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Adaptive Scaffolding toward Transdisciplinary Collaboration: Reflective Polyvocal Self-study

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Abstract. Contemporary global challenges require experts from various disciplines to work together. Since every field of knowledge has its unique language and discipline-based culture, collaborative inquiry presents an additional challenge during such collaboration. Ideally, collaborators from each discipline can transcend their respective linguistic and cultural boundaries to achieve transdisciplinarity, where this includes sharing and taking perspectives, active listening; and adaptive, relational metacognitive scaffolding. Within such a framework, the merging of ideas, theories, research design and methodologies, technological applications from each discipline can be achieved through active collaborative, sense-making, and sustained constructivist relations. Within the context of the Disaster Resilience Analytics Center (DRAC) research team, we developed a model of adaptive scaffolding via self-consistent, iterative refinement. This convergence project focused on socio-economic aspects, outreach, and STEAM education, along with postgraduate education. The research team comprised researchers from STEAM disciplines in physical sciences, mathematics, computer sciences, social sciences, humanities, education and library science. It proved essential to occasionally step away from the research topic and to critically co-reflect on the initial and ongoing challenges in the convergence path. This resulted in more constructive integration and transcendence of disciplines, leading to the development of an adaptive scaffolding framework. We present this framework and additional reflective insights and limitations related to its potential application in different contexts.

Keywords: adaptive scaffolding framework; convergence science; disaster science

1. Introduction

Figure 1 serves as an outline of this paper and visually captures our discovery of an adaptive scaffolding model that might be applied in collaborative explorations when appropriately contextualized. Briefly, we will first introduce our work within the Disaster Resilience Analytics Center (DRAC), the significance of both disaster science and its transdisciplinary nature, and how that came about to be at the center of our team's attention. We will further describe the challenges we faced due to the team's composition related to the expected collaborative work, the discovery of potential improvements through reflective thinking, and the consequent conclusion to investigate this experience as a reflective polyvocal self-study. The purpose of this polyvocal self-study was to capture lessons learned during the team's engagement in research within the Disaster

Resilience Analytics Center (DRAC) [54]. Furthermore, we describe a potentially transferable framework of collaborative inquiry that emerged from our work and which contributes further to the reflective nature of this paper.

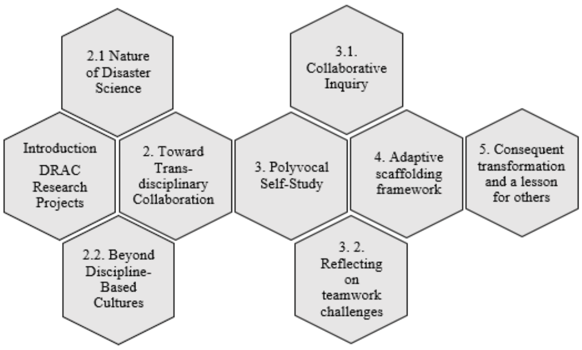

Figure 1. Outline: Visualizing the process.

The DRAC project and its multidisciplinary team were one of a number of successful proposals under a convergence initiative by the university. It provided an opportunity for a diverse group of faculty members to engage in research for improving the prediction of natural disasters and the resilience of communities to such disasters, and to explore, investigate and provide community outreach.

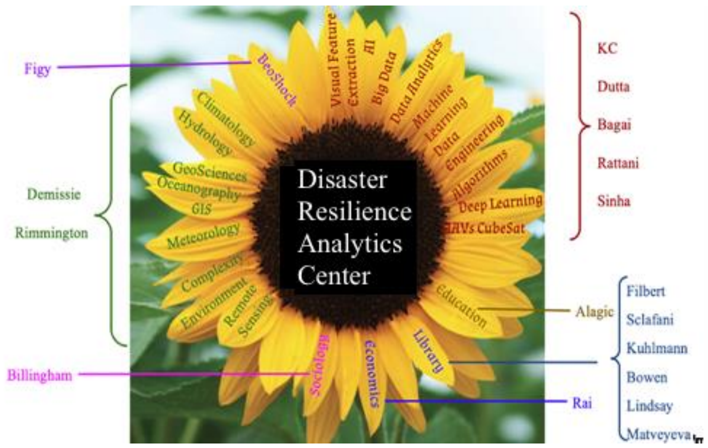

Figure 2. Visual proposal for the competitive Convergence Initiative [54]

More precisely, our project had the following goal:

> *The ultimate goal of the research cluster is to create a digital platform for the Great Plains area that can help the region with all four phases—mitigation, preparedness response, and recovery—by enabling the prediction of the various type of disasters as well as the potential impact of the disasters on the economic, social, ecosystem, human capital, and other aspects. We propose to create a test-bed digital platform for a small geographic region of the Wichita area that allows us to predict/analyze/simulate various what-if scenarios so that the community is more resilient to disaster focusing on Mitigation and Preparedness* [54].

