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Research, part of a Special Feature on Convergent Science for Sustainable Regional Systems

Whither convergence? Co-designing convergent research and wrestling with its emergent tensions

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ABSTRACT. Convergence has emerged as an important paradigm for conducting research that tackles grand societal challenges. It demands deep integration of multiple disciplines for a holistic understanding of the complexity of these challenges. In the last decade, most convergent research efforts have focused on the integration of science, technology, engineering, and mathematics (STEM). However, addressing societal challenges necessitates greater integration of the social sciences in order to bring in critical and reflexive thinking. Design, as a discipline, integrates social science foundations with the creative arts and a strong future orientation, to understand human behaviors and interactions across socio-technical systems. Although design has gained attention at the U.S. National Science Foundation (NSF) as a means of identifying use-inspired research and facilitating cross-disciplinary collaboration, it has not been more widely recognized as a valuable discipline contributing to convergent research. This paper examines design's role in activating convergence within Multiscale Resilient, Equitable, and Circular Innovations with Partnership and Education Synergies for Sustainable Food Systems (RECIPES), an NSF-funded Sustainable Regional Systems Research Network. RECIPES aims to develop scientific breakthroughs in characterizing the complex challenges surrounding food loss and waste in the U.S., as well as to develop innovative, circular, and socially equitable solutions for reducing and managing wasted food. The network uses design to help infrastructure convergence. Prioritizing authentic whole person engagement among network participants, fostering critical reflection through convergence and divergence cycles, and making space for open-ended inquiries around emergent tensions are vitally important. This article is a reflection on this role, with insights and recommendations for more effectively leveraging design in convergence.

Key Words: *complex adaptive systems; food loss and waste; human centered design; sustainability; transdisciplinary research*

INTRODUCTION

Convergent research has emerged as an important paradigm for conducting research to tackle grand societal challenges (NSF 2019). It requires a holistic understanding of the full complexity of these challenges, which can only be obtained by seeing them through multiple lenses and disciplinary approaches. It also requires new theories, methods, and ways of working that build on, integrate, and emerge from bringing together distinct disciplinary fields and methodologies (Roco et al. 2013, Roco and Bainbridge 2013). Convergent research relies on the creation of a shared vision among a diverse group for addressing a complex, real-world challenge; a culture and mindset that primes group members to collaborate; and the infrastructure and processes that enable members to bring their knowledge and experience to effectively develop highly innovative research and solutions (Roco et al. 2013, National Research Council 2014).

There have been calls for greater integration of the social sciences into convergent research, as addressing complex societal challenges requires understanding their human, social, and political dynamics (Peek et al. 2020). Too often, social sciences are brought in as secondary partners to fill gaps on proposals where engineering and natural sciences take the lead.

Design shares foundations with social sciences and arts, rooted in understanding of human behaviors and interactions across socio-technical systems. With its future focus and creative approach to problem solving, design offers tools and strategies for integrative problem-solving across multiple disciplines (Brown 2008), contributing to its increasing recognition in addressing grand challenges. It has been gaining attention at the U.S. National Science Foundation (NSF) as a means of grounding research in human experiences and facilitating cross-disciplinary collaboration, such as in the Convergence Accelerator program (NSF 2023a), but has not gained wide recognition as a valuable discipline contributing to convergent research.

In this paper we examine design's role in activating convergence within Multiscale Resilient, Equitable, and Circular Innovations with Partnership and Education Synergies (RECIPES) for Sustainable Food Systems, an NSF-funded Sustainable Regional Systems Research Network (SRS-RN). The paper also reflects on how design enabled the network to wrestle with the tensions that emerged from such collaborations.

BACKGROUND

Convergence

In the mid-2010s, the NSF began developing programming around convergent research, labeling it as one of 10 "Big Ideas for Future NSF Investments." This initiative aimed to bring together researchers from diverse disciplines, predominantly computational sciences, natural sciences, and engineering, for "solving vexing research problems, in particular, complex problems focusing on societal needs" (NSF 2019). A 2011 Massachusetts Institute of Technology (MIT) report suggested that convergence could be "a blueprint for innovation" that could lead to more impactful science, technology, engineering, and mathematics (STEM) research by intentionally integrating diverse disciplines to address real world problems, and creating solutions that are more than the sum of their parts (Sharp et al. 2011).

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NSF defines four characteristics of successful convergence: (1) focus on a complex, societal challenge that requires a multipronged research approach, (2) readiness of team members to engage in convergent research, (3) novel ways of integrating contributing disciplines, and (4) opportunities to involve younger researchers (NSF 2023b). Critical elements of an effective convergent research network are noted to include a diverse and supportive culture, and structures for enabling cross-institutional partnerships, addressing probable issues, and engaging diverse stakeholders (National Research Council 2014, National Academies of Sciences, Engineering, and Medicine 2019, Ernakovich et al. 2021).

In NSF's approach, there is an intentional centering around STEM disciplines and a noticeable gap in the positioning of the social sciences with respect to this work. Peek and colleagues caution that these grand challenges are "at their core, moral, ethical, social, and political problems," and warn that without a deep inclusion of social scientists, this research risks delivering "technical fixes for what are fundamentally human problems" (Peek et al. 2020). Sundstrom and colleagues (2023) contend that convergence optimally emerges from "iterative cycling between focused (Apollonian) and transcendent (Dionysian) perspectives," where the former is the task-oriented approach common in STEM fields and the latter relies on more open-ended, intuitive and creative inquiry. Roco (2020) suggests that convergence requires different cultural norms from traditional STEM research, such that research networks should be "dominated by horizontal links and self-organization principles."

