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Convergence, transdisciplinarity, and team science: an interepistemic approach

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ABSTRACT. The challenges facing the Intermountain West are characterized by extreme complexity and enormous consequences. They include climate change and associated ecological effects, such as catastrophic wildfire and drought. They are also inextricably linked to social inequities, including freshwater availability, land conversion, and access to basic human needs such as quality food, affordable energy, and access to healthcare. A meaningful response to these challenges requires new thinking. Convergent research is designed to foster new thinking by creating novel frameworks and conceptual models that drive innovation. Here, we share our approach to convergent research in the Transformation Network (TN), a National Science Foundation supported Sustainable Regional Systems Network. A key element of the TN's design is an interepistemic and even interontological approach that builds across different knowledge systems throughout academia and among Native American and community partners. After first providing an overview of the development of the field of convergence research and its relationship to transdisciplinary research, we provide an outline of the TN's approach, which draws from two schools of transdisciplinarity thought—the metaphysical approach of the Nicolescuian School and the more solution-focused Zürich School. We then explain how we operationalize our approach with systems thinking and systems dynamics modeling, as well as community engagement, diversity, equity, inclusion, and justice efforts, and continual learning with reflexive assessment and training practices. This includes an example where TN faculty and students partner with members of the Navajo Nation to support the independence of Native American communities in the San Juan River Watershed through the implementation of small-scale sustainable off-grid food-energy-water systems.

Key Words: *community engagement; convergence; interepistemic; interontology; transdisciplinary*

INTRODUCTION

Convergent research is designed to foster new thinking by creating novel frameworks and conceptual models that drive innovation (Angeler et al. 2020, Peek et al. 2020). This approach to research is increasingly necessary due to the extremely complex and enormously consequential challenges facing the Intermountain Western United States (Craig 2020). These challenges include climate change and associated acute disturbances, such as catastrophic wildfire, and social inequities, including freshwater availability, land conversion, and access to such basic human needs as quality food, affordable energy, and healthcare (Barnosky et al. 2011, Flint and Diehl 2019). Here, we outline the Transformation Network's (TN) approach to convergent research. The Transformation Network is a network of eight academic institutions and dozens of community partners focused on the challenges facing the Intermountain West arising from climate change and related issues, including food sovereignty, adaptive and participatory governance, and shifting water futures. The TN is one of the National Science Foundation's (NSF) first investments at this scale. Our aim is to advance basic theory and applied knowledge of sustainable urban-rural systems' dynamics, resilience, and trajectories.

To accomplish this work, we engage in convergent research, following an increasing trend by the NSF to emphasize this approach (Gropp 2016). Here, we discuss how convergence

research differs—if at all—from transdisciplinary research and discuss the TN's integration of these concepts into our research design. Broadly speaking, both convergence and transdisciplinary approaches practice “team science,” an umbrella term that includes several different modes of collaboration (Fiore 2008). These concepts are frequently studied by the field of Science of Team Science (SciTS). Table 1 provides a set of definitions from the literature for many of the key concepts used in this manuscript and demonstrates the varied and sometimes contradictory ways in which these and related terms are often used.

We observe that related concepts and themes within team science, while similar, have distinctions worthy of examination. Transdisciplinary research, for example, is not monolithic, and there are two trajectories to this research that each have important contributions to the SciTS field. As will be discussed, the TN's approach incorporates elements from both trajectories of transdisciplinarity—Zürich and Nicolescuian—and includes elements unique to the concept of convergence, including an emphasis on innovation and the development of novel frameworks and paradigms.

A key element of the TN's design is an *interepistemic* and *interontological* approach that builds both conceptual and quantitative models for working across different knowledge systems from academia to Native American and other community partners. By interepistemic, we mean working across and within

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Table 1. Definitions from the literature for concepts related to convergent research.

Term	Definition
Team Science	<p>“Scientific collaboration, i.e., research conducted by more than one individual in an interdependent fashion, including research conducted by small teams and larger groups... Most team science is conducted by 2-10 individuals, and we refer to entities of this size as science teams” (National Research Council 2019: 22).</p> <p>“cross-disciplinary engagement and collaborations around the longer-term interaction of groups of investigators” (Falk-Krzesinski et al. 2010:263).</p>
Science of Team Science (SciTS)	<p>The study of the interpersonal process and leadership styles on scientific collaborations is the science of team science or SciTS (Stokals 2006).</p>
Convergence Research	<p>NSF identifies Convergence Research as having two primary characteristics: (1) Research driven by a specific and compelling problem. Research requiring a convergence paradigm is generally inspired by the need to address a specific challenge or opportunity, whether it arises from deep scientific questions or pressing societal needs. (2) Deep integration across disciplines. As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities and languages become increasingly intermingled or integrated. New frameworks, paradigms or disciplines can form from sustained interactions across multiple communities. The convergence paradigm builds upon transdisciplinary approaches to research by intentionally bringing together intellectually diverse scientists and/or engineers at a project's inception in new collaborations that can generate multiple solutions to complex problems (National Science Foundation 2018).</p> <p>“an approach to knowledge production and action that involves diverse teams working together in novel ways - transcending disciplinary and organizational boundaries - to address vexing social, economic, environmental, and technical challenges in an effort to reduce disaster losses and promote collective well-being” (Peek 2020:1).</p>
Transdisciplinarity	<p>“an integrative process in which researchers work jointly to develop and use a shared conceptual framework that synthesizes and extends discipline-specific theories, concepts, methods, or all three to create new models and language to address a common research problem” (Stokols et al. 2008:79).</p> <p>Transdisciplinarity is a new form of learning and problem-solving involving cooperation among different parts of society. Transdisciplinary research starts from tangible, real-world problems. Solutions are devised in collaboration with multiple stakeholders. A practice-oriented approach, transdisciplinarity, is not confined to a close circle of scientific experts, professional journals and academic departments where knowledge is produced. Ideally, everyone who has something to say about a particular problem and is willing to participate, can play a role. Through mutual learning, the knowledge of multiple participants is enhanced, including local knowledge, scientific knowledge, and the knowledge of industries, businesses, and NGO's. The sum of this knowledge will be greater than the knowledge of any single partner. In the process the bias of each perspective will also be minimized (Häberli et al. 2001:18-19).</p> <p>The methodology in which reality is multifaceted, creating a space for the intellectual fusion, cross-fertilization, and integration of ideas and perspectives leading to the emergence of new knowledge while preserving their difference (McGregor 2015).</p> <p>“the practice of transdisciplinarity consists in application of the theory and methodology of transdisciplinarity to 1) the understanding of the relations between specific disciplines; 2) the solving of specific practical problems and 3) the understanding of the relation of transdisciplinarity to structured human thought, philosophy, logic and epistemology” (Brenner 2015:88).</p> <p>“While there is no universal definition of transdisciplinary research, similarities across definitions emphasize the integration of knowledge and expertise across disciplines with the engagement of societal actors, the end goal being knowledge that leads to societally desirable outcomes” (Gajary et al. 2023).</p>

