CH15. Inquiry within, between, and beyond disciplines

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Brief Abstract

As scientists are called to solve complex problems, they need more than subject area depth and sophisticated methodological tools, they need to build relationships, trust, and common languages across disciplines.

This chapter explores how one large transdisciplinary team formed and evolved. Through the description of one team's journey, this chapter will explore the common challenges (stakeholder engagement, working across disciplines, conflict resolution, team management) and solutions that make for long-term, successful collaboration in complex, community-engaged teams.

Glossary Terms

- Multi-disciplinary
- Inter-disciplinary
- Community Engaged Research
- Community Based Research
- Community Based Participatory Research
- Participatory Action Research
- Participatory Team Science
- Science of Team Science
- Transdisciplinary Science
- Translational Science
- Team Science

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Introduction

The burgeoning food system community of practice has many dedicated researchers, practitioners and communities who are working to better understand and address sustainability and resilience issues across the US, and in a global context. Much scientific research on food systems has goals of serving diverse communities, improving local economies, and addressing inequality in food access and quality. These efforts, however, are often disparate, sectoral, and fragmented, which limits how actionable food system research outcomes are within communities. As you have read in the previous sections, researchers and community partners face a variety of challenges in connecting research across disciplines and additional barriers for connecting research with communities and decision-makers in meaningful ways. Striving to make change in complex systems, such as food systems, requires that researchers engage in larger and more diverse teams including community stakeholders and researchers from multiple disciplines.

Food Systems research needs to be transdisciplinary rather than interdisciplinary because it reaches beyond discipline specific approaches to create new frameworks to address complex problems (Aboelela 2007). Additionally, food systems research requires a paradigm shift in how knowledge is created by valuing interdisciplinarity as well as community-based knowledge production. It includes new habits of mind characterized by inclusivity versus exclusivity, collaborative versus independent exploration, and reflectivity and adaptability rather than directive and inflexible. For researchers, it includes several new competencies that include systems thinking, interpersonal communication skills, collaboration skills, and adaptability. Overcoming current barriers require that food systems researchers develop new skills for communication and coordination across disciplines, establish meaningful long-term connections with stakeholders and communities, integrate data and knowledge sharing across groups. Achieving transdisciplinarity means that food systems research teams are able to co-create new questions, new data, new methods and new understandings. In this chapter, we share key principles of team science, best practices to strengthen the evaluation, assessment and research efforts that are undertaken in food systems and use a couple of case studies to illustrate how these principles guide effective team projects.

Food Systems Research and Participatory Team Science

Food systems research is ripe for an approach that Tebes and Thai (2018) call *participatory team science,* which is defined as public engagement in interdisciplinary team science. Over the past several decades, we have seen the expansion of participatory action research, community engaged research, and community-based participatory research, which engage community members as more than research participants but as co-creators of knowledge (Jason and Glenwick 2016). Despite the variety of names for these participatory approaches to research, they share in common several key features 1) a focus on application of knowledge rather than only discovery, experimentation, and theory creation; 2) require interdisciplinary knowledge and methods; 3) value co-production between inter- or transdisciplinary teams and a variety of stakeholders community, industry and political; and 4) seek to create knowledge that is embedded in local context and cultures (Nowotny, Scott, & Gibbons, 2003).

We argue that food systems research needs a participatory team science approach. Team science is the broad term which describes interdisciplinary or transdisciplinary research in which individuals from various disciplines work together to solve major challenges, generate deeper understanding, and create scientific discoveries not possible within a single discipline (Disis and Slattery, 2010). Participatory team science, goes a step further engaging communities and decision-makers at the regional scale in order to embed community priorities in the modelling approaches undertaken by food systems research teams. A participatory team science approach should be framed and translated in a way that allows all communities to have better and more equitable access to knowledge, expertise, and tools that can help them find and connect strategies across scales, sectors, and issues. While much of the literature on team science and food systems does not use the term participatory team science, we will use it throughout the chapter in discussing team science competencies, our illustrative case, and assessment of transdisciplinary teams.

Individual Competencies for Participatory Team Science

As team science grows in necessity and popularity, a few frameworks have emerged which describe essential competencies and orientations for successful team science (Gilliland et al., 2019; Lotrecchiano et al., 2020; Nurius & Kemp, 2019). Overcoming the barriers to transdisciplinary science require the development of new competencies at three levels individual, team and organization (Lotrecchiano et al., 2020, 2016). Individuals need to bring a collaborative mind-set, openness to learning from others, capacity to learn from diverse others, and interpersonal relationship and communication skills (Lotrecchiano et al., 2020; Nurius & Kemp, 2019). These values, mindset, and interpersonal skills are the foundation needed for the more complex tasks of participatory team science. In the health sciences, the term translational science was coined to describe research which aims to turn observations and lab experiments into actionable knowledge that is adopted in clinical practice and developed into interventions that can be widely disseminated to improve patient and public health. Gilliland et al. (2019) argued that training within scientific fields is atomistic and maintains the silos and fragmentation so prevalent in science today. Translational scientists need to possess several skills beyond domain expertise and depth. They call these the characteristics of translational scientists (Gilliand et al. 2019). Drawing on this framework, we adapt the seven characteristics for scientists working on participatory team science projects, thinking specifically about characteristics, orientations, and competencies needed in food systems research (Table 1).

