accomplished by facilitating collaboration between physical and social scientists to learn about educational interests and context that would enhance the effectiveness of scientific communication.

The fourth objective is to **develop sustainable funding pathways for bilateral, multinational training and exchange programs**. Achieving this objective requires seeking appropriate funding across the SZ4D organization with the goal of perpetuating the training program and expanding it to other communities and countries after SZ4D. One approach could be to identify partnerships that can fund foreign

Figure BECG-1. *Research goals of the Building Equity and Capacity with Geosciences (BECG) group.*

exchange of students to assist with data collection, with an emphasis on supporting students from communities that are directly affected by subduction zone hazards. A potential SZ4D goal is to provide equal funding to US and international students.

Finally, we recognize an important objective is to **minimize imperialistic or colonial methods of interaction**. Such interactions can take the form of PIs "bestowing knowledge" upon international collaborators, in that the PIs simply need field support to accomplish the research while resisting any intellectual contribution or PIs "extracting knowledge" from their Indigenous populations and giving no credit to their contributions or any prior research done in-country (e.g., Cartier, 2019; Wight, 2021). Our community must work with international partners, host countries, and social scientists (Nordling, 2017) to implement cross-cultural and implicit bias training for international collaborations, including general core training and location-specific considerations that grow awareness toward underlying colonial attitudes embedded in traditional interactions (Stefanoudis et al., 2021).

Equity in Hazard Mitigation

RESEARCH QUESTION 2: Geohazards disproportionately affect specific communities. How do we translate improved understanding of subduction zone geohazards into products that can be used to inform and address social justice and equity issues in hazard mitigation? What considerations must be made to ensure equitable engagement of and outcomes for those communities?

The first objective seeking to address equity in hazard mitigation is to **strengthen ties with local hazard monitoring and emergency management agencies to maximize the local impact of subduction zone science**. The SZ4D community could significantly benefit from being better informed about the local agencies, resources, and hazard information available for specific regions of interest. To facilitate communication and strengthen relationships, we envision workshops and webinars conducted collaboratively with local experts that discuss the region's hazards, provide accounts of previous noteworthy hazard events, discuss geographic variations in exposure, and review what data are available. Specifically, we recommend inviting local agencies and government officials as well as nonprofit organizations working in these areas to discuss community vulnerabilities to hazards and which new hazard information would have the greatest impact on mitigating future risks. As the SZ4D community becomes more informed about locale, we envision SZ4D science will evolve to prioritize targets that address local needs in conjunction with intellectual merits.

The second objective is to **establish best practices in hazard communication within diverse communities**. This goal goes well beyond improving public outreach and requires establishing partnerships between physical and social scientists, science communicators, practitioners from nonprofits working on the ground, and educators to develop and implement techniques to communicate with diverse communities about the research plans and results. Activities to meet this need could include science communication training workshops with topics such as "how to talk to the public about your science" and "considerations for communicating with diverse communities." Recent research on communicating earthquake early warning to the general public has highlighted the importance of these efforts (Kamigaichi et al., 2009; Wein et al., 2016; Becker et al., 2020),

and indicates a need to invite social scientists and communication experts to present their findings at SZ4D meetings and conferences. Similar to the previous objective, we encourage cultivating internship opportunities for faculty, postdocs, and graduate students to work with specialists on hazard communication within diverse communities, including science communicators, education researchers, and social scientists. The ability to communicate our science effectively to local communities for each project will facilitate bringing researchers and instruments to field settings.

The third objective is to **support the creation of an open-access risk data repository** that includes physical data, hazard inventories, and vulnerability assessments. A portal for visualizing the integrated information would improve the ability for SZ4D researchers to recognize high vulnerability areas and critical gaps in hazard information. While the development of this repository is likely beyond the current capabilities of the SZ4D community, SZ4D should aspire to initiate its development through collaboration and advocacy. We recommend engaging with spatial scientists to learn more about the efficacy of risk data formats, software, and processing needs. Ultimately, the SZ4D community should consider ways to contribute to a comprehensive hazard inventory, which would rely on communication and collaboration with local agencies.

Educational and Training Strategies

RESEARCH QUESTION 3: Educational efforts that are more inclusive and have measurable learning outcomes are needed to equip and diversify our scientific community. How do we identify, develop, and implement these strategies?

A first objective in the SZ4D educational effort is to **ensure trainees are properly equipped with SZ4D-specific research skills**. There is consensus that trainees need to improve their:

1. Spatial and temporal reasoning skills to handle increasingly large and detailed 4D datasets,
2. Ability to work in large-scale fieldwork settings such as the human deployments proposed to collect critical SZ4D data, and
3. Capability to create and validate models (conceptual to computational) to generate new knowledge.

SZ4D is poised to be a catalyst for promoting the science of learning, which can be enhanced by sustained support of collaborations between physical scientists and education researchers. In addition, we recognize the need to embed more technical training (e.g., coding or machine learning) into existing curricula (NASEM, 2021) and encourage integration of datasets and models in order to build skills critical in undergraduate education (Mosher & Keane, 2021; Nyarko & Petcovic, 2022). SZ4D could energize this by motivating and facilitating reevaluation and revision of existing curriculum to meet these needs.