2. Toward Transdisciplinary Collaboration

2.1. Nature of Disaster Science

Transdisciplinarity is perhaps above all a new way of thinking about and engaging in inquiry. [31, p. ix]

It appears that the *transdisciplinarity concept* was first mentioned by the Swiss psychologist Jean Piaget at the seminar on interdisciplinarity in universities sponsored by the Organization of Economic Cooperation and Development and the French Ministry of Education in 1970. Piaget [35] mentioned transdisciplinarity as placing, "… relationships within a total system without any firm boundaries between disciplines…" (p. 138). The same year, Jack Lee Mahan [28] wrote in his doctoral dissertation, "Transdisciplinary inquiry would be characterized by a common orientation to transcend disciplinary boundaries and an attempt to bring continuity to inquiry and knowledge." Nicolescu elaborated, "Transdisciplinarity concerns that which is at once between the disciplines, across the different disciplines, and beyond all disciplines. Its goal is the understanding of the present world, of which one of the imperatives is the unity of knowledge," [32, p. 19]. That seems to be a foundational statement although there are many other contextual elaborations about how the transdisciplinary way of thinking challenges discipline-based thinking and seeks to create new knowledge through inquiry into problems that cannot be solved within a single discipline [5]. The history of the development of the modern concept of transdisciplinary research has been well-documented and represented. For example, Mittelstrass [29] explains this as an issue of the "Order of Knowledge," which he discusses as being "From Disciplinarity to Transdisciplinarity and Back" (p. 68), while most historical reviews present a reversal of this depiction. From the *socially responsible science perspective*, current complex social and environmental problems, from climate change disasters to a sustainable future, lend themselves to transdisciplinary inquiry. These complex, interconnected, so-called "wicked problems" [7] need creative solutions, between and beyond disciplines, traversing knowledge bases and value systems. The problems inherent to the prediction of disasters, disaster risk reduction, and resilience are those kinds of problems - problems requiring a transdisciplinary way of thinking, understanding, and knowledge creation.

Disaster Science (DS) as a field of study has become established through the various initiatives focused on the research of disasters and Disaster Risk Reduction (DRR) and by the creation of the journals *Journal of Disaster Science* in 2016, *Progress in Disaster Science* in 2019. The actual term has been used since the early nineties [3] and comes with a recognition that an essential change in scientific approaches to disaster risk reduction is needed by shifting the emphasis from individual hazard and risk assessment to a system analysis with transdisciplinary action-oriented research co-facilitated by researchers and stakeholders [24]. Many authors argue for the value of the transdisciplinary approach to research involving scientists from different disciplines to comprehensively study problems relevant to DRR. Although they do not offer a unique roadmap, there is a general agreement about the need to move beyond discipline-specific approaches to problem-related contextualization of disciplinary ontologies, and phenomenological, theoretical, and methodological innovations (e.g., [34]). Van Niekerk [50, p.13] suggested, "Transdisciplinarity provides a binding paradigm for disaster risk reduction." In our context, the three dominant features of this binding paradigm [24], extend to disaster education and are conceptualized as Collaborative Inquiry, Applied Problems, and Value to Multiple Disciplines:

- *Collaborative Inquiry:* agreeing on the research problem and how team members from different disciplines are going to communicate and collaborate.
- *Applied Problem:* creating a consensus that the goal of the study is the amelioration of the effects of well-specified problems through solution-focused, transferable knowledge.
- *Value to multiple disciplines:* creating the knowledge in ways that are of value from a practical as well as a scientific standpoint to individual disciplines.

DRR education in both formal and informal educational settings [41] is a crucial component of all efforts to predict and recover from disasters, especially considering the increased frequency and severity of natural and manmade disasters. In this context of education, interdisciplinary STEAM learning offers the potential for disrupting traditional disciplinary boundaries and collaboratively engaging with topics and ideas in a critical, and interconnected manner [15]. STEAM education should be designed to not only transcend disciplines but also impact individuals and communities outside of the classroom [8]. This is particularly important with disaster education, as recent large-scale disasters have revealed the inadequacy of disciplinary approaches to disaster education.