There are many challenges inherent in convergent research because of its high level of ambiguity, possibility of failure, and emergent nature of research trajectories, for which university research infrastructures and resource allocation are not well suited (National Research Council 2014, National Academies of Sciences, Engineering, and Medicine 2019). Barriers around trust, communication, a common language, and divergence in goals and desired futures are some additional challenges that can stunt deep integration of teams across organizational and disciplinary boundaries. Physical distance, lack of physical space, team instability, divergent styles among team members, and funding rigidities are particular hurdles across STEM and non-STEM teams (Boon et al. 2014).

To help deal with these challenges, convergent researchers are encouraged to prioritize and incentivize diversity in various forms, including functional diversity in problem-solving approaches and identity diversity regarding researchers' demographics, culture, and geographical backgrounds (Peek et al. 2020). Some researchers (Bilec et al. 2020) suggest that distinct "containers," or ways of working, are necessary for activating deep convergence: a "whole person immersion" where people bring their disciplinary knowledge as well as their lived experiences as members of different social identity groups and diverse abilities; "affective relationships" where participants can build relationships and trust outside of specific tasks to be accomplished; and "small, intensive, transdisciplinary" teamwork where the size of the group forces participants to learn how to work with each other around specific tasks. This may require making room for subjectivities, such as "mindfulness" (Wamsler et al. 2018) and "respecting the integrity of individuals" (Walsh et al. 2021).

Design

Design is a relative newcomer to NSF's convergence agenda, but it has been a frequent collaborator in multi-disciplinary and translational research (Peralta and Moultrie 2010). Design encompasses a broad span of specializations, each with distinct frameworks and methods. Among these, human-centered design (HCD) has proliferated in corporate and educational settings, and now at NSF, as an approach for creatively solving problems with deep understanding of people and their contexts. HCD, which includes a wide array of methods and process, has foundations in ethnography (Lubis and Shahri 2022) and anthropology (Gunn et al. 2013). Design is often confused with design thinking, its simplified adaptation to business context, popularized by global design consulting firm, IDEO. These approaches have been crucial in gaining broader recognition for design as a valuable collaborator and legitimate approach in addressing complex challenges, but at the cost of a narrower view of design, overlooking its full spectrum of capabilities and diverse socio-political underpinnings (Kimbell 2011, Baker and Moukhliss 2020).

The literature on design's role in multi-disciplinary research collaboration includes building collaborative and creative problem-solving capacity of researchers through trainings and toolkits (Holeman and Kane 2020); extensive and application-oriented collaborations involving formal expertise of designers (Norman et al. 2021); and the design of collaborative research environments (Brun et al. 2019). Mejía and colleagues (2023:77) describe design as a mindset, "a third way of knowing that is unique from arts and sciences" that can foster relational, critical, and future-oriented modes of collaborative work beyond boundaries. We identified five complementary capabilities ascribed to design practice as (1) convening and connecting, (2) orientation and visioning, (3) storytelling and visualizing, (4) making and prototyping, and (5) abductive reasoning.

Convening and connecting

Design is a boundary-crossing discipline that can help combine the creativity and knowledge of people and thus, bridge disciplinary or organizational silos (Mosely et al. 2021). Core to this capacity is establishing the conditions for novel interactions between stakeholders of varying expertise, perspectives, and power to foster co-creative emergence. Designers do this by convening participants in experiences beyond their daily practice, and by connecting the various, and often raw outputs of these convenings to synthesize insights and future directions.

Orientation and visioning

Design's fundamental future orientation aligns with transdisciplinary collaborations tackling complex societal problems (Yelavich and Adams 2014, Peukert and Vilsmaier 2021, Mejía et al. 2023), which typically require forming a shared vision based on novel research questions (Brun et al. 2019). Yet a purely evidence-driven outlook to the future can constrain imagination (Mejía et al. 2023), overlooking social and political underpinnings of societal challenges (Forlano and Halpern 2023). Design's speculative and imaginative approach to futures seeks to entice possibilities beyond participants' immediate horizon, and foster critical reflection on their implications (Mejía et al. 2023).

Storytelling and visualizing
Designers use visualization to create tangible and dynamic interfaces that facilitate collaborative exploration of abstract ideas among people with diverse backgrounds and expertise (Lee 2008). Visual representation of scientific models and frameworks can act as translators between different domains of expertise and act as invitations for stakeholder input, dialogue, and reflection (Ewenstein and Whyte 2009, Peralta and Moultrie 2010).

Making and prototyping
Making and prototyping is the most widely recognized capability of design in multidisciplinary research. Similar to visuals, mock-ups, and models, prototypes enable communication between researchers and users to ensure the fitness of solutions to user needs (Bessant and Maher 2009) and thus bridge the gap between scientific discovery and application. Apart from testing ideas, making and prototyping are also used for low-resolution and playful exploration of ideas, and to render their future implications tangible, which is significant especially in tackling complex challenges (Peukert and Vilsmaier 2021).