A second objective seeks to **increase the integration of societal relevance of geohazards into training**. This is inspired by the large-scale effort to incorporate societal relevance into educational materials and approaches via the *InTeGrate project* (Gosselin et al., 2019). InTeGrate created classroom-ready, peer-reviewed activities where students work hands-on with the complex, interdisciplinary challenges at the intersection of the Earth system and society. SZ4D is well positioned to create materials that can be used to teach about the risks of geohazards, with potentially large positive effects,

especially on communities within subduction zone regions. Exposing students to how SZ4D seeks to address geohazards also has the potential to inspire students to pursue SZ4D science as part of their career development. SZ4D should follow the collection, development, testing, and dissemination strategy demonstrated by the InTeGrate project to share its scientific findings through new educational resources.

A final key objective is to **implement effective educational strategies more broadly**. Although there has been considerable growth of peer-reviewed educational materials over the past two decades, faculty instructors still need to overcome obstacles to incorporating vetted educational materials into their teaching (McMartin et al., 2008; McDaris et al., 2019; SERC, 2012). A key pathway forward involves learning from research conducted on the professional development of geoscience instructors (e.g., Manduca, 2017), which indicates we should seek methods to help faculty instructors to incorporate evidence-based best practices. This can be achieved by developing or fostering professional development training for instructors that would include a focus on pedagogical skills and the scholarship of teaching and learning in addition to the training on educational materials developed with associated with SZ4D science. SZ4D should embrace professional development workshops as a means to disseminate new teaching materials and contribute to a cohort of knowledgeable and connected individuals who can advocate for best practices and the scholarship of teaching and learning.

Improving Outreach Effectiveness

RESEARCH QUESTION 4: Hazard monitoring and rapid response efforts inform decision-makers globally, requiring preparation and clear communication channels. What strategies for science communication would enable people to better understand geohazards and risks associated with them?

To address research questions associated with outreach, the first objective is to **connect SZ4D scientists to key non-scientist stakeholders** using evidence-based approaches to successful science communication. A step toward achieving this would be to support a series of workshops or a community of practice, attended by members of the SZ4D community, that focuses on the development of effective communication strategies. Materials for these trainings would be formulated in cooperation with international collaborators, nonprofit groups, and scientists working in hazard mitigation and rapid response efforts. Once the communication plan is finalized, it would be distributed to the broad, multi-institutional SZ4D community for implementation. An overarching principle is to support outreach efforts in ways that are scalable to large populations, are sustainable beyond the scope of an individual project, and can be integrated with ongoing activities.

The second objective is to **evaluate the impacts of outreach efforts**, with a particular focus on communities most affected by subduction zone hazards. PIs must commit the time and effort to evaluate an outreach project from its very beginning through to its completion. The evaluation of outreach projects could be facilitated using in-place nonprofit, nongovernmental groups that have experience with the particular issues concerning development and deployment of outreach campaigns. Initial evaluations should focus on understanding the strengths and weaknesses of past efforts such as EarthScope and GeoPRISMS, including both those led by PIs and those initiated by SZ4D Center staff. Information collection followed

by critical review could enable SZ4D to identify and apply best practices from these previous approaches and avoid some of the pitfalls. Another key need is to assess and evaluate outreach strategies aimed at increasing diversity. To address this need, BAJEDI should invite experts to share strategies that could then be implemented by SZ4D efforts.

The third objective is to **build a single portal that provides open access to collective outreach resources** that leverages existing, widely used platforms without duplicating them. A first step toward reaching this goal is to define the resource needs by the various audiences (e.g., K–12, general adults, stakeholders, residents in hazardous areas). Then, we will survey existing resources and organize them according to need. To increase the likelihood the resources would be used, we will provide clear descriptions of each resource and embed essential implementation support (e.g., video clips demonstrating use). Evaluation of the portal experience through user surveys will allow us to make improvements. Moreover, we will incentivize a portal model where the resources can be rapidly updated as new events occur.

Interdisciplinary Collaboration

RESEARCH QUESTION 5: What are evidence-based practices for interdisciplinary collaboration that break down silos and improve understanding across disciplines? How can SZ4D become an exemplar for interdisciplinary efforts to enact equity-oriented relationships and outcomes in community science?

The first objective for this set of research questions is to **collectively decide on SZ4D goals for successful interdisciplinary collaboration**. BECG identified a set of goals for consideration:

1. Develop innovative new ideas and construction of new knowledge,
2. Increase publications with authors from different disciplines,
3. Increase numbers of grant proposals and funded projects with PIs/co-PIs from different disciplines,
4. Involve disciplines less common in subduction zone research,
5. Train early career researchers with multidisciplinary understanding and more transferable skill sets, and
6. Share methodologies and data between different disciplines.

After collective goals are established through broad community input, the second objective is to **incentivize the tracking of information related to the interdisciplinary collaboration goals**. The data collection process will be important for investigating whether progress is being made. Identifying the specific data collection process will be clearer once the goals have been decided. Nevertheless, it appears reasonable to consider short surveys of the SZ4D community at regular intervals, possibly during SZ4D-sponsored research conferences or workshops. A fully online survey sent to the whole community could potentially collect information from a broader swath of participants. This is an example of a BECG data collection strategy that should be done in an scientifically ethical and accountable way. It should go through an Institutional Review Board (IRB) approval process to help ensure the results are presentable and publishable.

A third objective is to **follow strategies from prior work for facilitating successful interdisciplinary collaboration**. NASEM (2005) offered

recommendations for stakeholder categories (e.g., researchers, posdocs, graduate students, undergraduates) that provide guidance to SZ4D. Of note is that research team leaders should bring together collaborators early in the process to work toward agreement on key issues and ensure that participants strike a balance between contributing to and benefiting from the team. In addition to the categorical recommendations, SZ4D governance structures should include diverse representation and scientists from different disciplines. The working group structure has embraced this approach as they are focused on research questions as opposed to specific disciplines.