multiple ways of producing knowledge. By interontological, we mean working across multiple and within multiple ways of perceiving reality. By building paradigmatic frameworks that honor multiple ways of knowing and experiencing a landscape, its challenges, and its futures, the TN brings in scholars and community partners from a larger variety of disciplines and perspectives, benefits from the historic and contemporary knowledges and practices of Indigenous and local communities, and grounds our work in the lived experiences of the communities we serve. This requires careful attention to the role of community partners, incorporation of diversity, equity, inclusion, and justice commitments in both research and educational activities, and the reflexive use of social network analysis and other tools from the SciTS field to learn from our engagements and continually improve upon our efforts. After first discussing convergence research and its history, we relate it to the two schools of transdisciplinary research: the more theoretical and metaphysically based Nicolescuian School and the solution and team-focused Zürich School. We then discuss how all three approaches form core elements of the TN's approach. While there is no “one-size-fits-all” regarding research design among our team, the approach outlined here represents our philosophy as a research network.

CONVERGENT RESEARCH

Early effort and evolution

Early efforts engaging in convergence arose beyond the academic sphere. Disaster responders have historically facilitated the convergence of people, information, and materials to mitigate the effects of wildfires, hurricanes, and other disasters (Fritz and Mathewson 1957). Although primarily focused on the convergence of physical goods and human capital, these early efforts are a noteworthy precursor to modern convergence research. Today, disaster researchers focus on the integration of scientific and technical expertise to collect potentially perishable data for innovative and integrative solutions for societal problems and mitigate the effects of future disasters (Peek et al. 2020). The first examples of academic research engaging specifically in convergence arose in STEM during the early 21st century. Much of this work was carried out by Mihail Roco and William Bainbridge in a series of publications that sought to identify and expand convergence opportunities in biology, nanotechnology, engineering, and other STEM fields (Roco 2002, Montemagno 2004, Roco and Bainbridge 2013, Roco et al. 2013, Bainbridge and Roco 2016).

The NSF launched its “Ten Big Ideas for Future NSF Investment” in 2016, and one of those “big ideas” was growing convergent research (Gropp 2016). This reflected a growing momentum documented by the National Research Council (2014) that focused on the idea that the future of research required a large infusion of resources from grant funders—including NSF—to encourage researchers to engage beyond disciplinary boundaries to develop novel frameworks and paradigms to meet the growing needs of society (Roco 2002, Roco et al. 2013, Urban et al. 2013). NSF (2018) identifies convergence research as having two primary characteristics. First, convergence research is driven by a specific and compelling problem. It is generally inspired by the need to address a specific challenge or opportunity, whether from deep scientific questions or pressing societal needs. Second, the research involves deep integration across disciplines. As experts from different disciplines pursue common research challenges, their knowledge, theories, methods, data, research communities, and languages become increasingly integrated. Often, this includes the formation of novel frameworks to catalyze discovery and innovation. According to Gropp (2016), NSF’s view was that a convergent approach “augments a more traditional transdisciplinary approach to research by framing challenging research questions at inception and fostering the collaborations needed for successful inquiry.” Convergence research can be viewed as the next progression in the continuum of research thought, following multi-, inter-, and transdisciplinary approaches (Wilson et al. 2019, Ernakovich et al. 2021).

To date, much of the convergence literature has focused on cutting-edge fields of scientific innovation, including nanotechnology, biotechnology, information technology, bioengineering, and cognitive sciences. Perhaps for this reason, the National Research Council’s 2014 report notes the need to better integrate a broader range of academic fields:

The social sciences and humanities are under-tapped resources for convergence efforts. An enhanced and expanded partnership among convergence practitioners from multiple fields in the life, physical, and engineering sciences, the economic, social, and behavioral science and humanities research communities, and institutional leaders could be invaluable. The role of the economic, social, and behavioral sciences and humanities in convergence is multifaceted. Areas of convergent research, such as cognitive neuroscience, already benefit from the integration of behavioral, biological, and medical sciences. Moreover, many of the obstacles to effective convergence involve interpersonal interactions, and the translation of advances enabled by convergence into societal benefits involves economic, social, and behavioral dimensions.

More recently, Peek et al. echoed this need for better integration of social sciences and humanities in advancing what they term “the convergence revolution.” They argue: “This will not only broaden the horizons of scientific inquiry and discovery; it could also help to mitigate the unintended consequences of issuing technical fixes for what are fundamentally human problems” (Peek et al. 2020:4).

The potential for novelty and innovation is a key characteristic of convergent research. Research teams practicing convergence develop ongoing, productive relationships and collaborations that open new research vistas that could not be achieved by

adhering to traditional disciplinary boundaries and conventional approaches. This lends itself to the development of new conceptual frameworks, paradigms, scientific languages, and even new disciplines (National Science Foundation 2018). This is of particular value to large, interdisciplinary teams that need to grapple with the need to create ways to understand research questions across a broad range of backgrounds, epistemic frameworks, and trainings. “Over time, team members absorb knowledge from one another and think with a different mindset, rather than just coming from the perspective of their own training and conditioning” (Wilson et al. 2019).