Abductive reasoning
Witjes and Vermeulen (2020) highlight abductive reasoning as an essential principle of transdisciplinary research. Abduction is a process of logical inference that draws the most likely explanations from a set of incomplete observations, generating new potential value (Dorst 2011). Although informed by empirical evidence and theories, abductive reasoning is guided by "intuitive pre-knowledge" of researchers or other stakeholders. Abductive reasoning is a distinctive feature of design's way of inquiry, guided by prior experience and intuition cultivated through extensive practice, and manifested in the messy, behind-the-curtains process of forging connections that might seem almost "magically derived" or intangible to an observer (Kolko 2010). Abductive reasoning is supported by all previously listed capabilities that allow designers and researchers to gather a diverse range of inputs and externalize ideas, facilitating the creative and organic emergence of new connections. However, it is also a distinct mode of reasoning that is cultivated through extensive practice, beyond what can be provided in a toolkit.

Staging convergent research with design
Design is well equipped to support cross-disciplinary collaboration and knowledge co-production. However, most of the examples consist of technology-oriented research projects, where HCD plays a specific role around understanding user needs and experiences. Emerging design practices like systemic design (Jones 2021, UK Design Council 2023), transition design (Irwin 2015), and life-centered design (Borthwick et al. 2022) provide more holistic approaches to target the complexity of convergent research, and emphasize understanding people, systems, and their interactions. Although these methodologies align well with the orientation of convergent research, leveraging these requires the engagement of designers as researchers, rather than solely as enablers of applied research. Moreover, convergent research, with its need for deep and novel integration between researchers and disciplines, requires the creation of alternative learning infrastructures. A growing body of work focuses on the socio-material infrastructures that enable transformative research collaboration (Star 1999, Nicolini et al. 2011, Nogueira et al. 2020). Grounded in a participatory co-design approach, "infrastructuring" collaborative research is a long-term and open-ended process of building relations and cultivating enabling conditions to foster emergence of new approaches (Karasti and Syrjänen 2004, Björgvinsson et al. 2010, Hillgren et al. 2011).

CONTEXT

The complex challenge of food loss and waste

Food loss and waste (FLW) represents a significant social, ecological, and technological conundrum in the U.S. Ninety-one million (M) tons (38%) of the 241M tons of food grown and produced for human consumption in the U.S. remains unsold and uneaten (USEPA 2023). This includes surplus food, which may still be edible by humans, and food waste that is inedible. FLW occurs across the value chain, with 18% lost on farms, 14% during manufacturing, 20% during retail or food service, and almost half in household consumption (ReFED 2023). FLW represents a waste of the resources—land, water, energy, nutrients—needed to produce that food, as well as nearly half a billion U.S. dollars' worth of value.

FLW is driven by complex factors including economics, politics, health and safety, infrastructure, culture, and human behavior (Babbitt et al. 2022). Although scholars and practitioners agree that more research is needed to understand the FLW challenge, they recognize that many existing solutions have difficulty being deployed at scale because of extant policies, infrastructure adequacy and availability, and established patterns of human behavior (Babbitt et al. 2022). In addition, there are important social inequities in the food system, reflected by the abundance of wasted food that sits alongside food insecurity. This is not just a technical problem that better data and technology can fix, but rather there are deeply embedded values, policies, and infrastructures that are unlikely to change without being challenged from critical perspectives (Lopez et al. 2023).

Within academia, many disciplines focus on various aspects of FLW, however, research on these issues is often siloed. A convergent research approach is needed to bring together researchers with deep expertise in diverse areas to integrate their approaches to better understand the dynamics of why, when, and how FLW occurs, and innovate impactful and sustainable solutions that shift the needle on reducing food surplus and managing food waste.

RECIPES

RECIPES is an NSF-funded, 5-year, multi-institutional research network involving 14 U.S. universities, over 40 national, state, and local organizational partners, and external advisors. The network's vision is to "create generalizable knowledge that guides transformation of regional food systems towards sustainability, equity, and resilience by reducing waste" (Multiscale RECIPES 2024) The network aims to develop knowledge and solutions to transform the food system through waste reduction using convergent research focused on three core areas: circular economy, multiscale modeling, and human-centered design. Research in the network is oriented around three thrusts:

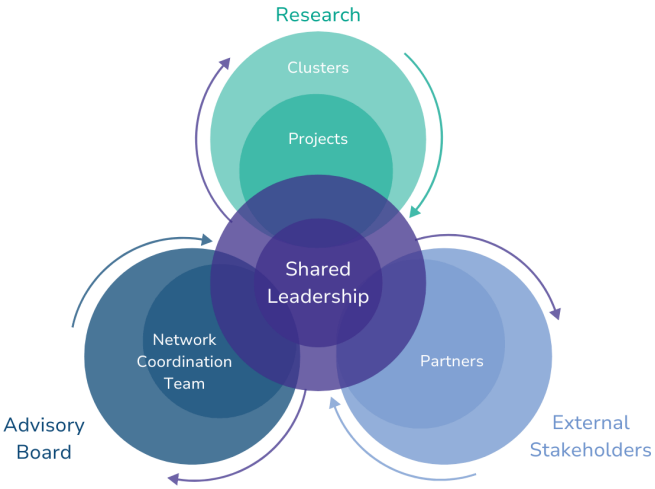
- Understanding patterns and dynamics of wasted food across scales.
- Assessing and proposing solutions that promote sustainability, equity, and resilience.

- Integrating currently disconnected disciplines and stakeholders to foster systemic shifts.