A final objective is for SZ4D to **acknowledge the potential disadvantages of interdisciplinary collaboration and decide how to address these issues**. Some of the potential disadvantages (e.g., Goring et al., 2014) for SZ4D to address are:

1. A decline in first-authored publications in the short term that can be significantly damaging to early career researchers,
2. Lower perceived "credit" for publications that have longer author lists,
3. Higher risk of innovative projects inspired by cross-fertilization,
4. The increased time it takes to learn other disciplines to have meaningful knowledge transfer, and
5. The power dynamics that can occur with researchers at different career levels.

While it would be difficult for SZ4D to influence current reward structures in academia that focus on first-authored publications, SZ4D can provide guidance to help early career researchers make decisions about interdisciplinary collaborations and how to showcase their positive outcomes if they decide to pursue them (e.g., Gewin, 2014). Overall, SZ4D will need to identify and implement strategies to address issues of interdisciplinary collaborations to be more equitable.

Belonging, Access, Justice, Equity, Diversity, and Inclusion (BAJEDI)

RESEARCH QUESTION 6: The diversity of the geoscience community has lagged behind other disciplines. What can SZ4D do in terms of BAJEDI to enact transformative change in the geoscience community? How do we design SZ4D to increase inclusivity and equity in our science endeavors? How can such a broad community science project be funded equitably and enact partnerships that are mutually beneficial for all stakeholders?

The first BAJEDI objective is to **capitalize on changing demographics to increase the pool of diverse students, faculty, and professionals in geoscience**. Census data clearly indicate the rising diversity of the US population, but NSF has recognized the "Missing Millions" of women and minorities from the science and engineering workforce (NSB, 2020). Likewise, recent research identified that racial diversity in geoscience doctoral degrees have not increased over several decades (Bernard and Cooperdock, 2018). Racial diversity has increased for geoscience undergraduate degrees but has occurred at a very limited number of institutions (Beane et al., 2021). An obstacle to broadening diversity is lack of wide access to geoscience programs for minority populations. One way SZ4D can help address this deficiency is to provide opportunities for minority-serving institution (MSI) students to participate in SZ4D activities. Another option would be for MSI faculty to become involved in SZ4D activities

that they could then share with their students. It will be important to learn about BAJEDI strategies that have been successful at MSIs.

Considering the options MSIs present for engaging a more diverse community in SZ4D, a second objective is to **encourage the building of mutually beneficial networks/partnerships between MSIs and research institutions involved in SZ4D** (NASEM, 2019; NCSES, 2019). While some of the research institutions involved in SZ4D are MSIs themselves (e.g., Arizona State University, University of California Santa Cruz, University of California Davis, University of Houston, University of New Mexico, University of Texas El Paso, University of Washington), most are not. Establishing relationships between SZ4D institutions and interested MSIs has the potential to provide new opportunities for both sides. However, forging new relationships requires trust, so the use of memorandums of understanding (MOUs) between geoscience departments at paired institutions is recommended to help describe the commitments in working together. MOUs could outline the range of opportunities each institution intends to offer (e.g., hosting, information exchange, training workshops), along with the expected timeline. In seeking to develop relationships with specific institutions, SZ4D should also work with minority-focused science organizations (e.g., Society of American Chicano and Native American Scientists [SACNAS], American Indian Science and Engineering Society [AISES], National Association Black Geologists [NABG], GeoLatinas, National Association of Geoscience Teachers at 2 Year Colleges [NAGT2YC]) that can provide guidance based on prior experience and their knowledge of the communities involved.

A third objective is to **promote rigorous science through changing the science culture to value diverse perspectives**. Studies demonstrate that we need diverse perspectives to ask and solve important science questions (e.g., Powell, 2018). They remind us that the people who have the means to participate in SZ4D science will get to define what questions get asked and researched. Based on these studies, SZ4D should ensure a diverse group of scientists are integrally involved in science planning and activities, including the funded research, the review panels, and the organizational leadership.

Finally, we seek to **increase geoscience literacy in diverse communities**. Research finds science literacy is connected to authentic uses of science in daily life (Feinstein, 2011). We recommend that SZ4D outreach efforts support community workshops and supply educational materials that provide information about local geohazards to help minority communities understand the risks and become more engaged with the geosciences (Basu and Barton, 2007). This engagement is important, as minority communities are often disproportionately affected by environmental and natural hazards. The *EarthConnections Alliance* is an example of an existing effort that we could build upon

CONNECTIONS AMONG RESEARCH GOALS: COMMON NEEDS AND ACTIVITIES

The traceability matrices allowed BEGC to identify a number of common needs and activities across the different BECG research goals. The needs showing relationships to the largest number of goals suggest they should

be SZ4D community priorities and addressing them would have the greatest impact. Similarly, the activities most commonly identified to address needs should be prioritized for SZ4D investment. **Figure BECG-2** highlights the most commonly identified needs and activities and illustrates the key connections between the goals, needs, and activities.

The next section describes how the key elements of a successful Collective Impact model directly meet the most common needs identified by the BECG traceability matrix process.