Where most scientists are trained to be domain experts and rigorous researchers (Gilliland et al., 2019), these characteristics are inadequate for participatory team science. A collaborative mindset and value for interdisciplinary perspectives are prerequisites for participation in any kind of transdisciplinary team science, allowing individuals to adopt a team orientation rather than a hierarchical or independent approach to science (Lotrecchiano et al., 2016; Nurius & Kemp, 2019). In addition to practicing a team approach, food systems research benefits when individual team members also build the skills to be boundary crossers, systems thinkers, and process innovators (Table 1).

Table 1. Characteristics of a Participatory Team Scientist

Domain Expert	Possesses deep disciplinary knowledge and expertise within one or more of the fields relevant to the aspects of the food system under study, ranging across the basic agricultural and food sciences, applied public health and environmental sciences to the broader social sciences, arts, and humanities affecting food environments and choices.
Rigorous Researcher	Conducts research at the highest levels of rigor and transparency, possesses strong analytical skills, and designs research projects to maximize impact to core fields and reproducibility.
Skilled Communicator	Communicates, compiles feedback and reinforces shared understanding across all stakeholders in the transdisciplinary project recognizing diverse social, cultural, economic and scientific backgrounds, including community members and stakeholders team intends to impact
Team Player	Practices a team science approach by leveraging the strengths and expertise and valuing the contributions of all players on the team and across engaged communities.
Boundary Crosser	Breaks down disciplinary silos and collaborates with others across areas and professions to collectively advance the development of integrated models that link key metrics and points where food system managers, eaters and policymakers make decisions that influence outcomes
Systems Thinker	Evaluates the complex external forces, interactions and relationships impacting the food system, including the regulatory and policy environment, consumer market and competitive landscape, public attitudes toward food, ag and environmental issues, and key social drivers influencing the system (equity, justice, diversity)
Process Innovator	Seeks to better understand the scientific and operational principles underlying transdisciplinary and community-based participatory research, as well as between rigorous researchers and community stakeholders, and innovates to overcome incongruencies and bottlenecks in the processes of engaged and applied research.

Adapted from Gilliland et al. 2019. Fundamental Characteristics of a Translational Scientist. *ACS Pharmacol. Transl. Sci.* 2(3): 213–216. https://doi.org/10.1021/acsptsci.9b00022

Since any transdisciplinary research should include a deliberate cross-disciplinary scientific process, engagement of key stakeholder groups (a theme revisited by several chapters in this book) and authentic integration of science and practice, a strategic blend of scientists with different skills and inclinations should be assembled to create an effective team. What may be most important to highlight about these characteristics for food systems work is that both content expertise (scientific fields) and context expertise (understanding of place, community, and issue) are essential, and that various combinations of team members may share roles, depending on the size of the team. Boundary crossers may have one of the most challenging tasks in moderating the tensions that may emerge between rigor and relevancy in the team's approach and work efforts.

Food systems research includes a diverse array of scientific fields—soil and crop science, animal and meat science, economics, public health, nutrition, engineering, ecology, and rural sociology—and stakeholders who will require the team to fully understand and appreciate the context of the situation in their industry or community, policy makers, producers, public health agencies, community groups and many others. This diversity in scientists and stakeholders requires that team members cultivate the ability to be boundary crossers, helping to translate science to community members and scientists from other fields as well as understand the diverse perspectives of others. Systems thinkers can evaluate complex forces, interactions, and relationships that need attention in food systems modelling as well as application and policy environment, consumer patterns, and public opinions. Being a process innovator is perhaps the most distinguishing characteristic because participatory team science faces a variety of institutional barriers, which a process innovator seeks to overcome. Later in this chapter, we will discuss tensions faced by participatory teams in search of balance between rigorous research, direct application, and policy relevance of food systems models and research.

Team Capacities for Participatory Team Science

In addition to the capabilities and characteristics of individuals, participatory team science also depends on building the capabilities of teams. Team science competencies include several domains, building trusting and genuine relationships, communication, collaborative knowledge generation, collective problem-solving, team management, and team leadership (Lotrecchiano et al., 2020). Like all community-based research methods, participatory team science begins with building trusting relationships which evolve from respect and valuing local knowledge, questions, and priorities (Cross, Pickering, & Hickey, 2015). Specifically in food systems research, respect for local community partners means seeking out current processes, blueprints or plans created by various partners in the more broadly defined team. It is essential to value work that was already done, even when the goal is to expand on that. For instance, if an agency initiative just identified six focus areas through a participatory process involving their network, that data must be valued and not discounted or ignored. When past community efforts are not used as a starting point, this degrades trust between researchers and communities and also represents a lost opportunity for mutual learning. Even if only focused on one aspect of the broader system you intend to map out, the priorities (and the process used to arrive at them) are part of the team building process and finding authentic ways to incorporate them builds necessary trust for long-term collaboration.