Theory, methods, data, and insights from each thrust inform work in the others. This creates a convergence approach where researchers participating in multiple, ongoing multidisciplinary and transdisciplinary research projects can learn from each other and produce specific outputs, including publications as well as generalized principles for conducting this type of research.

Five faculty co-Principal Investigators, each from a different institution, form the network coordination team (NCT), who provide the core decision-making governance for the network (Fig. 1). The network includes 11 multidisciplinary, thematic clusters that tackle either specific research questions, focal topics, or ways of working (see Appendix 1). Among these, the Co-Design cluster includes a core design team from Maryland Institute College of Art (hereafter referred to as the MICA team), responsible for facilitating the process of convergence, as well as other design researchers. Within each cluster, there are distinct research projects. Although some projects pull personnel from different clusters, each project sits within the most relevant cluster. Network members can join any cluster and may participate in projects they are interested in, within constraints of budget, time, and team dynamics. The NCT, whole network, and clusters meet virtually each month, and in-person annually. The network also uses several digital tools to share data and manage communications outside of these meetings.

Fig. 1. RECIPES' network structure enables guidance, opportunities, and insights to be shared between researchers, the advisory board, and external stakeholders. Created by Liz Sisk.



METHODS

We conducted a retrospective ethnographic study to understand the role of design as an enabler of convergence in the first year of RECIPES. We aimed to understand:

- The key roles design played in the network, with respect to the characteristics of convergent research networks.
- The contribution of design in facilitating convergence, and the frictions encountered and tactics used by designers.
- The changing understanding of convergence and design's role in it.

We looked at the period from the initiation of the project proposal through the end of the first year of the project (Fall 2020 to Fall 2022). We began with a review of the RECIPES proposal and key correspondence among project initiators to understand how design's role was conceived prior to and within the proposal. We then gathered archived text, graphic, and video documentation of year one's design-driven activities. These included Zoom video recordings, meeting notes, and Mural digital whiteboards, which held the direct inputs from network participants, as well as the work of the MICA team analyzing these inputs (clustering, developing themes, and visualizing ideas) and synthesizing insights and recommendations. These artifacts were organized by the MICA team and grounded the dialogue between members of the Co-Design cluster, NCT, and wider network in an accessible format.

In addition to this document analysis, we reviewed the rationale for various activities with current and former MICA team members who created and led the design activities. We also conducted semi-structured interviews with four NCT leaders to gain their perspective on design and its role in the network. We reviewed and re-organized the design artifacts, documentation, and interview transcripts into key themes on new Mural boards. We subsequently brought these boards to the rest of the co-authors during four Co-Design cluster working sessions to collectively make sense of these materials, and bring forth different interpretations of the themes. This synthesis enabled us to interpret the core characteristics of convergence, grounded in NSF's definitions, observe how design's key capabilities were manifesting in support of these characteristics, and identify areas of friction.

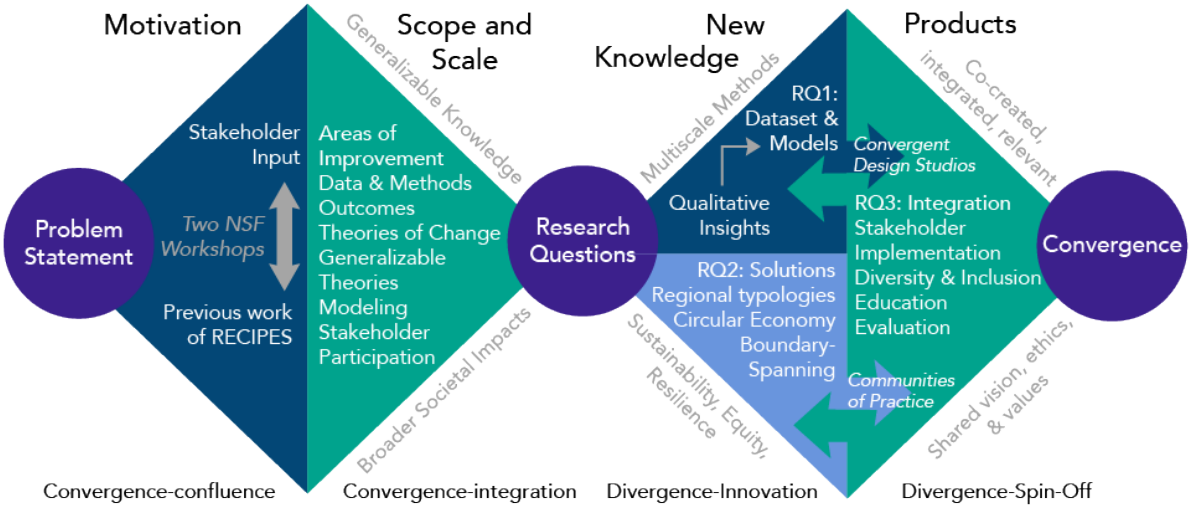
FINDINGS

The research network originated out of two NSF-sponsored workshops, independently conducted in 2019 to identify research needs and approaches for Sustainable Urban Systems, with an emphasis on food loss and waste (FLW). In both workshops, conveners' prior experience with HCD methods prompted them to include designers in these workshops. One of the conveners observed that "designers were very adept at learning things quickly and asking the right questions," bringing tools and techniques to frame and facilitate group conversations in ways where people could learn from each other and engage with new domains of exploration with a varying level of expertise. They also noted that designers often created activities that were fun and interactive, which could help "take people a little bit outside of their comfort zone." These positive experiences with HCD, as an enabler of transdisciplinary and exploratory collaboration, paved the way for integration of design in RECIPES.