AN OVERARCHING FRAMEWORK TO ACCOMPLISH THE RESEARCH GOALS: COLLECTIVE IMPACT

Kania & Kramer (2011) proposed the Collective Impact (CI) idea, in which a group of people from different sectors commit to a common agenda for solving a specific social problem using a structured form of collaboration. CI has quickly grown in popularity (Kania & Kramer, 2013) and has been recognized by the White House Council for Community Solutions as an important framework for progress on social issues (Jolin, 2012). In contrast with CI's collaborative approach, the isolated impact approach occurs more commonly as single entities try to make the most impact with the fewest resources. Isolated impact often results from grantors seeking to satisfy a specific goal when allocating funds: support the proposals that make the greatest impact with the fewest resources, within a limited timeframe that does not align with the pace of typical institutional change. This traditional system produces efforts that often have minimal lasting effects on communities due to a short-term focus on rewards and costs, and it motivates proposers to focus on distinguishing their efforts from others. In fact, studies indicate relying on the Broader Impacts criterion of NSF proposals to accomplish social impact is flawed (Bozeman & Boardman, 2009; Nadkarni & Stasch, 2013). We thus contend that the goals and objectives outlined in this chapter cannot be accomplished through physical science PIs proposing individual social impact efforts as addenda to proposals primarily focused on physical science research. Instead, **SZ4D PIs should be envisioned as playing a role in a larger cooperative effort that is seeking to accomplish long-term broader impacts through a CI framework**. The SZ4D community sees CI as an opportunity for transformative change, enhancing our ability to create more sustainable, positive outcomes to education and outreach efforts and BAJEDI issues within the geoscience community.

Previous research has shown that successful CI initiatives typically meet five criteria that together produce the alignment necessary to make meaningful and sustainable progress on social issues (Kania & Kramer, 2011). The first is a **common agenda**, in that all participants have a shared vision for change that includes a common understanding of the problem and a joint approach to solving the problem through agreed upon actions. The second is a **shared measurement system**, in which there is agreement on the ways success will be measured and reported with key indicators by all participating organizations. The third is **mutually reinforcing activities** that engage a diverse set of stakeholders, typically across multiple sectors, in a set of differentiated activities that combine together to form a coordinated plan of action. The fourth is **continuous communication** that involves frequent interaction over long

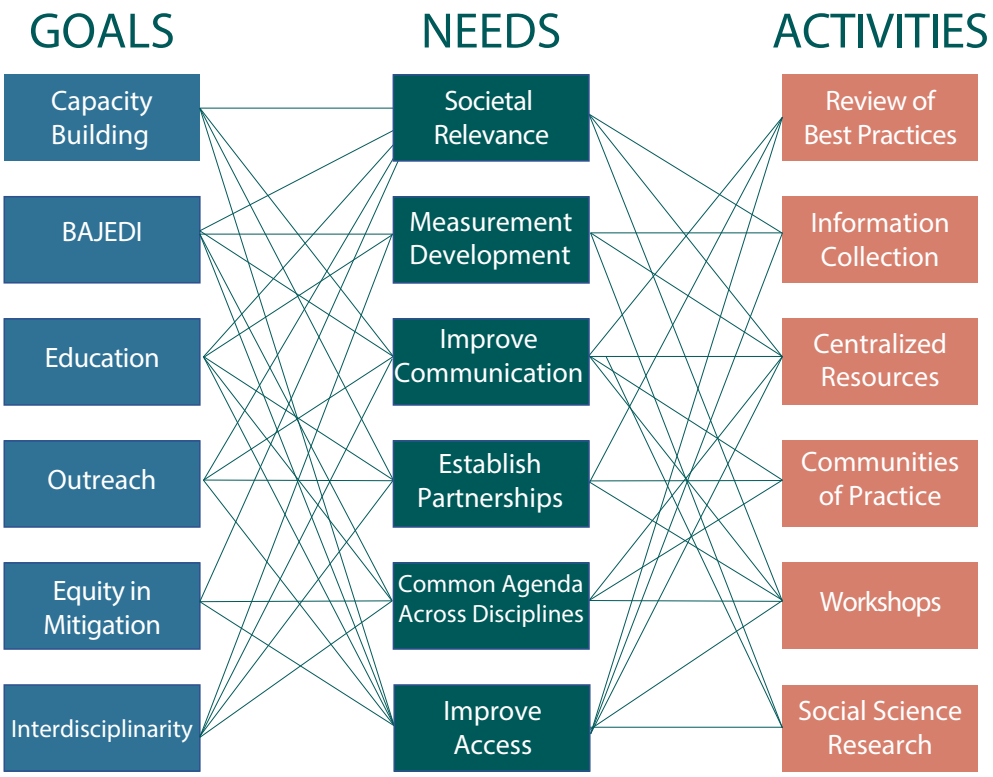

Figure BECG-2. *Diagram illustrating connections between BECG research goals, primary needs, and suggested activities. The overlapping connections illustrate how implementing an activity can meet several needs and how progress on a need can help several goals.*

periods among key players within and between organizations to build trust and encourage ongoing learning and adaptation. The fifth is a **backbone organization**, where independent staff provide ongoing support. The backbone staff and volunteers play several roles to move the initiative forward: guide strategy to match vision, support aligned activities, facilitate shared measurement practices, build public will, advance policy, and mobilize funding (Turner et al., 2012). If these five criteria can be met, the successful result observed involves cascading levels of linked collaboration (**Figure BECG-3**).

We are encouraged that SZ4D working and integrative group efforts have already made progress on the first CI criterion by agreeing on a common agenda with a shared vision. We have established the most important research questions through collective discussion and then vetted them through multiple town halls and all hands meetings with larger portions of the SZ4D community. The chapter draft review process, June 2021 All Hands Meeting, and Catalyst Proposal review process gave the SZ4D community an opportunity to review and provide feedback on the proposed approach of defined needs and suggested activities to answer the research questions. This process has strengthened our common understanding of SZ4D's scientific agenda and support for building a CI framework. The remaining CI criteria are less well developed in SZ4D efforts up to this point, but we find remarkable alignment between the CI criteria and the critical needs independently identified by BECG (**Figure BECG-2**). Finally, the need for backbone organization as a CI criterion indicates that SZ4D should be prepared to support several staff members to coordinate and sustain BECG activities.