Most food system research typically emerges from a narrow group of scholars, teams or organizations, yet it may require linkages to a broader set of sciences, partners, and initiatives. Building the network of researchers, industry, policy and community partners to form a participatory team requires simultaneously strengthening existing partnerships, rebuilding trust if it has been lost between any partners and inviting new members to address the complexity of the food system. Including existing partnerships may be as simple as developing a survey instrument that asks respondents to identify their organization, unit, collaborative and non-collaborative initiatives, and communities or areas where projects take place. Or it may require multiple steps to develop a shared vision, identification of issues that are most pressing, examination of what barriers are inhibiting development of research, and creation of strategies to build collaborative opportunities and overcome barriers.

Doing participatory team science requires commitment and patience because it takes time to build relationships and trust, create a shared vision, and overcome the many barriers to participatory research. The Team Science Development Ladder was created by the first author and CSU collaborators based on observations of 21 emerging transdisciplinary teams and literature on team science and group formation (Figure 1). Each step on the ladder represents the step and phases that complex teams progress through as they form, develop, and grow.

The ladder is visualized as an ascending arrow representing how teams progress through seven steps and three phases as they expand their capacity and identity as a team. The first phase, Team Formation is the earliest stage when a group come together around an exciting idea that inspires commitment and is based on an initial willingness to trust and form a team. Exciting ideas may bring a group together, but unless members are able to commit time and resources and begin to form a team identity, they may disband without movement to phase 2 activities. Success in phase 1 results in team members being able to articulate a preliminary team vision, enthusiasm for the idea, and a sense of belonging and willingness to continue working with the team.

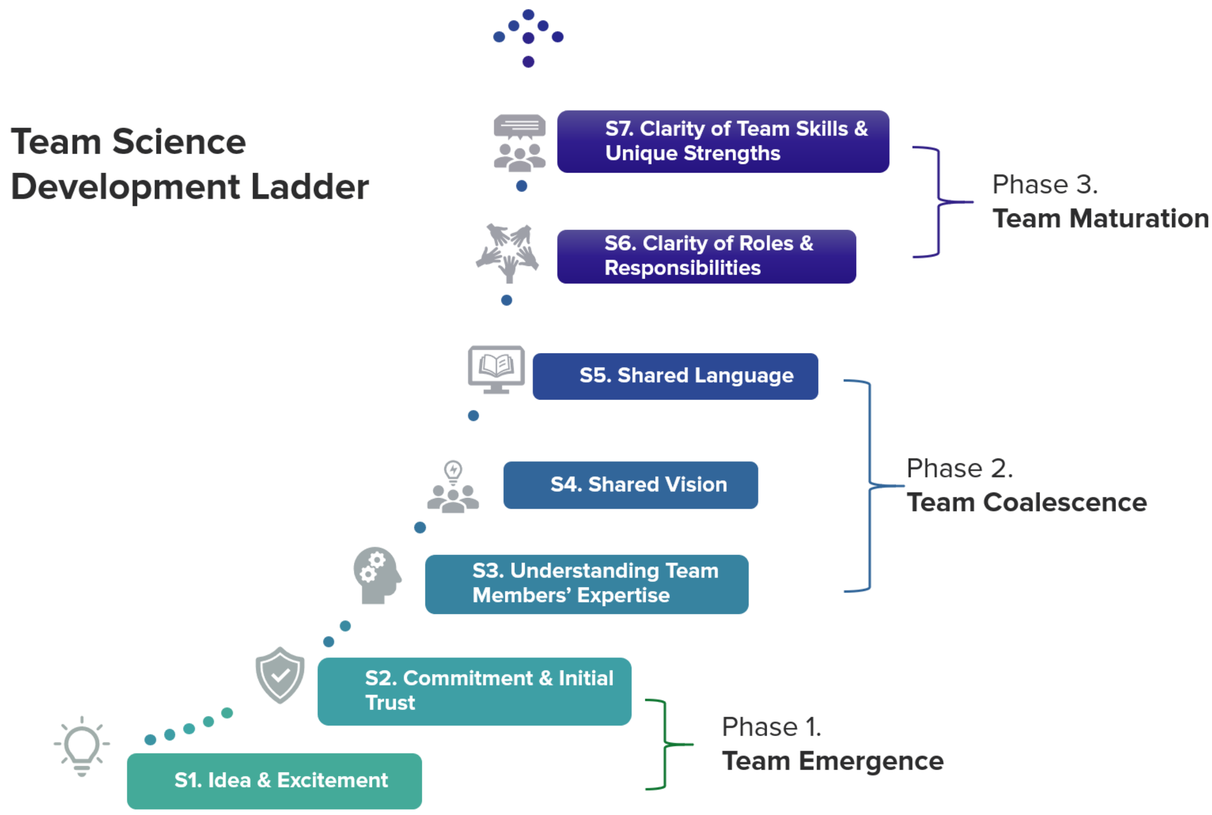

Figure 1. Team Science Development Ladder

Once members have committed, substantial work is required to coalesce a team around a shared vision. The three steps in this phase are distinct, each must be accomplished, but teams may shift back and forth between refining a vision, developing shared language, and gaining clarity around the expertise of all members and how that contributes to the vision. We found that teams must develop a certain level of clarity around the vision before they are able to satisfactorily build shared language around their theories, methods, and unique expertise. In phase 2, new members may join and those who don't feel their expertise contributes to the vision are likely to drop out. This shifting membership is to be expected in the coalescence stage. Teams may progress through this stage in a few months or it may take them several months to a year to feel settled around a shared vision. Success at this stage results in clear statements of team vision and direction and increased trust and sense of belonging and team identity.