Design's envisioned role in the proposal

The proposal articulated circular economy, multiscale modeling, and HCD as the core components of enabling convergent research in the network, where HCD is introduced as "an approach to co-create knowledge and new solutions with the human perspective as the main driver of the process." The approach was applied through an adaptation of the double-diamond model (Fig. 2; UK Design Council 2003).

Fig. 2. Application of the Double Diamond design approach to the RECIPES network. Created by Liz Sisk.



Key to the adoption of this model were convergent design studios, led by the MICA team and Co-Design cluster, to activate the process of "convergent collaboration, thinking, research, sharing, and practice" (from original proposal to NSF) both among network members, and with external stakeholders and partners. Studios were facilitated during monthly network-wide meetings, with the goal of "enabling authentic collaboration, sharing, reflection, self-assessment, and convergence among the RECIPES members" (from original proposal to NSF). Activities focused on cultivating alignment in mindsets and principles, creating systems for network communications and sharing, and establishing standards of self-assessment. As one member of the MICA team reflected, these studios helped "break down barriers between projects, between disciplines, between institutions, and bring people together in creative ways to get them to start working together and thinking differently, thinking creatively."

Shortly after project kick-off, the Co-Design cluster changed its name from the Process cluster (as it had been termed in the proposal) to reflect an emphasis on a more participatory approach to convergence, in which design was a key component, but not the only means to facilitate this process. It also reflected the broader types of design research (e.g., systemic design, life-centered design) that were happening in the network and became a place for design and design-curious researchers to learn from each other, as well as plug into various projects in different clusters.

Design's role in creating an enabling environment for convergence

During the first year of the network, the most prominent role of design was supporting network-level convergence. A series of exploratory and progressive activities characterized this phase. The initial three network meetings were focused on building familiarity on personal and professional levels. These activities emphasized building relationships and trust among personnel. Subsequent meetings sought to create the virtual environment for evolving the collective understanding of the meaning, relevance, and culture of convergent research, and collaboratively addressing practical concerns as they emerged. The MICA team followed an iterative and cyclical process (Fig 3):

1. Gathering input asynchronously from the members of the network to identify the topics of interest and concern (e.g., through surveys).
2. Designing and facilitating activities for monthly, online, network-wide meetings to open these topics for discussion and ideation (using Google Jamboard and Mural).
3. Synthesizing discussion points into key insights to guide NCT's decision making and planning (using recap slide decks).
4. Iterating potential approaches and sharing these for feedback, first with the Co-Design cluster and subsequently with the whole network.

Characteristics of convergence

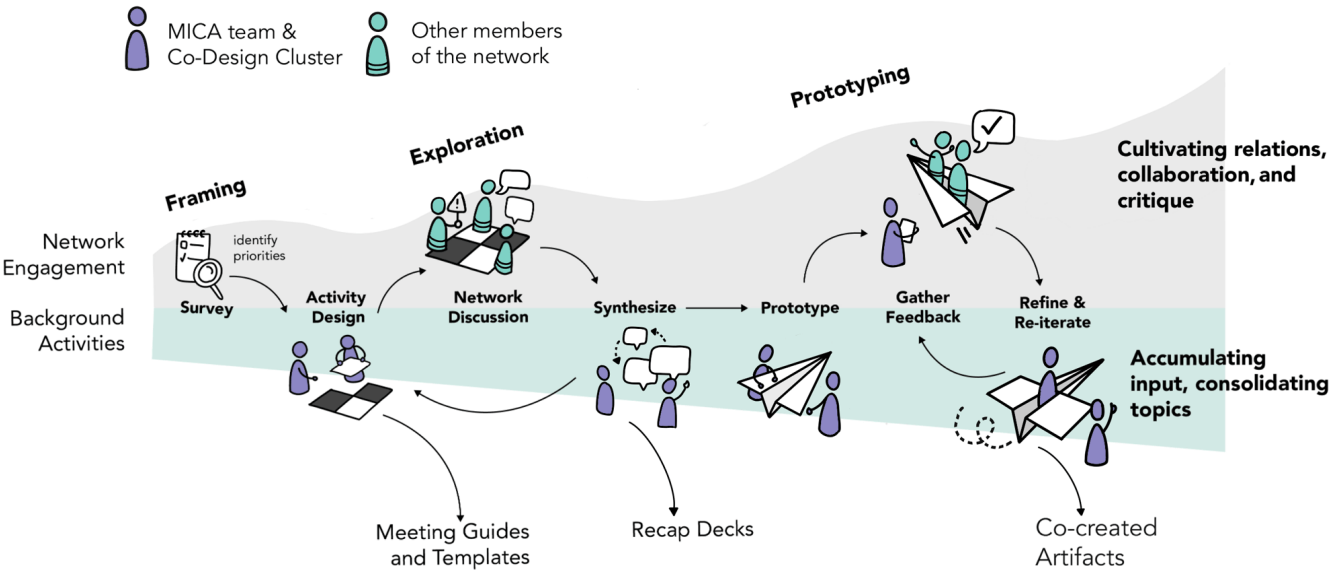
We discuss how these design activities helped foster an enabling environment for convergent research with respect to the four core characteristics as defined by NSF (2023b).