Disaster Science Challenges: Global and Local Disasters and Hazards. The increased frequency and severity of natural disasters observed in recent times have been linked to anthropogenically-driven greenhouse gas accumulation, which consequently has raised the global average sea-level air temperature by more than 1ºC compared to the pre-industrial era [1]. The global average air temperature reflects the overall energy content of the atmosphere. However, this energy is not homogeneously distributed due to the dynamic nature of atmospheric circulation and its interaction with oceanic circulation and the topography and albedo of landmasses. Thus, it is not unusual to observe simultaneous events at opposite extremes within the same continent or region [6, 11], for example with record floods in Eastern Australia at the same time as heatwaves and wildfires in Western Australia, during January 2022. This increased frequency and severity of weather-related disasters is a matter of some concern to insurance companies, governments, and humanitarian organizations [4, 12,16].

The consequences of natural disasters go beyond economic costs and insurance claims to include environmental damage and human lives and well-being. As stated above, the increased severity and frequency of these natural disasters can be attributed, in part, to climate change and impart to a lack of disaster resilience for known, recurrent disasters. Climate change could be the insurance industry's primary concern in the coming decades [42]. For example, in Britain, "...more than 570,000 new homes had been built since 2016 that would not be resilient to future high temperatures and more than 70,000 had been built since 2009 on flood plains" [45, p1]. Further, flood mapping data showed that 19% of British properties were susceptible to surface water flooding.

High fuel loads in grasslands coupled with abnormally windy, hot and dry conditions in Western and Central Kansas [39] attributable in part to climate change [20] helped the December 2021 wildfires to spread quickly, burning more than 350,000 acres in parts of Western and Central Kansas, leaving two people dead and three injured, and more than 42 structures destroyed [37] at a cost of more than $2.3m [33]. Additional consequences of these wildfires included disruption to grazing and cropping enterprises, and power outages, due to downed power lines. In the case of US Western wildfires [26], it is likely, insurance companies will not survive unless they manage the resilience of communities located in potential wildfire locations. Urgent action is needed from policymakers, developers, and insurers to protect homes and businesses from flooding and wildfires. Added to this challenge is the problem that the communities most vulnerable to flooding or wildfires are least able to change or adapt. Social stratification affords the higher SES communities the least vulnerable areas while penalizing low SES communities who are most often living in vulnerable areas. Low-lying areas in Houston, during Hurricane Harvey in 2017 and New Orleans during Hurricane Katrina in 2005, illustrate this point.

Disaster Science Opportunities: Remote-sensing, deep learning, and GIS. The science and application of remote-sensing technologies have advanced rapidly during the past five decades. An early example was its application to crop hail damage [48]. While the insurance industry has been slow to adopt remote sensing, it has been applied to fire [44], hail [58] and drought [40]. High-resolution (0.25-2m) multi-spectral or Synthetic Aperture Radar (SAR) imagery of before and after disasters can be used to detect changes [47] such as damaged houses, blockages to transportation routes, spills of toxic materials, or disruption to utilities; usually within a couple of days. Such information is helpful for disaster recovery efforts. In the longer term, it can also identify where to invest resources to improve community resilience for future disasters. Remotely-sensed differences, before and after a disaster, have the potential as a tool for insurance companies [10] to either re-calculate premiums for higher-risk levels or to provide incentives to improve resilience. Since local governments have access to georeferenced data for buildings and infrastructure, costs, and values, they can rapidly estimate losses due to a disaster and in the process compare the costs of disasters versus the cost of improved resilience [22, 38, 43]. The tedium of this type of work is being overcome with the application of deep learning and object recognition to satellite imagery [57].

> *...development of efficient risk mitigation and adaptation strategies is impossible without joint interdisciplinary efforts among actuaries, statisticians, atmospheric scientists, civil engineers, and policymakers; such truly interdisciplinary initiatives are still relatively rare.* [27, p. 13]

The ultimate solution to this problem calls for participation by team members from different disciplinary backgrounds-science, engineering, economics, sociology, education. For this to succeed, adaptive scaffolding will be needed to allow the development of a common language and shared perspectives among participants.