Movement through each stage may involve conflict that when addressed can produce deeper levels of commitment, trust, mutual understanding, and clarity of purpose. As conflict is productively resolved, the team expands its capacity to engage in the next level of work. As teams begin working in earnest in phase 3, the team must develop clear roles and responsibilities that allow the team to accomplish its goals and objectives. As people work together and clarify roles and responsibilities, they deepen their knowledge of each other's individual talents as well as how to leverage the disciplinary expertise of other team members. Success at this stage is evident in team accomplishments and expressions of appreciation for each other's strengths.

Research on teams and collective capacity show that trust and collaborative work are mutually reinforcing, that trust is required to work together and as people work together they increase their trust and thus their capacity for more complex collaboration and coordination. Each of the phases should be seen as not as a single task or a clearly bounded step, with a distinct end, but rather as a set of work that when engaged provides the foundation for the next level of work. While potential team members may be excited about an idea or willing to commit to the project and trust other partners, others will take longer to trust and will need to work on small things together before they are ready for higher levels of commitment and deeper forms of collaboration (Figure 1).

Developmental Evaluation

In 2015, the Office of the Vice President for Research (OVPR) at Colorado State University (CSU) launched the Catalyst for Innovative Partnership (CIP) awards to support emerging transdisciplinary teams (see sidebar). Dr. Cross initiated an evaluation of the CIP program and the teams participating to help the OVPR refine and improve the program as well as to develop near-term markers of success for teams. This model was created based on observations and analysis how 21 emerging transdisciplinary progressed or disbanded during their participation in the CIP or PreCIP program in 2015 and 2016.

Large transdisciplinary teams benefit from participating in evaluation and training activities designed specifically to enhance the capacity of the team to address team challenges and foster self-awareness about best practices in teaming (Wooten et al. 2014). The type of evaluation

Catalyst for Innovative Partnerships

The mission of the Catalyst for Innovative Partnerships (CIP) program is to facilitate and position Colorado State University, through the creation and support of interdisciplinary research teams tackling grand societal and scientific challenges, to achieve significant global impact, in accordance with our land grant heritage.

Each team is awarded $200,000 for two years with the expectation that they are using these funds to support team development and seek new and substantial external funding.

The program evaluation of the first cohort revealed that emerging teams were spending a year or more in the early stages of team development and were not ready for a $200,000 investment until they had begun to coalesce a shared vision and shared language. Therefore, a new program the Pre-Catalyst for Innovative Partnerships (PreCIP) was created.

The PreCIP program funds teams with $5,000 over nine months and provides teams with several workshops designed to support the earliest stages of team development. All PreCIP teams attend seven educational workshops designed to advance them along the Participatory Team Science Development Ladder (Figure 1):

- Scientific Basis of Team Science Lecture
- Team Science Best Practices for Leadership & Management
- Developing Shared Language Workshop
- Intellectual Property & 1:1 Coaching
- Value Proposition Creation and Validation
- Science Communication and Elevator Pitch
- Communication to Stakeholders
- Corporate & Foundation Grantmaking

used to assess and support emerging transdisciplinary teams in the CIP program is a model called *developmental evaluation*. Developmental evaluation is an approach to team development and assessment focused on continuous improvement, supporting team adaptation under dynamic and evolving conditions in real time (Patton, 2010).

Led by Dr. Cross, the evaluation team used social network analysis (SNA), team observations, informal interviews with team leaders, and social surveys to assess individual and team collaboration readiness, team management practices, and team interactions. SNA is the measuring and mapping of a variety of relationships between people, groups and organizations. In team science, SNA examines the structure and patterns of knowledge sharing, trust, and collaboration between teams, mapping these in sociograms. The combination of team assessments, feedback, team building workshops, and management advice is designed to assist teams in progressing along the Participatory Team Science Development Ladder (Figure 1).

Case Study Team: Meeting the Challenges of Team Science

Here we present a case study of an interdisciplinary food systems team (FST) from CSU. The FST provides an interesting example because they were awarded two team development awards, PreCIP and then CIP, which were specifically designed to invest in the formation and growth of new transdisciplinary teams on campus. Between 2016 and 2019, the FST was assessed and evaluated by external team science evaluators and participated in a variety of team development activities.

The first iteration of the FST started in 2015 with two seed grants: one was a Global Challenges Research Grant from CSU's School of Global Environmental Sustainability; and a Pilot Project Grant from CSU's One Health Institute. Though each of these seed funded projects had different faculty involved and different research questions, objectives and outputs, there was a core team of faculty that coalesced through these efforts. Through collaboration on these two grants, this team of had accomplished Phase 1 of the team development ladder and was eager to advance as a team.