Complex challenge

A fundamental characteristic of convergence is orientation around a complex problem. As with any complex societal challenge, participants bring diverse perspectives on what constitutes the problem, what the solutions might look like, and the role of convergent research in informing these. Thus, an initial step was evolving a shared understanding and common language about the collective purpose of the network and the impact it aspires to achieve.

At the network's kickoff, members were invited to collaboratively revisit and reinterpret the foundational concepts in the proposal's vision or dream statement. Small group conversations unpacked the complex, and at times, contentious interpretations of terms

Fig. 3. Cultivating a culture of convergence involved iterative processes of gathering input, facilitating discussions, synthesizing insights, creating prototypes, and finalizing outputs. Created by Azra Sungu.



such as "generalizable knowledge" or "equity" while challenging the underlying norms and mindsets that created the challenge. Some members emphasized the importance of accountability vis-a-vis the project's aspirational goals, as boldly expressed in a Jamboard comment: "How do we take the buzzwords that got us the grant and actually do the heavy lifting?" The MICA team gathered all these inputs, and synthesized them into a list of themes and opportunities, as well as emerging areas of tension. The dream statement proved a useful probe for provoking some of the fundamental questions and critique about collective purpose and meaning of these goals in practice, helping to identify divergent thinking, and to affirm a shared vision.

Participant readiness

The ability of researchers to engage in convergent research extends beyond possessing the necessary skills and prior experience. It equally concerns the creation of connections, relationships, and trust among individuals, and understanding the diverse values, behaviors, and attitudes they each bring and want to foster collectively.

This meant creating space for individuals to bring their whole persons to activities. A pre-kick-off survey asked personal questions like what foods are often wasted in their homes, as well as about professional interests. During the online kick-off meetings, participants were placed in small groups to discuss commonalities that arose, and activities were structured to encourage playfulness. For example, groups were tasked with "creating a recipe from the most commonly wasted food items in [their] homes." This helped to build connection, not as researchers, but as preparers and eaters of food, which encouraged them to be more open to connecting with others.

However, the limitations of the virtual environment meant that spontaneous collisions or serendipitous conversations were not possible, and that interactions were time-bounded and task-oriented. As one participant noted, they wanted to "[g]et to know folks better through random collisions/breakouts. RECIPES was a nice idea, but perhaps a bit too task focused, so having a bit more open-ended structure would be useful." Additionally, because attendance at monthly meetings was not mandatory, several team members never participated in such relationship- or culture-building activities.

This led to recognition that participants needed a soft infrastructure to empower a shared understanding of working together. This took the form of guiding principles that provided a values-based, aspirational direction and community norms that put these principles into action (see Online Resource). Through a 10-month effort, the MICA team, with guidance and advice from the Co-Design cluster, facilitated a series of discussions to co-create the "Guiding Principles and Community Norms" with members of the network, drawing on individuals' and collectively held values and experiences. The team synthesized insights from various activities, discussions, and surveys into iterative drafts of increasing resolution, which in the words of one participant, created "concrete ideas that people can latch onto." These drafts were presented back to the network and workshopped into new prototypes based on the feedback of members and the NCT, a process one participant summarized as "messy, as it should be". The discussions became a space for finding common ground while surfacing important tensions between the high-level aspirations for a network culture that prioritizes diversity, inclusion, and relationship-building, and the traditional norms and structures of scholarship that governs the professional lives of many members, such as academic hierarchies or publication-based reward mechanisms. A Jamboard feedback summarized this tension as: "if people are put first, what isn't being prioritized?" This effort culminated in publication of the guidelines on the network's website in Fall 2022 (Agarwalla et al. 2024). This outcome was significant as a first demonstration of how design

could help the network to co-create an impactful output, which represented a turning point in the perception among many in the network as to the role and capabilities of design.

Disciplinary integration

A third defining feature of successful convergent research is novel ways of integrating disciplines, an objective where design had a relatively limited influence within the first year of the network, as the structures for collaboration were determined by the NCT in the original grant proposal. Monthly network-wide meetings served as the main platform for members to connect and form relationships beyond their clusters. They provided space for people to explore ideas, learn about each other's work, and understand differing approaches and methods of other disciplines. Short activities in breakout rooms such as peer-to-peer exchange of skills and areas of interest or brainstorming a potential product that might emerge from combination of members' respective expertise aimed at increasing members' inclination to engage in transdisciplinary collaborative research. Playfulness was an important organizational consideration to help team members relax and be more receptive to new ideas and ways of working.

However, there was no platform between the project-focused cluster space and short encounters in the network meetings for members to form deeper connections, exchange ideas, and engage in in-depth conversations, a challenge further amplified by the limitation of fully remote collaboration. Although the clusters documented their ongoing work and conversations in shared online documents, the Jamboards that captured the network-wide discussion sessions remained static and did not support an ongoing debate. This challenge surfaced especially in discussions on building a diverse and inclusive culture where numerous comments emphasized a need for diversity in "ways of sharing, communicating, and participating" that can account for "multiple levels of interaction [...] across levels of power within the network."

Next generation

The fourth area involved engaging and training future convergence researchers, which was structured in two ways. First, junior scholars were treated as full members, placing them on equal footing with faculty, in network-wide meetings and activities. Second, all students and postdoctoral associates funded by the grant were expected to participate in the Student cluster, a dedicated space to share their work, learn from each other, and self-organize activities of interest. The MICA students formally introduced design to the cluster, which was the only cluster space where this happened. This encouraged junior scholars to join the Co-Design cluster and adopt the playful and highly interactive design activities in their work. By the second year, several of them led engagement activities during network meetings.