From the beginning, the convergence paradigm has intentionally brought together intellectually diverse researchers to develop effective ways of communicating across disciplines. Researchers adopt common frameworks and boundary objects, which may, in turn, involve taking on challenges in ways that develop new research and promote innovation. This was viewed as a necessary evolution in research due to the necessity of tackling complex challenges and achieving new and innovation solutions (National Research Council 2014).

With its emphasis on compelling societal problems, convergent research has a particular capacity to co-design and co-produce research questions and methodologies with community partners (NSF 2018). This involves addressing power imbalances, reframing agency, navigating differences, and empowering often marginalized voices as practices and norms are established (Chambers et al. 2021). Investments by the NSF in large-scale initiatives and programs include its Navigating the New Arctic program, the Convergence Accelerator, the Sustainable Regional Systems program, and others (Wilson et al. 2019, Ernakovich et al. 2021, Baru et al. 2022).

Relationship to transdisciplinarity

How convergence differs from other approaches—including transdisciplinary—has rarely been articulated. To date, few have even attempted to examine the differences between convergence and transdisciplinarity (National Research Council 2014, Peek et al. 2020). One reason for this is that there is no universally accepted definition of transdisciplinary. Gajary and colleagues (2023) assert that there is agreement that to understand convergence, one must also understand transdisciplinarity. The terms convergence and transdisciplinary research are often employed interchangeably or in tandem (Division on Earth and Life Studies and National Academies of Sciences, Engineering, and Medicine 2019). In describing convergent research, NSF vaguely notes that convergent research “builds upon” transdisciplinary research (NSF 2018).

Transdisciplinary research, however, is not monolithic. While definitions continue to evolve, it is generally agreed that there are two streams of transdisciplinary: the Zürich School and the Nicolescuian School. These schools provide two different conceptualizations of what it means to engage in transdisciplinary research.

The Zürich School is named after an International Transdisciplinary Conference held in Zürich in 2000 and conceptualizes transdisciplinary as a new type of “post normal” research. It reflects a normative turn within academia to respond to “real-world” problems (Jahn et al. 2012). The Zürich School’s

Table 2. Comparing key characteristics of team science across convergence and schools of transdisciplinarity.

Characteristics	Convergence	Nicolescuian School of Transdisciplinarity	Zürich School or Mode 2 of Transdisciplinarity
Collaborative engagement across academic disciplines	Yes; involves deep integration of disciplines (NSF 2018)	Yes, though emphasis not on integration of knowledge but on <i>integration</i> finding the meaning that lies <i>between, across, and beyond</i> disciplines (i.e., the meaning of trans)(Bernstein 2015) with an emphasis on epistemology and ontology	Yes, strong emphasis in creating diverse teams that can take on research questions effectively (Bernstein 2015)
Novelty, i.e., development of new paradigms, conceptual frameworks	Frequently; can result in formation of new research questions, approaches, trajectories (NSF 2018)	Yes, by engaging in this method unique understandings of the world are realized (McGregor 2015)	Not emphasized
Responds to societal problem	Not necessarily: NSF definition describes “deep scientific questions or pressing societal needs” as part of its definition (NSF 2018)	Sort of. Its goal is the understanding of the present world through unity of knowledge (Nicolescu 2002, McGregor 2015). The focus is more on the methodology (McGregor 2015)	Yes, responding to “real-world” problems (Jahn et al. 2012)
Involves nonacademic partners	Sometimes; when responding to a “societal problem” relevant community engagement and other actors are necessary	Not required; this methodology is not concerned with the status of the subject/object (academic v. nonacademic)	Yes, going beyond academia to involve other partners particularly from government and industry initially (Bernstein 2015) but now well beyond (Jahn et al. 2012)

approach is also referred to as “Mode 2” meaning it engages in a new mode of knowledge production (with traditional, siloed scientific inquiry qualifying as “Mode 1”; Gibbons et al. 1994, Ravetz and Funtowicz 1999, Jahn et al. 2012).

This approach to transdisciplinary research is societally responsive and solution-focused, with a strong emphasis on involving nonacademic partners to co-generate both research questions and methodologies (Jahn et al. 2012). Jahn and colleagues (2012) emphasize that this approach is a research method, not a theory, and that it involves mutual learning with nonacademic partners. As seen from the definitions provided in Table 2, it bears a close resemblance to convergence research in many respects, with its emphasis on societal response and integration across disciplines. It is less concerned, however, with novelty and creating new paradigms and conceptual models. The Zürich School is driven by practical concerns associated with how a new social contract between science and society might be constructed (Etzkowitz and Leydesdorff 2000, Nowotny et al. 2001). Much of sustainability science has embraced a Mode 2/ Zürich approach to transdisciplinarity (Lang et al. 2012, Jahn et al. 2022).

The Nicolescuian School is more theoretically based, grounded in complexity science, chaos theory, and quantum physics (Nicolescu 2002, Brenner 2015, McGregor 2015). It views transdisciplinarity as a new methodology wherein researchers acknowledge their own subjectivity and make efforts to engage reality differently by rethinking the traditional absolute separation between subject and the object (Bernstein 2015, McGregor 2015). “His concept of transdisciplinarity focuses on complexity as a fundamental feature of reality, on the premise of different levels and dimensions of reality, and on what he calls the logic of the *included middle*, in defiance of the Aristotelian axiom of the *excluded middle*, suggesting that Nicolescu, in the spirit of quantum mechanics, wants scientists to ‘rethink’ the traditional absolute separation of the subject and the object” (Bernstein 2015:5). The emphasis is on the creation of new knowledge that is emergent, embodied, and cross-fertilized from many perspectives/epistemologies/ontologies (McGregor 2015).

Steelman et al. (2019), engaged in a Nicolescuian research design in the engagement of First Nations peoples from three inland delta regions in Canada and as a team of interdisciplinary scholars and students who worked together to better understand long-term social-ecological change in those regions. They describe a “transformative transdisciplinary space” that can be created for respectful interaction for diverse parties to identify problems and work on solutions, theoretically bridging the duality of a scientifically objective worldview and a subjectively experienced worldview (Steelman et al. 2019:775).