This new supergroup subsequently applied for and received a PreCIP grant. During this award period, the team increased team membership from 10 to 21 researchers across six academic colleges at CSU. As a PreCIP team, the FST received a small financial award and participated in a variety of professional development workshops. In addition, this was the first time that team members participated in team science workshops and developmental evaluation, including team readiness surveys and social network analysis of team integration.

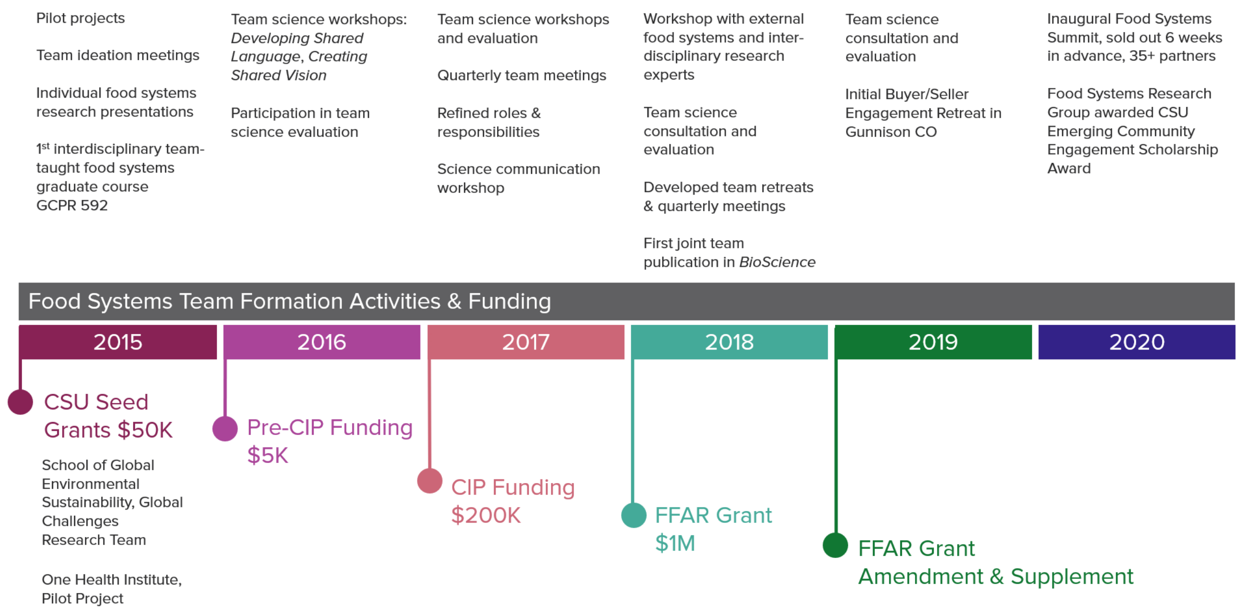

Figure 2. FST Team Development and Assessment Activities 2015-2020

Phase 1. Building a Transdisciplinary Team

The early stages of building a transdisciplinary team take time, which is why the PreCIP Program was initiated by the Office of the Vice President for Research. For the FST, Phase 1 (Figure 1) had been completed in 2015 and the team was ready to progress to a larger more diverse team. The PreCIP award encouraged and supported the team to utilize their funds and time on activities specifically focused on Phase 2 of the Team Development Ladder.

Phase 2. Team Coalescence

The funding provided by the CIP and PreCIP programs were instrumental in supporting team development in the early stages. Figure 2 provides an overview of various team development and evaluation activities the FST engaged in during the PreCIP and the subsequent CIP award, aligned with the sidebar presented earlier.

Step 3. Understanding Member's Expertise

To build cohesion, the FST took time to have meetings that were focused not on a specific research agenda but on helping the team get to know each other's expertise and interests (Figure 2). Team meetings centered around presentations of each member's disciplinary knowledge. The team also organized social events and tours with Extension Specialists to see various activities around the state. The PreCIP award provided funds and support to spend the year with no objective beyond building team cohesion and getting to know each other's expertise.

While scientists are sometimes frustrated that no action or research is taking place, spending time on Steps 3-5 is essential for building the capacity to quickly coalesce a team vision around emerging funding opportunities or response to emergent issues and opportunities. The investment in thoroughly sharing and exploring the knowledge of diverse team members, Step 3, builds trust and mutual understanding.

Step 4 & 5. Building a Shared Vision and Language

Similar to many investments, considering team members as a portfolio of talents and skills may provide the best context to recruit the right team. Team diversity allows each member to focus on one aspect of the project's needs (rigor, communications, modelling, or community engagement), knowing that others in the team will complement those skills with their contributions. Teams must also discuss how each of the skills are needed and valued for what they contribute to the portfolio. As the team builds a vision that includes diverse disciplinary expertise, consideration should also be made for assuring that a full spectrum of the Characteristics of Team Scientists (Table 1) is also present on the team. Most team members will contribute both scientific expertise as well as one or more characteristics of team scientists.

Figure 3 uses social network analysis to illustrate how the FST built a team with diverse disciplinary knowledge and characteristics of team science. This network illustrates learning ties between team members at the beginning of the CIP grant (2017), and then at the end (2020). From 2017, when the CIP funding was awarded, to 2020 the team grew from 17 members to 28 members. The average degree, number of ties between people, grew from 2 to 6.2 when asked, "who do you learn from?". The sociograms in Figure 3 illustrate the scientific collaboration ties (collaborated on research, publications, grant proposals, and student committees) at the beginning and end of the CIP program.