INSIGHTS

During the first year of the project, tensions emerged around the collective understanding of convergence: should it be understood as a task-driven combination of skills and knowledge between researchers, or a more relational, values-driven, and open-ended mode of collective inquiry, which makes room for divergence and diverse perspectives and ways of knowing? This suggests that we consider convergence as a mindset and practice to be fostered, or infrastructured (Karasti and Syrjänen 2004, Nogueira et al. 2020), rather than an ideal state to be attained. In this light, we discuss the evolving role and contribution of design in cultivating the conditions for convergent research practices. We examine three specific ways design helps to infrastructure convergent research: (1) prioritizing authentic relationships, (2) navigating cycles of convergence and divergence, (3) making room for open-ended forms of inquiry. We reflect how certain design capabilities were utilized to navigate emerging tensions, while others remained unrealized because of various constraints, and suggest ways to better leverage capabilities of design.

Design's evolving role and tensions

In the RECIPES proposal, design's role was framed as a "driver of convergence." This convening and connecting role initially overshadowed the broader capabilities of design. Over time, design's role and expected contributions evolved as other researchers better understood designers' expertise, such as their abductive reasoning, captured in the translation of the various inputs into actionable recommendations. This shift was also marked by the renaming of the cluster from Process to Co-Design, emphasizing the role of design within convergence, contributing to the co-creation of a collaborative learning environment, rather than being the primary driver of it. By the second year, the MICA team gradually reduced its network-wide facilitation role, offering templates and guidelines, and shifted focus to cluster and project-based work. As one participant noted: "A design toolkit would have been useful; [a] 2–3 page guideline on how to use HCD in your daily research. Distributing the guide to individual teams and maybe having 'a design representative' at each university."

Critical to this shift was a recognition of design's abductive inquiry as a distinct, rigorous, and legitimate form of research in itself, rather than a way to support the work of engineering and natural sciences disciplines (Kolko 2010). This mirrors historic challenges faced by social sciences, which risk being relegated to supporting roles such as validating or disseminating research outcomes, rather than being seen as integral parts of the research process. Such tokenization often stems from entrenched disciplinary hierarchies and stereotypes that perpetuate a narrow view of scientific knowledge.

Prioritizing authentic relationships for convergence

The ethos of co-design embodies authentically bringing people together who will use a designed system (Peralta and Moultrie 2010, Karlsson and Redström 2016), in this case, to co-create the culture and conditions for convergent research. Core to this approach was creating a welcoming space for members to bring their whole self, with their diverse identities, values, and aspirations, as opposed to solely being represented by their expertise or role (e.g., faculty vs student) in the project. Relational approaches align with suggestions to create space for affective relationships and whole-person immersion, moving beyond task-based and purely-rational modes of relating (Bilec et al. 2020, Walsh et al. 2021). This was a crucial effort for forming a community, particularly in the absence of in-person encounters where such interactions can develop more organically.

The "Guiding Principles and Community Norms" became the first tangible output co-produced through the active engagement of a majority of network participants with widely different disciplinary perspectives. The process surfaced important

frictions in materializing the ideals of a caring and supportive learning community, against the transactional tendencies of academic research. A major challenge in the virtual setting was fostering engagement beyond intellectual participation to include sensory and emotional experiences. The limited ability to make and prototype physical, tangible manifestations of abstract ideas risked reducing the critical conversations to simply rhetoric. Such material engagement only became possible in the network's first in-person gathering, where participants collaboratively made physical prototypes of their ideas.

Fostering reflexivity through convergence and divergence cycles

Nurturing divergence is essential for transformative research, valuing not only a variety of skills and expertise, but also the diverse positionalities, values, and cultures of researchers (Boon et al. 2014). Surfacing and valuing these differences can help foster a reflexive research practice enabling researchers to understand their roles (Ervin 2005, Beck et al. 2021) and to "critically (self-) reflect on often implicit premises of our thinking and working styles, norms and foundations of knowledge" (Vilsmaier et al. 2017:175). Such reflexivity is essential for generating new ways of thinking, which are different from the paradigms that created the challenges, as well as to address extractive and exclusionary research practices (Friedman et al. 2018, Bozeman et al. 2022).

Early network activities oriented members toward a shared vision and set of values. These sessions invited people to exchange stories and perspectives in small groups, questioning core premises of the network and ways to actualize these, without seeking consensus. However, the conversations were constrained by meeting time limits.

Although the role of design was envisioned as guiding collective inquiry through sequential phases of divergence and convergence (Fig. 2), such neat separation fails to reflect the untidy reality of multiple parallel inquiries unfolding within the network, which can be better described as "several smaller divergence and convergence patterns" (Jiang 2023). The recap decks created by the MICA team captured the diverse ideas and perspectives that emerged from network-wide sessions and highlighted tensions in significant moments of divergence. But there was no process or infrastructure to unify these perspectives or resolve emerging tensions. This embodies "a notion of doing design together as a process not ideally converging towards consensus but instead as a process of unfolding divergence within a political space still oriented towards a shared whole" (Karlsson and Redström 2016).