We should note that CI is not a magic elixir and that several criticisms of this framework have been made (Wolff, 2016; Wolff et al., 2017). In particular, CI has been criticized as promoting a top-down model that doesn't sufficiently engage those most affected by the issues in shared decision-making. However, we believe that several BECG goals address this issue by focusing on BAJEDI, international partnerships, and inclusiveness throughout strategies for community engagement. Nevertheless, the criticism is a reminder that SZ4D, with the guidance of BECG, would need to be open and available for all to participate and influence the direction.

Implementing a CI framework for SZ4D activities will help transform the mindset of our geoscience community to embrace education, outreach, capacity building, belonging, access, diversity, equity, inclusion, and social justice as critically important for the success of the SZ4D scientific endeavors.

IMPLEMENTATION PLAN AND PHASING

The open review and comment period for the draft Implementation Plan in 2021 gave the broader SZ4D community an opportunity to provide feedback on the goals, needs, activities, and Collective Impact framework proposed by BECG. BECG also received feedback from NSF on the initial draft of the report.

BECG considered all of the feedback and used it to help construct a defined work plan for implementation that focused on five areas with the greatest opportunities:

1. Establishing and sustaining partnerships with key communities,
2. Shepherding communities of practice for social change,
3. Cordinating existing and new international capacity building efforts,
4. Improving education and training by strengthening relationships between SZ4D and key partners, and
5. "Matchmaking" between PIs and BECG efforts.

To organize the projected supporting activities by topic, expected timeline, and key parts of SZ4D responsible for the effort, BECG developed a preliminary *phasing spreadsheet*. This spreadsheet uses the phasing described in **Chapter 5.3**, highlighting activities from the RCN, proposed activities for a two-year catalyst Phase 0, and then estimates activities for Phase 1 (1–3 years), Phase 2 (~10 years), and Phase 3 (~5 years). Please refer to **Chapter 5.4** on Program Structure and Governance for details on the key parts of SZ4D that will be responsible for accomplishing BECG's vision.

Establishing and Sustaining Partnerships with Key Communities

Key to SZ4D's success is building partnerships with national and international organizations that monitor natural hazards, as well as with marginalized communities that are often the most affected by hazards. As a first step, during Phase 0, SZ4D will meet with MSI faculty and students on MSI home campuses and later in a group workshop, with the goal of engaging in mutually beneficial dialogue to define a common agenda for implementing BECG's vision. In particular, SZ4D needs to learn from MSIs what BAJEDI looks like at their institutions so that other SZ4D institutions can implement those practices to increase BAJEDI in our community. Meeting people on campus will be important for communicating SZ4D's

commitment to establishing relationships and provides opportunities to simply listen to MSI faculty and staff. The goal is for this dialogue to lead to workshop participation and sustained connections between MSI faculty and SZ4D staff (NASEM, 2019). The workshop will be designed to foster honest and unobstructed communication between MSI and SZ4D representatives (Ballysingh et al., 2017; Gonzales et al., 2021). It will be modeled after recommendations made for how NSF can better support MSI capacity building (ASEE, 2020).

Growing a trusted network of community partners to regularly communicate critical information on geohazards is fundamental to SZ4D broader engagement. Based on literature review and discussion with experts (e.g., Kozo et al., 2020), we will **develop a "Partner Relay" model, where SZ4D will partner with emergency management agencies and a network of trusted community organizations, including locally operating nonprofit, nongovernmental organizations that regularly work with targeted populations**. Although we initially considered a more distributed model for outreach that would train SZ4D community members to communicate directly with the general public, BECG identified expertise and research that indicates science communication and outreach is more successful when delivered by trusted organizations (Fischhoff, 2013; Weingart & Guenther, 2016). Thus, SZ4D will focus on providing key takeaways and science messaging to trusted community agencies, who will then relay this critical information to the general public. This approach will also enable SZ4D to accomplish more equity-oriented engagement and strategies for preparing bi- and multilingual communities for natural hazards and risks associated with them (Kozo et al., 2020). Based on its initial work, BECG will develop a prioritized list of agencies and organizations to target during Phase 0 so that SZ4D can begin establishing partnerships. Additional follow-up will include identifying key community vulnerabilities and determining how SZ4D might better convey information to the groups. The results of these meetings would be compiled and shared with the SZ4D community.

Training the SZ4D community in best practices for interdisciplinary and international collaboration and awareness of BAJEDI issues will be central to partnership development. For example, to help ensure success of the 2022 SZ4D National Meeting in Chile, BECG developed cultural competency training and offered it to all US participants before the meeting. BECG will continue to develop and implement these training sessions on a regular basis to build trust, stay connected, and promote and encourage sharing of resources, ideas, and inclusive strategies across the partnerships.

Shepherding Communities of Practice for Social Change

Studies of the physical processes of solid Earth geohazards can make limited contributions to hazard risk mitigation. Research indicates that disasters are a result of natural hazards interacting with social structures (e.g., Kelman, 2018), and misinterpreted scientific results may have deleterious effects on communities in the event of a disaster (e.g., Albris et al., 2020; Alexander, 2014).