2.2. Beyond Discipline-based Cultures

"Disciplines are the result of artificial fragmentation of knowledge. Real-world problems are rarely confined to the artificial boundaries of academic disciplines" [9 p. 357). The recognition that one perspective is often not enough to address a challenge is not new, nor is the desire to seek out perspectives other than that held by a person or group of people within a field to address that challenge. One famous literary example of this practice may be traced back to ancient Athens. Plato's recorded version of Socrates' *Apology* [36] to the Athenian court contains a story in which Socrates recounts his being told that no one was wiser than he. Questioning the truth of that assertion, he proceeds to consult with others around Athens attempting to find a person or group of people wiser than him. There are reasons to view this story as peripheral to any contemporary discussion of disciplinary culture, or any attempt to foster transdisciplinary dialogue (for example, Socrates concludes that, as of his *Apology*, he had yet to find anyone wiser than him, and had begun questioning the value of wisdom anyway). That said, the story represents an ancient articulation of an idea still present in contemporary scientific inquiry – outside perspectives are essential to address a challenge perceptible to a researcher or group of researchers within a field. It is from this broad perspective that any endeavor to build a transdisciplinary model of thinking and apply it to a specified challenge begins [52].

As an examination of global and local disaster-related challenges highlighted, knowledge, practices, and technologies developed by multiple fields may be brought to bear on both preparing a community to respond to a disaster as well as responding in the wake of a disaster. Certainly, all voices in that conversation possess a shared desire to address the challenge posed to a community by a disaster. While this shared desire makes an excellent starting point, it cannot by itself facilitate the full conversation. Many models exist to address aspects of communication, such as intercultural aspects [53] or sustainable aspects. That said, articulating a broad model of transdisciplinary communication remains a challenge and this challenge, in turn, hampers actionable efforts to construct transdisciplinary teams to address issues of disaster resilience. Any such model must account for the fact that every field of knowledge has its unique ontology, vocabulary, and disciplinary culture(s). It must provide a framework to build upon those field-specific elements as a means of drawing all relevant language, concepts, and technologies into the model to help a community prepare for a disaster or respond to one in a meaningful way. *Thus, an essential criterion for judging the success of transdisciplinary research is the extent to which they promote the development of novel conceptual models and empirical investigations that integrate and extend the concepts, theories, and methods of particular fields* [46, p. 67].

3. Polyvocal Self-Study

The polyvocal aspect of this participatory self-study is dialogic [17], and it has been co-constructed through intentional reflections and co-reflections while evolving and unpacking an understanding of multiple layers comprising the DRAC team's collaborative inquiry as well as necessary relational understandings for keeping up with that inquiry.

3.1. Collaborative Inquiry

There is a notable uniqueness along the continua of collaborative inquiry to which convergence initiatives strive. Attempting to converge on a real-life problem-inspired model that transcends multiple disciplinary boundaries and is engaged with all societal stakeholders reveals many collaborative tensions and obstacles [13]. In this context, principles of collaborative inquiry are concerned with the development of mutually beneficial relationships, which is achieved not only as a component of research but also as a way of presenting an alternative formulation of what counts as knowledge [49]. The convergence of these models and methods toward complex research endeavors and the collaboration of diverse and often disparate project partnerships points to the opportunities for knowledge innovation. Gibbons [14], have conceptualized this goal as Mode 2 in the production of knowledge:

> *Mode 2 knowledge production is transdisciplinary. It is characterized by a constant flow back and forth between the fundamental and the applied, between the theoretical and the practical. Typically, discovery occurs in contexts where knowledge is developed for and put to use, while results – which would have been traditionally characterized as applied – fuel further theoretical advances… Knowledge is always produced under an aspect of continuous negotiation, and it will not be produced unless and until the interests of the various actors are included.*

This kind of collaborative inquiry goes beyond *collaboration* in integrating and applying contributing knowledge and practices toward *convergence* via co-creating novel concepts, methodologies, theories, and models for genuinely innovative approaches relative to 'wicked' or increasingly complex global socio-environmental and community-based problem-solving strategies.

3.2. Reflections: What did we learn through this inquiry process?

One of the biggest challenges was having *in-depth conversations with scholars in other disciplines* since almost everyone was looking at disaster science from their discipline-based perspective. It might be worth mentioning that the COVID pandemic resulted in having only virtual meetings and so, side conversations that might have been helpful were almost nonexistent, and not easy to facilitate. After all, each member was an expert in a particular discipline but not nearly as well versed in others. At times team discussions took significant time and energy for a scholar in Sociology, for example, to communicate with scholars in Economics and the Geosciences. One member noted that the team needed to foster more dialogue, between those with expertise in machine learning and those with expertise in meteorology early in the project when some students were studying how machine learning can be used to predict hurricane trajectories, for instance. From such a dialogue, the machine learning specialists could learn more about meteorological processes underlying hurricane formation and trajectories, while the meteorologist could learn more about how machine learning works. Purposeful dialog, supported by appropriate scaffolding, often needed to follow in which the gaps in knowledge and understanding were filled. Listening carefully and formulating the questions to fill gaps in knowledge, required a sustained and substantial investment of time. In fact, on some occasions, technical vocabulary needed to be explained before team conversations could proceed. In addition, team members did not always share the same assumptions about the research process, such as what questions to ask about natural disasters, and how to proceed in researching natural disasters. These cross-disciplinary challenges often appeared during the first year of the DRAC project.