As shown in Table 1, an assessment of the key characteristics comparing convergence research with the two schools of transdisciplinary thought reveals some key differences and commonalities between convergence and the two schools of transdisciplinarity. All three involve collaboration across disciplines, though the Nicolescuian School is less concerned with expertise per se than moving to and understanding what lies beyond expertise (Bernstein 2015). One key characteristic of convergence is its focus on novelty and the potential to support the development of new conceptual frameworks that drive innovation and shift paradigms. There is a strong recognition that existing knowledge systems are not adequate for the task and that by deeply integrating across disciplines and going beyond traditional disciplinary frameworks, there is potential to reach new ideas. This bears some similarity to, but is not quite the same as, the Nicolescuian approach, which sees the potential for the arrival of a new understanding of the world. Similarly, both the NSF and the Zürich School place a strong emphasis on responding to the needs of society. Yet, the more practically based Zürich School is less concerned with the arrival of “new knowledge” or innovation and is more concerned with solving the problems at hand. The Zürich School prioritizes involving partners from outside academia, a practice also emphasized in the literature on convergence (Etzkowitz and Leydesdorff 2000).

Transdisciplinarity is a component of convergent research, yet as Table 2 illustrates, convergence requires a deep integration across disciplines. As will now be illustrated in the TN’s approach, our

team needs a research design that is *interepistemic* and *interontological*, building across different knowledge systems across academia and with Native American and other community partners.

The Transformation Network's approach

The TN's approach includes elements of both schools of transdisciplinarity and is fundamentally grounded in NSF's two-pronged convergence research elements: deeply integrating across disciplines and responding to the needs of society. Central to its design is an emphasis on creating new and novel frameworks that, we argue, are unique to the convergence approach. The TN draws from all three, including the NSF's leadership in novelty and innovation as characteristic of convergent teams and their outputs, and the Zürich School's emphasis is on the need to go beyond "the academy" and focus on real-world solutions with community partners. The TN also pulls strongly from the more metaphysical elements of the Nicolescuian School, recognizing that to accomplish our work effectively, wholly new understandings of our world must be reached that could not be achieved by any one discipline, method, or perspective alone.

The TN recognizes that community partners often have local and Indigenous knowledges that have the capacity to form new and novel approaches and trajectories. For this reason, while NSF's definition of convergence does not always require a response to a societal need, we argue that when researchers are responding to the needs of society, the integration of community partners into its design is necessary for convergence.

This engagement is *interepistemic* and, when appropriate, *interontological* and exists inside and outside the academy. One significant node of epistemic difference we have observed within the TN, especially those of us within the academy, is between positivist and constructivist approaches to research. A positivist science seeks to understand the world as it already exists within a series of natural phenomena that can be studied via the scientific method. A positivist epistemology "attempts to construct empirically verifiable, universal and ahistorical knowledge in the form of general laws" (Goff 1980, as cited in Madhi 2019:25). Seeing the world as a knowable and finite object, positivist science pursues objectivity in scientific research, seeking to remove all influence by the researcher to generate knowledge that is universal. This approach presumes a unity within science, or coherence across the scientific disciplines, suggesting that interdisciplinary work can proceed without significant difficulty (Boon and Van Baalen 2019).

A constructivist approach, by contrast, frames the world (including its social, ecological, and technological components) as constructed through our own engagement with it and thus seeks to understand this interaction (Berger and Luckmann 1966). Within this framework, knowledge must itself be constructed - it is not a literal representation of a world "out there" - which means, of course, that our disciplinary and personal life experiences will shape how we construct our knowledge about the world (Boon and Van Baalen 2019). Constructivist research sees all knowledge as situated (i.e., in our own bodies, biographies, and social locations or in particular histories, geographies, or structures) and, therefore, also partial (Haraway 1988). This approach re-emerged within feminist research and was honed by Black and Indigenous scholars who challenged universalizing scientific

perspectives as part of epistemic politics where "the personal is political," and situated knowledge is emancipatory (Harding 1991, Collins 2008). This approach is not an anti-empirical or purely qualitative framework; nonetheless, constructivist research sees a more limited role for generalizable science in approaching social-ecological problems. It also does not assume unity across scientific disciplines; rather, it proposes that interdisciplinary work requires deep learning and reflexive metacognition to build shared vocabulary and construct knowledge across disciplinary paradigms (Boon and Van Baalen 2019).

At this point, the challenge of integrating these approaches is clear, including why constructivist approaches cluster in the social sciences and humanities disciplines that are less integrated into convergence efforts (Overland and Sovacool 2020). With an emphasis on critical examination of the histories, hierarchies, and structures that lead to ecologically untenable or socially unjust outcomes, many social scientists and humanities scholars find it difficult to adjust to the research agendas, templates, and timelines of interdisciplinary teams shaped by the often ahistorical and depoliticizing assumptions of more positivist approaches to research (Lövbrand et al. 2015).

The first step in pursuing a convergence science across such differences is to recognize that such differences exist and to build shared vocabularies for naming the cognitive difficulties that emerge because of them (Boon and Van Baalen 2019). This requires both an embrace of methodological pluralism (Midgley and Rajagopalan 2021) and a self-conscious pursuit of metacognitive scaffolding, the development of communication and integration skills that allow us to pursue deep *interepistemic* learning without epistemic hegemony (Boon and Van Baalen 2019). The key lies within the ability of researchers from both frameworks to see the value in each other's contribution to the larger projects at hand.

The TN consciously values both positivist and constructivist approaches. We also recognize that underlying these differences are not only different approaches to knowledge production, but also different worldviews (Creswell and Creswell 2023). Honoring differing worldviews addresses the challenge of *interontology*, which also comes to the forefront when we examine working with community partners.

Outside of the academy, community partners integrate local knowledges and Indigenous knowledges to convergent research projects. This knowledge is not only diverse, reflecting a variety of backgrounds and experiences of a variety of types of actors across the Intermountain West, but it can be, in the case of our Native American or Hispano partners, grounded in a different ontology. This is, in part, why the Nicolescuian approach is key to the TN's design. It embraces the *interontological*, what Escobar (2018) refers to as the *pluriverse*, a multiplicity in which different forms of knowing exist. As this work unfolds and we co-create knowledge with these partners, our process includes building capacity for collaboration, innovation, and synergy across these differences to develop multi-valent efforts that generate effective approaches.