To illustrate the importance of the Characteristics of Transdisciplinary Scientists, nodes have been colored based on the characteristics from Table 1. The outer ring indicates each member's strongest contribution to the team, and the inner colors indicate additional characteristics enacted on this team. In 2020, the five members in the center of the network, a position that reflects their centrality to the team, all demonstrated three to six of the characteristics of transdisciplinary team members. Members in the center were more commonly skilled communicators, systems thinkers, and boundary crossers, while those on the outside were more commonly rigorous researchers and domain experts. Based on our evaluation and observations of the team, team members who demonstrated multiple characteristics were both junior and senior scientists. Those team members who brought domain expertise and unique research methods were important contributors to the team and tended to be in the periphery of the network. These team members also included both graduate students and senior scientists, indicating that the type and breadth of transdisciplinary characteristics was not associated with seniority or experience on this team.

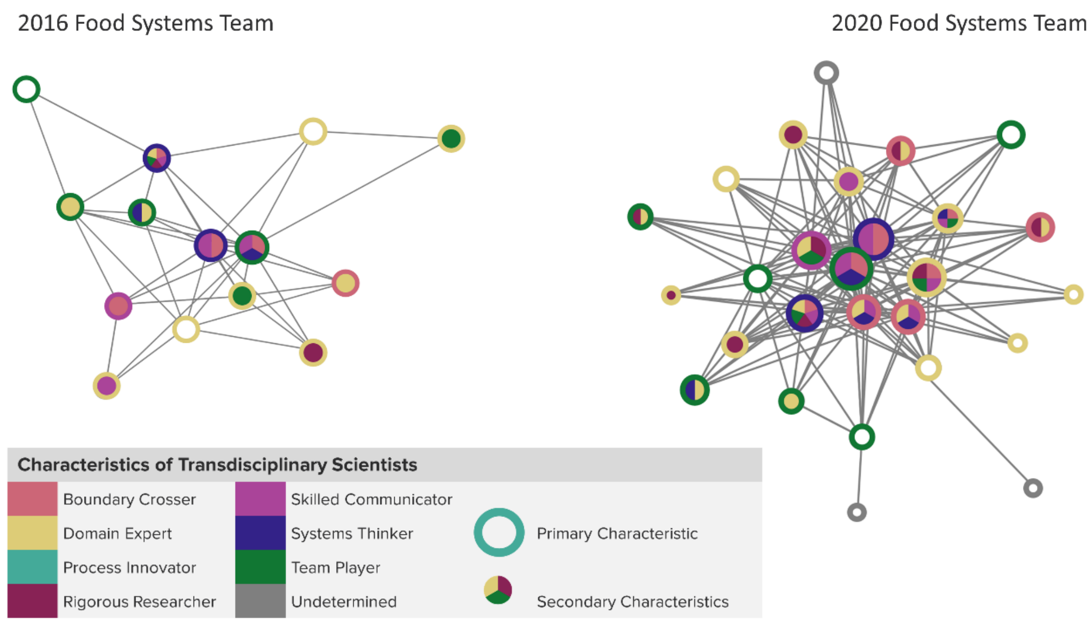

Figure 3. Social Network Diagram and Characteristics of Team Members

Because of the complexity of food systems modelling, this team benefitted from having both members who were boundary crossers and systems thinkers as well as those who brought depth of disciplinary knowledge and rigorous research methods.

The PreCIP provided time, space and permission to develop a shared vision and language. First, having funds to support facilitated discussions without a particular research objective was invaluable. Second, finding time for monthly discussions, including presentations by team members on their own research helped the team to understand where there was confusion around language. For example, one team member was defining "food systems" when one of the external facilitators was with the team. The facilitator turned to the team member and said, "You just defined a food supply chain, not the food system." This comment spurred an important discussion that was useful to the team in developing shared language about this core concept. It was clear that prior to this point the team, unknowingly, had not been on the same page.

The variety of workshops and assessments illustrated in Figure 2 were essential to the team coalescing a shared vision and building shared language. Following a successful PreCIP experience, the team was awarded the Team Research Award from the CSU College of Agricultural Sciences in 2017, as well as a full-scale CIP grant, which provided $200,000 for the team for two years with the expectation that the team would use those funds to collect preliminary data, intentionally build the team, and prepare a research proposal $2 million or larger. Working on Steps 3, 4, and 5 during the PreCIP meant that upon award of the CIP, the FST had achieved the level of coalescence required to put together a successful proposal for external funding.