During Phase 0, SZ4D will establish several **communities of practice** (CPs, i.e., groups of people who share common interests or goals). Each CP will include people from its diverse network of disciplines, institutions, stakeholders, communities, and nations, bringing multiple perspectives to bear on the challenges faced

by SZ4D. During Phase 0, year-long CPs will gather groups of physical and social scientists to build components of the CI framework for SZ4D. The CPs will target three of the BECG research goals:

1. BAJEDI,
2. Capacity building, and
3. Interdisciplinary collaboration.

Stipend support will be used to attract both physical and social science experts and to ensure participants commit to achieving the goals over a longer timeframe (Ward & Selvester, 2011). Financial support also honors the importance of this work and encourages its participants to engage with one another and with the project in more purposeful ways. Participation and formative and summative assessment of the outcomes will be monitored. Outcomes will be presented to SZ4D governance for decisions about implementing recommendations.

Initial Community of Practice Descriptions

The **BAJEDI CP** will build on the MSI workshop to identify opportunities for increasing the pool of diverse students, faculty, and professionals in SZ4D (e.g., Powell, 2018; Hofstra et al., 2020). The CP will identify mutually reinforcing activities for increasing access to SZ4D science for underrepresented populations. To recruit and retain a diverse SZ4D community, it will be critical to develop effective strategies for communicating the relevance of BAJEDI efforts to everyone in the SZ4D community. The CP will develop rubrics to assess the effectiveness of the various BAJEDI efforts across SZ4D, as self-examination is crucial for identifying and addressing BAJEDI issues (Velasco et al., 2021).

SZ4D provides an exceptional opportunity to establish equitable international capacity-building partnerships to improve capabilities (e.g., skills, data, technology, understanding) for all stakeholders involved. The **Capacity Building CP** will identify mutually reinforcing activities for cooperative international field research, sustainable human capacity building, technical infrastructure development, and FAIR data and research policies (Fecher et al., 2015). Efforts to minimize colonial methods of interaction will be central, including continued development of cross-cultural implicit bias training (e.g., Nordling, 2017; Cartier, 2019). The CP will also consider strategies to increase adoption of and participation in the scholarship of teaching and learning to improve training efforts. Measures for assessing whether trainees are properly equipped with SZ4D-specific research skills will be developed in collaboration with geoscience education researchers. The CP will also focus on outreach strategies for understanding geohazards and associated risks by identifying mutually reinforcing activities to connect SZ4D science to key non-scientist stakeholders and evaluating effectiveness of outreach with shared measures.

The **Interdisciplinary Collaboration CP** will seek to implement evidence-based practices for collaboration that break down disciplinary silos and improve understanding across subject areas. The CP will establish a consensus set of key elements in a successful interdisciplinary collaboration, accounting for both costs and benefits, and develop methods to assess and improve SZ4D collaborations (Goring et al., 2014). This will build on a review of best practices and common obstacles of prior community efforts being compiled by the SZ4D RCN, extending into research on collaboration (Collins et al., 2007; Lenfle & Söderlund, 2019).

There are **compelling recent examples that SZ4D can use to model its CP approach**. The ShakeAlert® Earthquake Early Warning (EEW) Joint Committee for Communication, Education, Outreach, and Technical Engagement (*JCCEO&TE*) is a vibrant international effort that, over six years, has assembled a broad spectrum of practical resources, tackled difficult questions, and provided great insight into the social systems that are inherent to hazard mitigation. Over the same period, the NSF GEO Directorate has sponsored BAJEDI-themed grant programs (GOLD, GOLDEN) to foster organizational diversity and transformation and has increasingly required the inclusion of social scientists in efforts to diversify the culture of science (Posselt et al., 2019). SZ4D will follow this lead in recruiting and compensating experts in equity-centered higher education to design CI components of SZ4D from the very beginning stages.

Coordinating Existing and New International Capacity Building Efforts

Through its effort during the RCN stage, SZ4D is now positioned to leverage, coordinate with, and complement existing international capacity building activities, especially those relevant to a South American focus site. We will use workshops to **bring existing groups/leaders together to identify similarities and differences in current efforts and identify gaps where there are opportunities for new initiatives/developments**. SZ4D will organize one-day "add-on" workshops of opportunity associated with established community meetings (e.g., AGU, EGU, GSA, SSA, IUGG, LACSC, SAGE/GAGE). These meetings of opportunity are an efficient way to entrain new participants, including early career investigators, build relationships with international partners and stakeholders, share experiences, and plan/coordinate specific capacity building activities. SZ4D will strive to support virtual meeting options to encourage participation of groups that are unable to travel; this option became available during the COVID pandemic and was used for Special Interest Group meetings with themes on international collaboration held at the 2021 (fully virtual) and 2022 (hybrid) SAGE/GAGE community workshops.

The SZ4D Center will **facilitate regular meetings between both SZ4D governance and SZ4D project principal investigators to prioritize needs and develop opportunities** for capacity building efforts. SZ4D communications with Chilean and Argentine collaborators and with other international partners has made us aware of the needs and challenges facing local stakeholders. These international relationships also provide SZ4D governance with a foundation for coordinating project execution with specific SZ4D PIs. SZ4D governance will cultivate and engage its contacts at both international and domestic sites to broker sustainable project plans from PIs that maximize the impact of their work. SZ4D will continue to reinforce the use of FAIR practices across all SZ4D data and data products, building off models developed by IRIS, UNAVCO, and IEDA, and extending into other communities. SZ4D has helped to initiate conversations between data providers in the United States and Chile for this purpose.