Every research endeavor has its own context. Particularly as we co-create knowledge with the community partners across the Intermountain West, there is no "one-size-fits-all" approach. We

endeavor here to put forward our intention and philosophy for engaging in convergent research in the TN, but each team taking on research within a watershed or community context will have its own unique experiences reflecting the need for co-creation, respect, and diversity of participants in any given project.

While we use the term “community partners,” traditional binaries that define researchers and researcher participants as either “inside” or “outside” of the academy are problematic. Many members of our research team hold multiple positionalities, including as community members or “boundary spanners” and disciplinary “experts” (Hatch et al. 2023). Many community members also have diverse and complex positions within their communities, holding both formal and informal roles and bringing different types of knowledges. Our approach ultimately challenges this binary in embracing multiplicity while also honoring the varied roles many of us play. Methods for engaging these partners are participatory, grounded in environmental justice and draw from a long-standing history of work with Native American communities (Wilson 2008). For the researchers who also identify as Indigenous, their efforts are not simply “research.” It is personal (Wilson 2008).

CORE STRATEGIES FOR CONVERGENCE

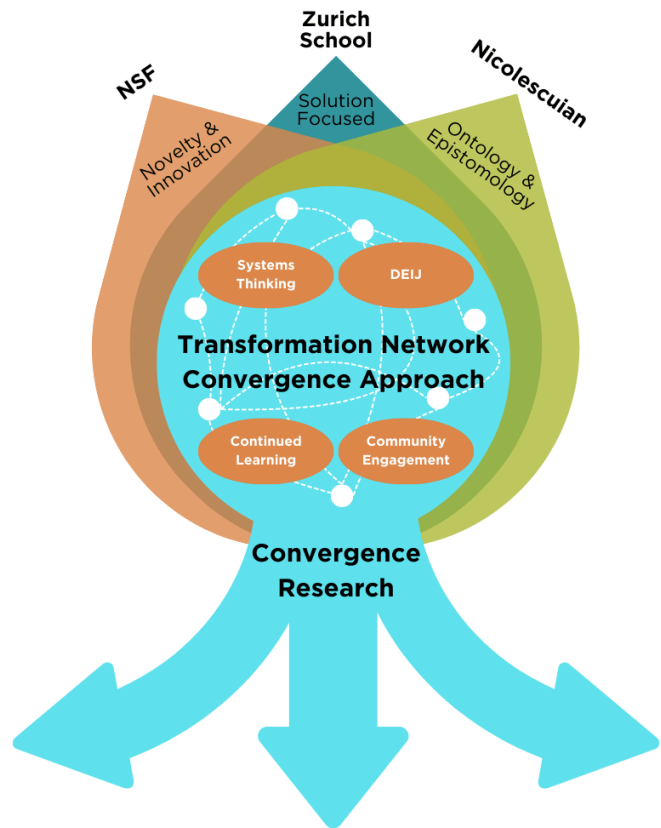
Turning to the tools and approaches used in the TN to accomplish its goals, it is important to acknowledge how much easier it is to talk about convergent research than it is to actually do it. Disciplines exist for a reason. Upon graduating with a degree from a specific discipline, there is a common language and a cognitive map shared with a specific group of people about how to approach questions about the world. Going beyond traditional disciplinary research requires a number of additional skills and approaches. These include ways to create shared understanding via the identification of a shared language, boundary object, or conceptual model, a willingness to value other ways of knowing and being, and a commitment to continued learning (Hubbs et al. 2021).

Below are four core strategies identified by the TN to implement its vision for convergent research: systems thinking, community engagement, DEIJ practices, and evaluative practices. In actual implementation, these strategies intersect and overlap. Systems thinking work, for example, engages community partners. Also, our work takes place within our commitment to DEIJ and is subject to our self-reflexive evaluative process. Nevertheless, the four core strategies have their own literature and traditions of practice and are therefore useful to consider distinctly before considering how the TN draws on all four to do convergent research. They are represented in Figure 1 as a part of the TN’s approach to convergence research and are now discussed in detail below.

Systems thinking

Systems thinking is one pathway explored in the TN to embrace an interepistemic approach. It has been described as “the art and science of making reliable inferences about behavior by developing an increasingly deep understanding of underlying structure” (Richmond 1994:139) and includes a wide range of modeling approaches that range from conceptual and qualitative to computational and quantitative. Qualitative and quantitative approaches are often used iteratively together as part of the whole process of investigating a system.

Fig. 1. A conceptual diagram of the Transformation Networks’ convergence approach. Key themes pulled from the different schools of thought (NSF, Zürich, and Nicolescuian) are combined with four core strategies of systems thinking, Diversity Equity Inclusion and Justice (DEIJ), continued learning, and community engagement. The small white circles represent projects within the Transformation Network, which engage with all four strategies through the course of their research (this interaction is depicted by the white dashed lines).



Within this definition, a “system” is defined as a set of interconnected things that produce patterns of behavior over time (Meadows 2008), and “models” are defined as any stylized representations of a system (Frigg and Hartmann 2006). Some qualitative, conceptual systems thinking approaches include mind maps, process inquiry maps, causal loop diagrams, and stock and flow diagrams. The latter approach is considered by some to be at the heart of System Dynamics Modeling (SDM), which describes a set of systems thinking approaches that emphasize interacting inflows and outflows to describe system behaviors (Richmond 1994). With this and other approaches, quantitative models can be developed after qualitative models have been created, with some common options for software, including STELLA and Vensim (Ford 1999). Other “semi-quantitative” approaches, such as Cross-impact Matrix Multiplication Analysis (MICMAC), explore relationships between system elements by surveying knowledgeable researchers and/or community members (Duperrin and Godet 1973). Notably, systems thinking has already been widely proposed and used for transdisciplinary