Very quickly after receiving the CIP grant, a call for proposals was released for the inaugural Tipping Points grant from the Foundation for Food and Agriculture Research (FFAR). The Tipping Points grant supports projects that identify leverage points or tipping points in food systems where specific changes can improve overall community health and the economy. Though the team was perhaps a bit early to have fully coalesced a transdisciplinary research agenda, the seed grants received between 2015-2017 had enabled a significant amount of trust to be built across disciplines. Thus, when the team made the decision to apply for the Tipping Points grant, they were better able to very quickly put together a credible research proposal that demonstrated strong collaboration and understanding across disciplinary lines. Organizing for a grant of this scale was only possible for such a diverse team because they had already dedicated time to Steps 1-5. Given the short timeline and busy schedules, preparing the proposal necessitated 7am convenings at coffee shops. Team members were willing to commit to that higher level of teaming because they had already begun advancing up the Participatory Team Science Developmental Ladder.

Team Management and Leadership

Advancing from Coalescence to Team Maturation requires that teams dedicate time and effort to a variety of management and leadership activities. Creating a team charter is one team activity that can be especially helpful in the early stages of team development and set the stage for later success (Figure 5). A team charter helps improve team management by explicitly (1) defining team purpose-mission, scope, and goal; (2) identifying skills, responsibilities, and metrics for success; (3) establishing group values, norms and how you will connect and celebrate team success; and (4) selecting communication and collaboration tools that will help enable collaboration. A team charter is both road map for a team and a process of cultivating a group identity, clarity of purpose, and building trust. It should be considered a living document, not something to be created and never revisited (Hall et al. 2019).

Team Charter Template

Mission	Scope	Goals
Why: reason for forming the team	**Boundaries:** within and outside team goals	**What:** the world will BE different because the team achieved its highest aspirations
Strengths & Skills	**Roles & Responsibilities**	**Metrics for Success**
Diversity: the variety of strengths and skills brought by all team members—disciplinary knowledge, interpersonal skills, lived experience, methodological tools	**Who:** specific roles and duties required to meet the team goals, which team members are best suited to take on each role	**What:** measurable team outcome/performance
Values	**Norms**	**FUN!**
How: team conducts business, treats each other,	**How:** team routines, expectations, interaction rituals, decision-making processes, and resolving conflict	**How:** events and group rituals to bond, create team identify, and celebrate success

Communications Plan and Coordination Tools

What & How: tools the team will use to stay connected, interact formally and informally, share data internally and externally, store data, and foster regular interaction

Figure 4. Team Charter Template

Shared Authentic Leadership

Large, complex teams benefit from a clearly articulated leadership approach. Guenter et al. (2017) proposed a model, called Shared Authentic Leadership, as the ideal leadership model for transdisciplinary scientific teams. Shared Authentic Leadership occurs when leaders share leadership influence across several members and team members see it as their joint responsibility to lead the team (Guenter 2017). Authentic leadership describes a form of leadership where team leaders are "true to the self" and act according to their personal values and convictions and are thus able to garner high levels of trust with teammates (Guenter et al. 2017). This approach can be effective for large teams, but it requires clear role definition. In a large team, a small group of core-decision makers can help teams maintain momentum as the capacity of individuals ebbs and flows with other responsibilities, personal or professional. When one member of a leadership team needs to take leave or faces competing priorities, a team of leaders can more easily adapt than more hierarchical structures. Guenter et al. (2017) found that Shared Authentic Leadership and team trust were positively associated with perceived team performance and team satisfaction. Additionally, they found that team coordination was improved by Shared Authentic Leadership (Guenter et al. 2017). Specifically, team's self-awareness and relational transparency enhances team coordination.

Shared leadership can enhance transdisciplinary work. It helps leverage all the different members of the team, their disciplinary expertise and contributions to the team dynamic outlined in Table 1, and authentically involve the communities where food system work is focused. Shared leadership supports collaboration that includes joint problem definition and representation from community partners. This approach encourages teams to be self-reflective, and to make space for many types of experts to be leaders on teams.

Roles, Responsibilities and Network Structures

As transdisciplinary teams grow in size, so does the diversity of roles and responsibilities and the complexity of coordination. All teams have better performance when members have clear roles and responsibilities, and large teams require it. While there are a variety of different structures teams might choose, we propose thinking of teams as networks rather than as a group. Once teams group beyond 6-8 people, different network structures begin to appear (Read et al. 2021).

Some teams are organized around a central hub with a lot of interaction, some split into small teams with few connections between the teams, and yet others build a team that is more like a web than distinct sub-teams. Thinking of large teams as an integrative network, will likely mean that some members have weak ties or infrequent interaction with the large team, while others will have more frequent communication with more people (Cross et al. 2015). Effective teams do not need everyone to participate with the same level of depth or frequency, this is where social network analysis can help inform effective team structures.