A fundamental element of capacity building is bringing people together to work in the same space. SZ4D will **provide funding to support travel and SZ4D staff coordination to enable bi-directional international student/postdoc exchange programs**. The initial focus will be on developing an **international network focused on subduction geohazards (SZNet)**, with the

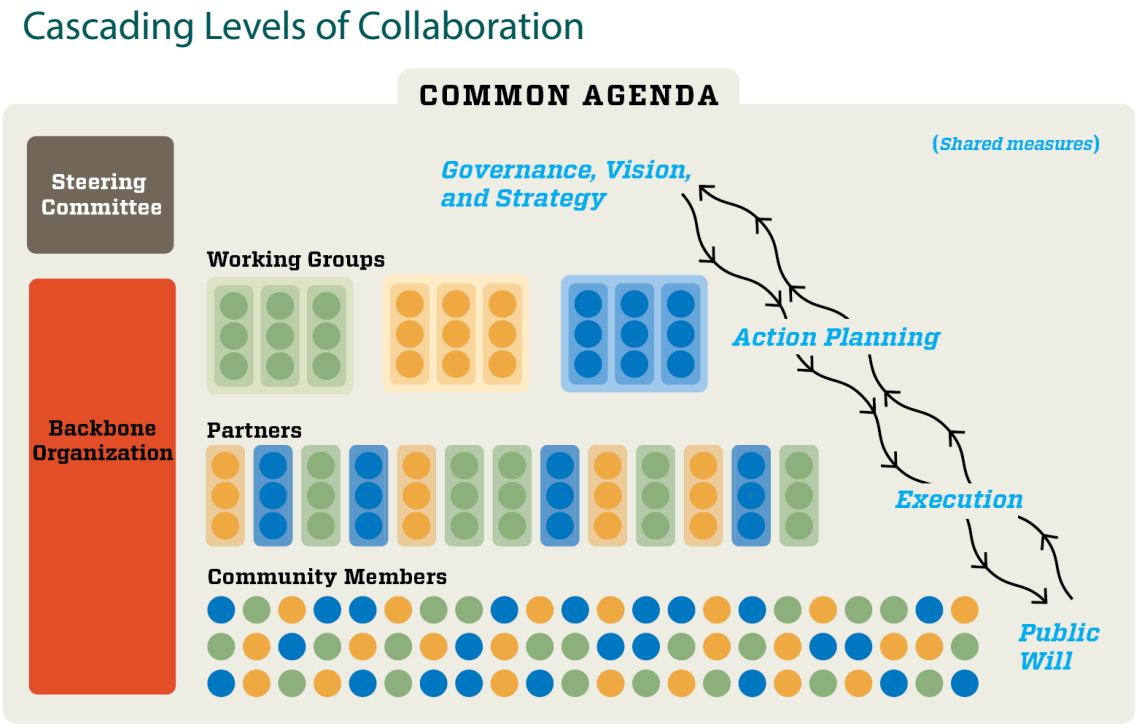

Figure BECG-3. *Cascading levels of collaboration that are observed with a successful Collective Impact framework. Figure from Kania and Kramer (2013).*

goal of fostering a cadre of early career scientists who can synthesize information from different subduction zones and who have a diverse set of international contacts. The NSF AccelNet program can facilitate international training and exchange of students and postdocs within SZNet. We expect that groups like SZ4Grads will participate in SZNet as well as channel awareness to their own networks. Funding for SZNet would enable a variety of activities, spanning in-person fieldwork collaborations to travel to an institution in the United States, Chile, or other countries participating in SZNet to conduct sustained, collaborative research. SZ4D PIs would also be encouraged to consider different levels of experience, including summer/winter break research experiences for undergraduates, utilizing student cohorts and dedicated mentorship, similar in style to UNAVCO's and IRIS's summer undergraduate internship programs. These interactions will benefit from a continued emphasis on cultural training, implicit bias, and equitable models of collaboration to avoid imperialistic and colonial interactions (e.g., Cartier, 2019; Wight, 2021).

Any new capacity building activities must **leverage existing resources to develop a sustainable model** beyond the sunset of SZ4D. Capacity building has been facilitated by a variety of academic, monitoring, and philanthropic organizations (e.g., *IRIS International Development*, *Volcano Disaster Assistance Program*, *Earthquake Disaster Assistance Team*, *Geoscientists Without Borders*, *Engineers Without Borders*) distributed in the United States and internationally. SZ4D will engage with these groups to learn from their experiences and, ideally, collaborate on shared opportunities. In particular, we would like to better align and learn from academic groups that our community has some familiarity with already, including the Earth

Observatory of Singapore and the International Centre for Theoretical Physics in Trieste, Italy. In addition, through SZ4D's strong connection with the USGS, we will draw from its significant expertise from its Volcano Disaster Assistance Program (e.g., Lowenstern & Ramsey, 2017) and Earthquake Disaster Assistance Team to navigate the complexities of in-country capacity building with hazards applications. Throughout this process, SZ4D will continue to engage with and learn from complementary efforts such as the AGU-sponsored *Hazards Equity Working Group* and *Thriving Earth Exchange*.

Lastly, a key practical consideration for SZ4D will be the **translation of all associated educational/training materials** as they are developed, to broaden and maximize their utility. With a primary international site in Chile, Spanish and Indigenous language translations will be the first-order product and will be able to provide immediate impact to other stakeholders throughout Latin America. This effort will initially focus on scientific and educational products, such as topical scientific or research presentations, public outreach presentations, synthesis reports, methodology or field practice training materials, technical workbooks, and classroom lessons, and will build upon existing resources (e.g., SERC, UNAVCO, IRIS). In cases where material is being developed from scratch, Native language participants recruited from SZ4grads and elsewhere could be supported to participate in the development of educational content and subsequent translation. We will continue to establish connections in the research and teaching communities in Latin America to ensure that our products have meaningful applications and to provide opportunities for feedback. We will also use partnerships with other international groups, especially those working in other parts of the developing world and in regions with subduction processes and associated hazards (e.g., Indonesia), to determine how best to adapt these products to wider audiences. As appropriate, we will work with local experts to factor in cultural context and national educational standards in the development of training pedagogy and to ensure that any classroom-specific material is appropriate.