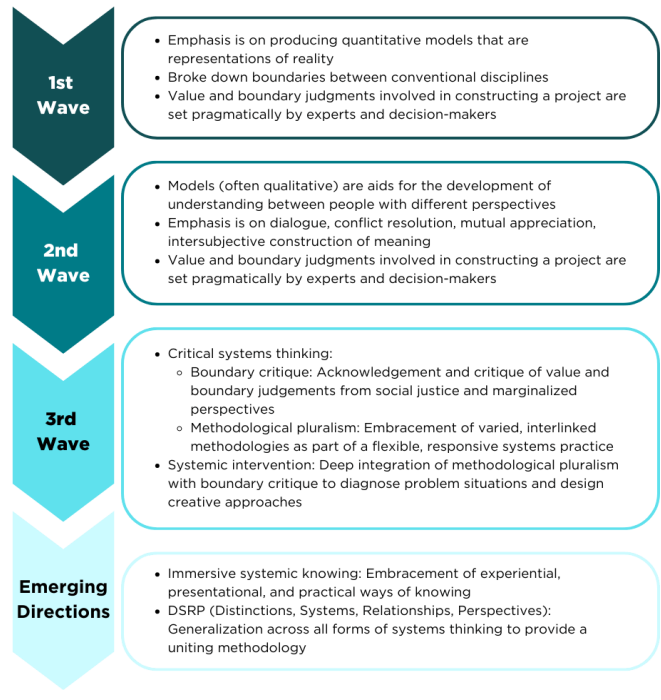
and community-engaged modeling, especially when working with stakeholders and other community partners (Tidwell et al. 2004, Gunda et al. 2018, Dhirasasna and Sahin 2019).

A systems thinking approach holds promise for interepistemic engagement given that the suite of tools within systems thinking is quite broad and versatile and has been used to map difficult and even inconsistent system conceptions through approaches such as Fuzzy Cognitive Mapping (Van Vliet et al. 2010, Jetter and Kok 2014). This methodological pluralism has been explored and formalized into several “system of systems methodologies” frameworks, which provide both rigid and dynamic approaches for applying and adapting the diversity of system thinking methodologies to different situations (Midgley and Rajagopalan 2021). Emerging approaches in systems thinking broaden methodological pluralism to include what can be considered theoretical and ontological pluralism (Fig. 2). Ontological pluralism embraces multiple ways of knowing, including experiential, presentational, and practical ways of knowing (Heron and Reason 1997, Midgley and Rajagopalan 2021). Theoretical pluralism is closely connected to the practice in systems thinking known as boundary critique, which calls for iteratively examining the assumptions and value judgments involved in constructing and defining the boundaries of models (Midgley and Rajagopalan 2021).

One key strength of systems thinking is providing a visual vocabulary that requires the explicit definition of relationships and interconnections between system elements, presenting an opportunity for potentially facilitating interepistemic and interdisciplinary conversations that may otherwise go unsaid. System modeling has the potential to make visible the differences between positivist and constructivist formulations of a system. Conceptual systems thinking approaches can work to define model structure in a deeply collaborative means and represent inter- and transdisciplinary understandings of a particular system. However, quantitative systems modeling for convergence in practice (e.g., parameterization needed for quantitative modeling and hypothesis testing) depends on the state of knowledge and its readiness for synthesizing.

There are, of course, challenges within systems thinking, as with any approach. First, the incredible diversity of methods and views in systems thinking makes it difficult to describe it to newcomers and familiarize even seasoned systems thinkers with all the approaches. In this context, it is easy for people to make assumptions about their ability to engage in systems thinking as it relates to their work or to assume that one form of systems thinking they may be familiar with represents all systems thinking. To combat these assumptions, we find it instructive to provide a brief history of systems thinking evolution (Fig. 2, see Midgley and Rajagopalan 2021), which provides context for the variety of approaches used and how they have been built on over time, ultimately providing a spectrum of methodologies, from more positivist to constructivist, that can be employed in a methodologically, theoretically, and ontologically plural approach. Understanding where an individual is in their understanding of systems thinking can help teams relate to each other and provide pathways toward diversifying and unifying their approach.

Fig. 2. A history of systems thinking theory and practice as three paradigmatic waves and emerging directions, summarized from Midgley and Rajagopalan (2021).



Across most popular implementations of systems thinking, the heavy use of visual diagrams to represent the systems in question is inevitably reductive. The use of “stocks” and “flows” to represent systems dynamics can be too simplistic to capture the complexities of a system. However, it is important to remember that the goal of SDM is rarely to capture the whole system in total detail. As Walker and Salt (2012:53) emphasize, the requisite simplicity must be kept in mind, i.e., “as simple as possible, but not too simple.”

This work can also be time-consuming. To be effective, it is important for everyone to have a common understanding of certain ideas and identify unproductive assumptions. One person’s common terminology is another person’s jargon, and conflicts over terms can be a common source of conflict. Such conflicts often reveal differences in underlying assumptions about how rigorous research is conducted which are deeply embedded, sometimes unconsciously, in scientists’ epistemologies, ontologies and methodologies (Cravens et al 2022:6). Finally, SDM needs to be tested. In the TN, efforts to implement systems thinking include work in Eastern Washington with farmers and producers exploring and adopting regenerative agriculture to reverse the degradation of soil ecosystem health to improve conventional agriculture’s negative impacts on the food system. Additionally, the use of multiscale systems thinking in the Santa Fe Watershed fosters an understanding of water resource management strategies and provides resource managers with adaptive approaches.

Community engagement

NSF's definition of convergent research does not always require responding to a societal need. As noted above, at times, it is focused exclusively on a deep scientific question. However, when there is a pressing societal need, we argue that meaningful involvement with community partners is a critical, ethical component of any successful research design. In many cases, the academic research team—even when it includes members of diverse disciplines who are also members of the impacted community—is either not in a position to act as change agents or does not have a complete understanding of the factors that will ultimately determine whether the research results will contribute to the needed change, or both (Mease et al. 2018). Researchers carrying out this kind of convergence research, therefore, need to engage community partners effectively and equitably throughout the research process.

Community engagement has been defined in different ways, both within and outside academia. These definitions range from the very straightforward, “the process of meaningfully involving communities affected by a research finding in the research process” (Brett et al. 2014, Han et al. 2021) to a more holistic definition that may be better suited to inform researchers interested in convergent research with community partners:

Engagement is a process of establishing effective and productive relationships to enable a shared understanding of goals or a shared commitment to change. Engagement processes are those that inform communities, consult with communities, and get communities actively involved. Effective engagement needs to consider diverse dimensions: engaged individuals understand the issue, have supportive attitudes toward the issue, and are actively involved (Dean et al. 2016).