Another challenge was the *bifurcation of the research team into two smaller teams titled* Prediction and Resilience. This division enabled highly technical research to proceed within the Prediction team and its weekly group meetings. Disappointingly, this was without the benefit of insights from other disciplines, such as sociology, economics, or education. During this same period, the Resilience team held its weekly group meetings and made advances in studying disaster risk reduction and community-focused research as well as theoretical discussions about the ideal of achieving true convergence per the initial proposal leading to conversations about scaffolding, understanding each other's perspective and as mentioned in a reflection, *learning to collaborate in a transdisciplinary way of thinking.*

Members of the entire DRAC team, from both Prediction and Resilience, met monthly and shared progress. However, the initial division within the overall team, especially when combined with the corresponding separate meeting times, created some unforeseen problems. For example, it was difficult to participate in whole-team conversations or to enjoy the fruits of truly convergent scientific research. On a more basic level, it was hard to stay abreast of the work of the other team. It became clear that the entire DRAC team needed to meet and integrate all activities. The DRAC team has settled into this pattern and is showing signs of helping members to evolve toward disciplinary transcendence. What we were learning along the way was that for this evolution a better-structured awareness of adaptive scaffolding is required.

4. Towards a collaborative framework: Adaptive scaffolding

The analogy of scaffolding construction for a building to cognitive scaffolding in the construction of knowledge [56] combined with the Zone of Proximal Development [51] is usually considered a teacher education concept. The Zone of Proximal Development (ZPD) is the "...distance between the actual developmental level…and the level of potential development…" (p. 86). It may be limited to small distances without scaffolding, or larger when higher developmental levels are desired and addition of appropriate scaffolding is required. Scaffolding may be defined as elements that help bridge the gap between one's initial developmental level and a higher, desired developmental level, by providing the appropriate amount of support. Thus, it implies the important role of the professional educator or teacher in providing the scaffolding. Careful consideration of these concepts leads to the recognition that the goal of a teacher (expert in education and learning theories) is to equip the learners with the ability to eventually scaffold for themselves as well as for other learners. This leads to an expanded concept of scaffolding— r*eciprocal/relational scaffolding* [18] where team members learn from each other's knowledge with scaffolding fluctuating constantly as the DRAC team collaborates toward shared goals and collaborative inquiry into disaster science. The scaffolding metaphor has been extended by considering the scaffolding *domain* (conceptual and heuristic), *agency* (expert, reciprocal, and self-scaffolding), and self-scaffolding as *metacognition.* Furthermore, based on a combination of domain and agency there are six potential zones (Figure 2) of scaffolding activity distinguished by the relative positioning of the team members in the associated scaffolding: (a) Conceptual/Heuristic by an expert; (b) in a reciprocal situation; or (c) by a self-scaffolder [18]. These zones are inherently related to the four functions of scaffolding: (i) to navigate inquiry; (ii) to structure tasks; (iii) to support communication; and (iv) to foster reflection [19]. Each needs to be implicitly integrated into DRAC teamwork.

Creating an environment that fosters successful team culture requires, in addition to a shared goal, the attention of all team members to dialogic interactions. That kind of *relational scaffolding* with attention to metacognitive self-scaffolding is necessary for successful teamwork. Some consideration has been given to similar concepts in the literature. For example, conversational scaffolding—"how organizational members engaged with various media alone and in combination to accomplish both individual and concurrent conversations" [55, p.1]. Building from conversational scaffolding, three dimensions—content, relationships, and technology—of relational scaffolding have been considered in computer-mediated communication [30]. Furthermore, in this context, *adaptive scaffolding* refers to regulated learning and understanding by activated prior knowledge, monitored emerging understanding, and engaged seeking of a reciprocal understanding. In terms of scaffolding categories, attention has been given to *conceptual* (conceptual understanding and knowledge development) and *procedural scaffolding* related to processes and supporting structures. *Strategic scaffolding* that promotes analysis, planning, and decision-making during the study, was carried through collaboration, and, via the DRAC team's reflections, it was learned along the way. *Metacognitive scaffolding* (Fig. 4) concerns how to deal with thoughts during the learning in the self-thinking process, as mentioned in DRAC team reflections but not discussed before the design of Fig. 3, which captures our thoughts about the adaptive scaffolding framework that should be considered before any convergence initiative.