Improving Education and Training by Strengthening Relationships between SZ4D and Key Partners

An essential part of the SZ4D mission is to freely share its scientific findings and advances in research methods and technologies, and nurture and sustain the reciprocal relationships it will build within the research community as well as the communities where it does research. SZ4D should proactively contribute to **formal education** (at universities, colleges, and K–12 schools), to **informal (public) education and interpretation** (at museums, science centers, and parks and preserves), and to the **training and professional development** of a diverse cadre of new and experienced scientists and educators alike. Many in the SZ4D community already have accrued valuable experience in one or more of these realms that can help guide SZ4D educational strategies. However, there are numerous organizations with ongoing educational efforts that SZ4D should seek to partner and coordinate with, including the National Association of Geoscience Teachers (NAGT), National Earth Science Teachers Association (NESTA), National Science Teachers Association (NSTA), Science Education Research Center (SERC), and the education divisions of AGU and GSA, as well as affiliated scientific organizations such as the EarthScope Consortium, OpenTopography, Computational Infrastructure

for Geodynamics (CIG), Community Surface Dynamics Modeling System (CSDMS), USGS, NASA, NOAA, and State geological and hydrological surveys. During the first phase of SZ4D, we will organize a workshop with representatives from these organizations to establish partnerships and plan activities with the SZ4D community. PIs and instructors will be encouraged to contribute presentations at regular large conferences and in smaller workshops and short courses specifically focused around teaching and training. Coordination with organizations such as SERC for the **curation of educational resources** will also be essential to ensure the efforts persist beyond the timescale of individual research projects.

SZ4D staff and a rotating set of PIs will offer **topical summer institutes** that focus on incubating research to address SZ4D science questions. These institutes will be based on the successful model established by CIDER Summer Programs. CIDER places a strong emphasis on intensive teamwork on a specific research problem to foster communication across disciplines and scientific generations while also providing mentorship and new research opportunities for the next generation of solid Earth scientists.

The breadth of SZ4D's planned activities also provides an opportunity to investigate best practices in geoscience education. Educational research will be needed to evaluate optimal training strategies for developing:

1. Spatial and temporal reasoning skills to handle increasingly large and detailed 4D datasets,
2. The ability to work coherently in large-scale fieldwork settings such as the human deployments proposed to collect critical SZ4D data, and
3. The capability to create and validate models that reveal essential new information. An SZ4D Science Program should also support complementary geoscience education research that investigates strategies to improve how we equip SZ4D students and postdoctoral researchers.

"Matchmaking" Between PIs and BECG Efforts

SZ4D's CI framework will facilitate scientists working together across disciplines rather than in parallel on individual projects. For this effort to be successful, we need structures that foster, support, and reward impactful collaborations whose efforts span both scientific and broader impacts.

All topical SZ4D workshops will bring together participants from a wide range of disciplines and at various career stages. **Each topical workshop will highlight professional development programming that fosters successful approaches for research program development and collaboration** (e.g., Youtie & Boseman, 2014).There will be a focus on early career researcher attendance so that we can reinforce the benefits of interdisciplinary collaboration in an academic culture that tends to focus value on specific research outputs such as primary-authored publications (Goring et al., 2014). We will establish mentorship structures for these participants to leverage as they develop discipline expertise but with an eye toward interdisciplinary applications.

To facilitate PI engagement in impactful broader impacts projects, we need to **build a system where PIs can contact SZ4D in the proposal planning stage to ask for assistance in developing broader impact strategies that align with and leverage existing BECG**

efforts and resources. SZ4D staff can identify potential connections, share points of contact, and facilitate dialog. Because the SZ4D staff will be maintaining a database of local scientists and other potential collaborators, they would be able to help PIs make connections within the areas of geographic focus. For example, the application and attendance information collected as part of the 2022 SZ4D national meeting in Chile provides a starting point for SZ4D to establish connections with local scientists based on shared interests.

By maintaining a **publicly accessible database that highlights activities and collaborations, PIs can explore how their efforts fit into a broader context**. To provide an accurate view of BECG efforts, the SZ4D database should seek to include activities that are funded through a SZ4D science program and those that are funded by other programs, agencies, and governments that are related to SZ4D research questions. This information can be collected in two ways:

1. Proposals requesting additional research funding will be contingent on providing information on previous, ongoing, and planned BECG efforts, and
2. All workshop participants will be required to provide information on their BECG efforts with their registration.

Opportunities for collaboration presented by the database can be highlighted in SZ4D communications to encourage participation.

While elements of these approaches have been used by other science centers, such as the Southern California Earthquake Center, we are not aware of any organization that has provided mechanisms to foster and assess collaborative capacity building efforts to this extent. To help ensure equity on this new pathway, SZ4D will annually assess the balance of ongoing broader impacts efforts and recruit collaborative endeavors for critical, underrepresented activities. The committee approach, drawing from a wide cross section of the community and stakeholders, offers a broader-based platform to make connections outside of the traditional modes of collaboration. It is SZ4D's intent that the collaboration development strategies will successfully transform how we create and sustain equitable collaborations that will serve as models for future efforts within geosciences.

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