Open-ended inquiry vs predictable outputs

Design played an important role in helping network members navigate the challenges posed by the open-ended and often ambiguous convergent research approach. This role nurtured the collective capacity to thrive in ambiguity, encouraging fluid roles that move beyond the rigid, output-oriented norms of traditional scientific research. Although these efforts predominantly tackled social and cultural obstacles, there were important structural barriers to open-ended inquiry, presenting challenges that were beyond the scope of design's influence.

The primary structural challenge was the inflexibility in allocating resources to activities and outputs other than those stipulated in the proposal, which limited the network's ability to redirect resources toward emerging ideas or areas. A participant described this as a challenge of "institutionalizing convergence," noting the tension between the premise of adaptiveness of convergent research and conventional budgeting mechanisms. This rigidity also constrained researchers' ability to move between work streams, as another expressed "I think what's showing up in the network is not that convergence isn't yielding answers, but it's that there's something really interesting happening over here, and it might not look like convergence. It might actually look like divergence. But I'm not allowed to go over there because this project is on convergence." Moreover, because output driven research work was the basis of resource allocation, there was limited time and resources to continue important, but lengthy, critical conversations about collective knowledge production or exploring new ways of working.

The pursuit of open-ended research often clashes with traditional metrics of success in academia such as publications, citations, and grant funding, which are significant for researchers' career advancement. This leads to a risk-averse attitude toward ambiguous explorations with unpredictable outcomes (Sundstrom et al. 2023). One participant described this ingrained mindset as "[T]here's always this trained, innate [thinking]... 'Is this useful? Is it going to lead to a publication? Will I be able to fund students on it, and is it going to be able to collect data?' It's [...] sort of trained towards that product, versus the process of exploration." For example, members published collaborative work early on, but this largely reflected research and relationships that pre-existed the grant. Convergent research outputs came later, suggesting that it takes time to create the mindsets and conditions necessary to co-produce outputs that rely on collaborations across very different disciplines.

CONCLUSION

Design's generative and collaborative mode of inquiry can be seen as a natural fit to the ethos of convergent research, but it is not a seamless one. In the first year of RECIPES, design made significant contributions in cultivating a culture for convergent research, one that centers people's diverse identities, perspectives, and creativity over merely combining skills and expertise. We emphasize infrastructuring this culture because it involves nurturing new attitudes, ways of working and relating, all within the confines of more rigid structures of scientific and cross-institutional collaboration. Important tensions were found around prioritizing discrete tasks and limited time for engagement versus building authentic relationships; navigating cycles of convergence and divergence, and allowing time for deeper, critical and reflexive thinking; and the need for open-ended forms of inquiry, not just conventional research outputs.

To truly leverage design in convergent research, it is essential to foster understanding across disciplines, through awareness and appreciation of their unique approaches to knowledge creation and sensemaking. The five key design capabilities can be applied to different aspects of convergent research. The popularization of design thinking has been a dual-edged sword: more people know about and are open to design, but they oversimplify its contributions and do not recognize the formal research expertise of designers. Although certain capabilities of design can lubricate the boundaries between disciplines, such as visual communication or facilitation, these can be carried out by dedicated staff on projects, rather than by design researchers with specialized

expertise and interests. Beyond design, networks can support convergence by dedicating resources to emergent, especially divergent, multi-disciplinary ideas, and creating learning environments that encourage open-endedness as well as specific deliverables.

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Conceptualization (WA, AS), Methodology (WA, AS, AK), Data Curation (LD, VA, ED, SE), Formal Analysis (AS, AK), Validation (WA, MB, LD, KH, NL, MS, SV, NW), Resources (WA, LD, MS, SV, NW), Writing - Original Draft (WA, AS, AK), Writing - Review & Editing (LD, SE, KH, SV, NW), Visualization (AS).

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Data Availability:

The data and code that support the findings of this study are available at http://hdl.handle.net/10560/islandora:1025356. Ethical approval for this research study was granted by Illinois Institute of Technology IRB-2024-76.

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Appendix 1

Description of RECIPES 11 thematic clusters

Cluster	Core disciplines represented	Focus
Co-Design (formerly Process)	Design, anthropology, public health	Integrate network-centered, human-centered and nature-inspired design approaches and test their potential for realizing convergence
Community	Anthropology, public health, design	Understand wasted food dynamics with critical insight into relevant behaviors, beliefs, cultures, and institutions, from community perspectives
Data	Data science, environmental engineering, agricultural economics	Understand the drivers and interactions in urban-rural food systems, create a data architecture and ontology for wasted food
Diversity and Culture of Inclusion	Engineering education, anthropology	Study the extent to which the structure and procedures undertaken within the network effectively promote diversity, equity, and inclusion, and derive insights that can guide best practices.
Education	Education	Engage a broad range of academic (undergraduate, graduate, K-12 students) audiences to provide knowledge and research skills to transform public understanding of food systems
Modeling	Mathematics, engineering, transportation	Model projections of current wasted food outcomes and test proposed solutions
Policy (emerged in Year 1)	Political science, anthropology	Research on and for policy and governance related to wasted food prevention in particular and food and agricultural systems at large.
Rescue	Public health, environmental science	Research into recovering high quality food surplus and use it to improve food access and public health outcomes
Students	All	Share research and build future convergence researchers
Typologies	Mathematics, engineering	Create the first regional system typology framework specific to wasted food.
Valorization	Ecology, engineering, business, transportation	Evaluate new integrations of technology to valorize wasted food.