ADAPTIVE SCAFFOLDING		**AGENCY**		
		expert	peer/ reciprocal	self
DOMAIN	conceptual	zone1	zone3	zone5
	heuristic	zone2	zone4	zone6
	relational	**PSPT**	reciprocal/ relational	**METACOGNITION**

Figure 3. Adaptive scaffolding framework.

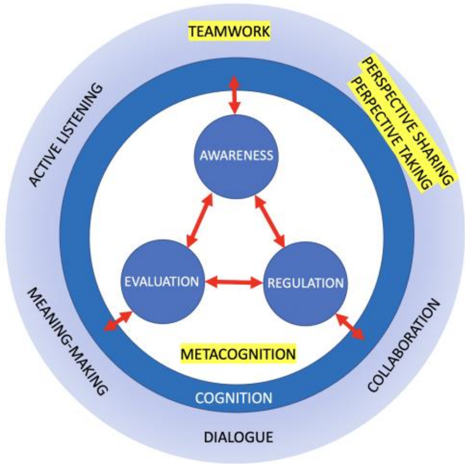

Figure 4. Role of metacognition within the adaptive scaffolding framework.

Dialogic sharing and construction of meaning is one type of relational scaffolding that may help in a project like ours. Consider the word, "field". For library scientists, it may have a particular meaning, but it may have many meanings for people in other disciplines. Physicists discuss gravitational and electromagnetic fields. In abstract algebra, the field has another. In the graphic design of graphical user interfaces and programming, it has yet another. If it is easy in a conversation to start forming a concept in your mind based on your discipline's meaning for a word, but then become confused when the person in the other discipline elaborates and starts making use of their discipline's meaning, which makes no sense to you. So in our dialogs, we tried to be more deliberate about questioning each other, to make sure we are constructing the same meaning. It is quite a process of understanding each other's perspective, *perspective sharing - perspective-taking*, PSPT [2]. The Japanese Enryo-Sasshi concept [21], teases out stages of the process of communicating in which we are trying to either articulate our intended meaning in such a way that the other will arrive at the same meaning, and the interpretation of the messages from the other, to try to construct what we think they meant. Enryo and Sasshi occur in cycles, with pauses or thinking time between utterances.

5. Teamwork Transformation & Lessons for Others

In this paper, we first introduced the Disaster Resilience Analytics Center (DRAC) research project in which faculty members and graduate students from different disciplines collaborate on prediction of natural disasters and improvement of community resilience to such disasters. We considered the prevalence of natural disasters, particularly under the effects of global climate change and the need to improve both prediction and community resilience. We discovered early in the project that the success of this multidisciplinary team and its collaboration would hinge on thinking beyond the topic and to giving some consideration to the processes of transdisciplinary collaboration. As a team, we reflected on the first two years of the project, through a polyvocal, reflective self-study. We considered characteristics and relative success of the collaborative inquiry and the challenges experienced as we worked in a team. These reflections gave rise to an adaptive scaffolding framework, which incorporated a *Relational* domain with Perspective Sharing and Perspective Taking (PSPT), reciprocity in mutual, metacognitive scaffolding, continuous dialog for meaning making, and active listening in which we aimed to practice Enryo-Sasshi (Figs. 3 and 4). This framework carries with it additional tasks and investment of time that may be seen to take away from time that should be spent on the research topic of disaster resilience. On the other hand, we could argue that progress with the research topic was enhanced by our application of the framework. These findings are preliminary and more time will be needed to fully assess the degree of success due to the adoption of a framework for adaptive scaffolding. One could argue that the most successful multidisciplinary project team would be one that comprises members, who are already well-versed in the application of adaptive scaffolding. However, in reality, most teams will need to be both working on the research topic and putting into practice the adaptive scaffolding framework. There is also always scope for improvement in the framework itself in a variety of contexts. Each multidisciplinary context, with its unique characteristics, will require appropriate application of the adaptive scaffolding framework. Ideally, having an understanding of this framework, through formal/informal education and/or professional development, promises a fast track to successful collaborative teamwork.

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