A strategic framework for community engagement has been created by the U.S. Centers for Oceans and Human Health (COHH), which outlines four dimensions of community engagement focused on *who* the partners are, *why* they would participate, in *what* activity, and *how* they would engage (Carson et al. 2022).

The TN developed a resource guide for community engagement, employed existing resources, and curated key publications, case studies, and toolkits on community engagement to assist researchers in the TN interested in engaging with communities in convergence research. It highlights (1) the interconnected nature of these dimensions and how they inform decisions on the most appropriate approach to community engagement (including, when appropriate, cultural competency training), (2) the importance of early conversations between researchers and potential community partners to explore (and ensure) alignment between their respective goals and expectations for the research and the engagement process, and (3) the dynamic characteristic of community engagement, that requires continuous reevaluation of these dimensions and alignment between researchers and community partners.

Through achieving a shared project clarity (i.e., the WHAT, the WHO, and the WHY; Fig. 3), the convergence team—which includes researchers from multiple disciplines and community partners—can determine the approach to participation that best suits their particular circumstances. Given the diversity in communities, research projects and disciplines, and goals and

Fig. 3. A modified representation of Carson et al.'s (2022) strategic framework, highlighting the interconnected nature of the four dimensions: What, Who, Why, How, their relation to the community engagement continuum, and the iterative nature of the process to align these four dimensions among research and community partners. Modified from Carson et al. (2022).



expectations, no type of engagement will suit all projects. Multiple resources exist describing different levels of engagement and what each is best suited to achieve (National Institute of Health 2011, Environmental Protection Agency 2014, Key et al. 2019, Carson et al. 2022).

An example of convergent research, interepistemic engagement, and decolonized research methodologies (Wilson 2008, Smith 2012) is taking place on the Navajo Nation under the leadership of Dr. Karletta Chief to build small-scale, off-grid food energy water (FEW) systems using a Diné systems approach (Indigenous Innovations Food, Energy, Water Systems 2020) and Sà'áh Naagháí Bik'eh Hózhóó (SBNH) model (Chief et al. 2016, Teufel-Shone et al. 2021). The Diné worldview is a systems model where all living things and elements are connected and approached holistically. The SBNH model is this Diné worldview and is applied for wellbeing, environment, problem solving, harvesting cycle and more. Based on previous projects like the Gold King Mine Diné Exposure Project, the University of Arizona team set their co-design model within the SBNH model as recommended and requested by Diné partners and practitioners. Approximately fourteen percent of U.S. Native American households lack access to electricity (Guevara-Stone 2014). On the Navajo Nation, approximately 30% of dwellings are not connected to central power or potable water (Glennon 2023). The Navajo, whose Indigenous name is Diné, are the largest tribe in the U.S., have the largest reservation, and are located in the Southwestern

United States. Lack of connection to central power and water is due to low population density, available sustainable and effective technologies, and economic practicalities. Food apartheid is a major issue on the Navajo Nation as there are a small number of grocery stores serving Diné residents and access to fresh produce is limited and expensive. Working with communities to co-identify technical solutions to these challenges requires an understanding of Indigenous societies, governance, and culture and the ability to work effectively in these contexts (Anaya 2004).

The vision for this research is to increase Indigenous community resilience and food energy and water security (FEW) and sovereignty through grid-independent FEW systems that are designed, built, and operated by Diné citizens. The central goal of this project is to facilitate Indigenous FEW security through the development and implementation of water treatment systems and controlled environment agriculture greenhouse units integrated with resilient photovoltaic (PV) systems.

Since 2017, this team has been piloting demonstration off-grid water units in several communities in partnership with Sixth World Solutions and Diné College. They are testing the water quality of non-potable source waters that remote Diné use for drinking, including springs and livestock wells. During the COVID-19 pandemic, FEWS insecurity was amplified and the Navajo Nation Council reached out to the University of Arizona to downscale the larger solar powered water treatment systems to the household scale.

The work includes conducting surveys and focus groups with community members to learn about food, energy, and water needs; agricultural, water, and energy practices; and perceptions toward FEW systems from community partners. This project is approved by the Navajo Nation Research Review Board Protocol Number #NNR-21.398 and the University of Arizona Institutional Review Board. This survey includes identifying possible solutions that are perceived by community members.

This work reflects the TN's commitment to both community engagement and its interontological approach. All installations are co-designed and co-installed greenhouse and water treatment/filtration systems. The community is central to reaching solutions which is why co-design is central to the project. The project develops training components and curricula with Diné partners under a "train-the-trainer" model that aims to support Indigenous students and STEM learning and success. Reciprocity is a central value, i.e., how the project can give back to the Navajo community. One way is through training and education that will contribute toward capacity building. This project has the advantage of longer-term relationships with community partners and leverages other NSF funded efforts, including both the Native FEWS Alliance, an NSF INCLUDES program, and an NSF Research Traineeship Indigenous Food, Energy, Water Security and Sovereignty from 2017-2023 at the University of Arizona with the aim to develop the next generation of scientists and engineers to work with and within Indigenous communities to address FEW challenges. These training programs, and the underlying research the supports the water filtration and greenhouse systems, is highly interdisciplinary and reflects expertise in both civil, chemical, environmental, biosystems, electrical and computer engineering, anthropology, and environmental science among others.

The investment of time and energy is a key factor that has allowed partnerships to form—both between researchers and with community partners. By building across several funded projects, Dr. Chief and her core team have been able work with the same community partners over time and invest in these relationships. Many Native American and other place-based communities are understandably reluctant to work with researchers who have short time horizons that are tied to a few years of funding. Funding cycles of five years or less seldom provide sufficient time for this type of community-based research.

Diversity, equity, inclusion, and justice

Diversity, equity, inclusion, and justice play an undeniable role in convergence. Convergence is an integrative approach that thrives on the harmonious fusion of knowledge from diverse fields. As such, it greatly benefits from a multitude of perspectives. It is essential to create an environment where every voice, especially those from marginalized communities, can be heard and valued (Keiffer-Lewis 2022). Cultural humility, which cultivates a deep respect and understanding of the worth of various cultures and knowledge systems, is a powerful tool in our quest to address systemic inequities, ignite social justice, and foster a sustainable and inclusive convergence. In line with these goals, Diversity, Equity, Inclusion, and Justice (DEIJ) initiatives are core to the TN's convergence research approach.

The TN's project management plan frames its DEIJ efforts to intersect with climate justice, racial justice, and education justice, playing a disruptor role in STEM education by replacing normativity-centric education with inclusive, equitable, and just education (Cranston and Jean-Paul 2022). Since every institution in the TN has its own DEIJ training programs, part of the TN's work is to identify and compile the existing resources and conduct a gap analysis. We then develop programs that uniquely address the needs of the team. Here, we highlight a few examples of work accomplished during year two, of the project led by DEIJ coordinator Dr. Asa Stone (Fig. 4). Each year, activities are reflected upon during our evaluation process, and new trainings, series, and workshops are designed for the coming year.

Fig. 4. The Transformation Network's approach to integrating its Diversity Equity and Inclusion commitment into its research approach.



The Cultural Humility Workshop Series was one of these key initiatives of year two, symbolizing the TN's commitment to intertwining ethical considerations within the realm of convergence. This series provides a platform for TN researchers and educators to reflect upon and confront their implicit biases, thereby attempting to avoid skewing the trajectory and effectiveness of convergence research and education (Corsino and Fuller 2021, Kam et al. 2024). The Cultural Humility Workshop Series was pivotal in allowing many participants to explicitly identify and counter their biases toward underrepresented communities, thereby paving the way for increasingly inclusive research practices (Williams et al. 2023). The series was designed to practice the first principle of cultural humility: engaging in reflective and life-long learning.

Both students and faculty found the Cultural Humility Workshop Series a powerful experience. When asked to “describe cultural humility using your own words and/or experiences” after participating in the series, responses included:

Cultural humility is a life-long commitment to engage in reflective learning toward fostering respectful relationships based on trust. It involves constant and consistent evaluation of our biases and positionality, and learning about each individual as their own unique person through open and direct communications.

and

Cultural humility means being proud of my ancestors, where I came from, and how I was raised. It also allows me to have the same respect for others and not make them feel uncomfortable for doing what they believe in. Becoming aware of other peoples' cultures and traditions strengthens my understanding and cultural humility.

In addition, the TN supported a Facilitator Apprenticeship Program that made significant strides in addressing power imbalances. This program invested in Indigenous graduate students, supporting them in taking leadership in internal convergence meetings. The goal was to ensure the participation of Indigenous and other underrepresented perspectives and voices instrumental in shaping convergence research. This series was designed to practice the second principle of cultural humility, which focuses on the TN's desire to address power imbalances.

Similarly, the TN's Innovators in the Landscape and Native Voices in STEM series disrupted prevailing assumptions within the convergence community by actively partnering with Indigenous and other place-based practitioners. This collaboration not only honors the profound wisdom within Indigenous communities but also spurs the exploration of unique approaches that can enrich convergence. One critical element throughout the series was to reflect on how to ground TN's convergent approach in cultural practice and multiple ways of knowing as expressed in its mission. This series was designed to practice the third principle of cultural humility, which is to model institutional accountability.

This work underscores the importance of honoring diverse ways of knowing by recognizing the vast pool of knowledge and expertise that lie beyond conventional boundaries. This acknowledgment broadens the scope of convergence research and

education, inspiring more holistic and inclusive solutions. Initiatives such as the Cultural Humility Workshop Series, Innovators in the Landscape Series, and the Facilitator Apprenticeship Program exemplify this commitment.

Continued learning and self-evaluation

Finally, the TN is committed to continually informing its processes and training its students in convergent research design. The network has a robust evaluation plan tied to its annual reporting process that includes evaluating key project outcomes, including convergence research, DEIJ, and community engagement. It employs social network analysis and other tools from SciTS to assess efficacy in meeting project milestones toward goals, such as the extent of integration across the network and the success of educational activities, etc. (Stokols et al. 2008, Read et al. 2016). Figure 5 provides an example of a network analysis used at our 2023 annual meeting to assess the status of TN integration across individual team members, community partners, and project charters. The TN was plotted using Gephi (Bastian et al. 2009). TN connection data was clustered using the ForceAtlas2 algorithm (Jacomy et al. 2014) to identify the naturally forming clusters in the group's social network.

Training a workforce capable of working in the arena of convergent science is one of the core goals of the TN. Each year, we host a convergent workshop for graduate students to advance participants' understanding of convergence principles and practices. At the conclusion of the workshop, the goal is for graduate students to be able to describe convergence principles and their significance, apply convergence principles to a scenario-based key topic emphasized, and evaluate the effectiveness of convergence principles as solutions to the applied scenario relevant to their research. As team members, these students enrich the TN's engagement in convergent research and help define and refine its application through mutual and continual learning.

CONCLUSION

Convergent research is the future of research. As NSF and other major funders push thought leaders to be more inclusive, innovative, and responsive in taking up the challenges facing society, researchers will be motivated to take up the challenge of convergence and find ways to engage effectively in this emerging form of team science. The TN's vision for convergent research embraces convergent research and explicitly incorporates both Zürich and Nicolescuian transdisciplinary approaches into our design. A key element of this design is using new tools from system thinking to embrace *interepistemic* strategies for working across different knowledge systems across academia and with Native American and other community partners. Our approach to community engagement is one example of efforts underway in the TN to build collaboration and co-production capacity across diverse research teams and their community partners. For convergence research to be successful in the context of a pressing societal need, meaningful involvement with community partners is a critical component of any successful research design. This takes time and effort, and traditional grant funding cycles are not always conducive to building these types of partnerships. Communities, particularly, Native American partners, are understandably reluctant to invest their resources in projects with limited time horizons. Moving forward, NSF and other funders will need to grapple with the reality that, to support convergent

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Data Availability:

The data and code that support this manuscript are openly available in the Transformation Network Atlas: <https://tntatlas.erasm.com/>

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