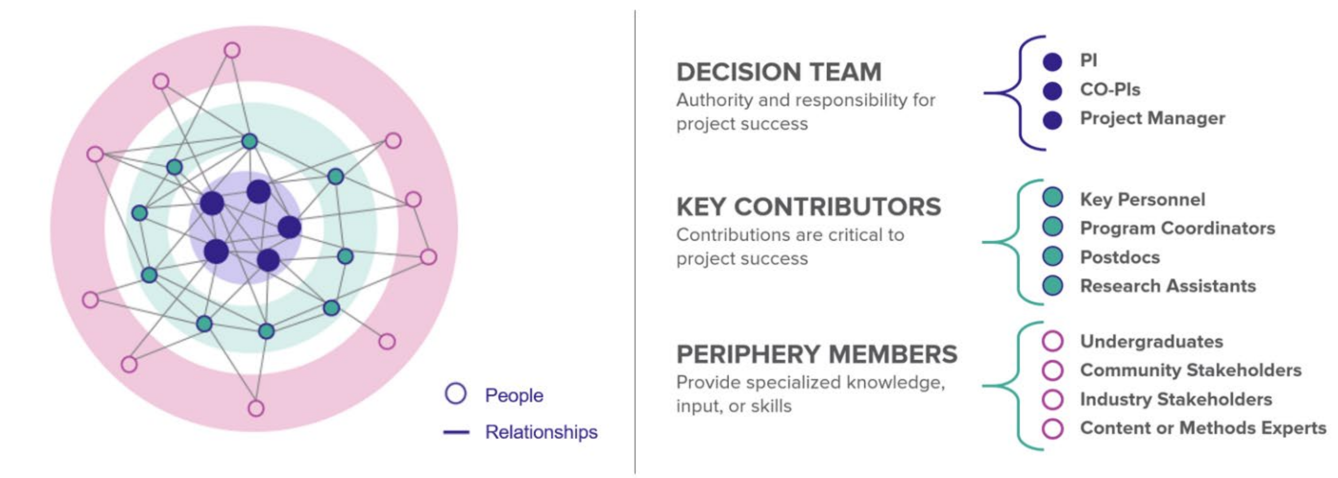

Figure 5. Managing Teams as Networks with Varying Levels of Responsibility and Integration

One structure that can be highly effective for teams larger than a couple dozen is what is called a core-periphery network. In the center is a small core team, which interacts frequently with each other and engages in a variety of collaborative activities. We call this the decision-making core. It is handling the logistics and administration of team activities, guiding the scientific direction, and has final decision-making authority. This small team has the most frequent meetings and is responsible for setting the agenda and designing larger team meetings or sub-group meetings. Around that small decision team is a densely connected core of contributors (Cross et al. 2015, Cross and Plaut 2019). The group is highly connected, actively engaged with the team, attends meetings frequently, makes substantial contributions to the team, and communicates frequently across the network. This group tends to be where the systems thinkers, boundary crossers, and process innovators are clustered in large teams.

The outer ring, or periphery, includes a variety of team members that are essential to the project but who may engage less frequently in team events. This group includes those people whose roles and interactions are more limited. It also includes community and industry stakeholders, graduate and undergraduate researchers, as well as domain experts and rigorous researchers whose roles are smaller. It is important to realize that the contributions of members in the periphery are essential to team success. Being in the periphery means that they attend few communicate and interact less frequently than those in the core, it does not mean their contributions are less important.

Managing from a network perspective can help team members identify what type of role is best suited to their skills and available time for the team. It can also help leaders understand that managing a large team does not require every member to be present for all discussions of team direction. One helpful team activity is to create a conceptual network map of how a team could be structured. The team discussion of this network map helps create a focused conversation about what roles need to be filled and what collaboration is needed across teams. Online systems mapping or network mapping tools and old-fashioned marker on flip charts can both be engaging and fun ways for a team to explore team roles and responsibilities (Holley 2019).

A typical networked management strategy includes meetings of different subgroups at different intervals (Robertson 2014). The Core Decision Team typically meets or talks on the phone weekly or bi-weekly. The Key Contributors typically meet with Decision Team on a bi-monthly basis in small sub-teams. The full network, including the Periphery members typically occur 1-3 times a year, depending on the size and geographic dispersion of the team. The FST held three full team meetings a year, with the Decision Team doing substantial preparation for these meetings. The agenda typically included: 1) revisiting team accomplishments since the last meeting, 2) celebration and recognition of team members, and 3) discussion of upcoming efforts to maintain shared vision and plans. In the earlier years, these meetings lasted for one to two days, and shortened to half-day retreats as the team progressed through the stages of team development. When working to craft shared vision and develop strategic plans, the team typically brought in a 3rd party facilitator, which is demonstrated to improve team success (Thompson 1993). These events were typically held off-site in order to help foster team rapport and the focus on team development. Spending focused and social time together as a team is important for building the trust and relationships necessary for integrative teams (Cross et al. 2015).

Project Management

During the first cohort of CIP teams, the OVPR recognized that teams that hired project managers were more successful that those that did not. For Cohort 2, of which the FST was part, teams were required to dedicate a portion of their budget to a project manager. While clinical sciences commonly use study coordinators and industry research and development teams widely use project managers, the hiring of project managers is less common in transdisciplinary science teams.

The size of this team and complexity of coordination activities required a dedicated person to take on the role of project manager. Once the FFAR grant was awarded, the FST conducted a national search, recognizing the important role that this person plays in coalescing the team. Unfortunately, the team had a failed search and ended up using a series of two postdocs, and an administrative assistant to formally fill this role. None of these situations were ideal. Neither postdoc was in the role for a long enough period to make a positive impact, and the administrative assistant did not have enough context to do more than ensure meetings were being scheduled. As a result, much of the project management responsibility fell on the PI, a faculty member with limited time to dedicate to this role.

Fortunately, towards the end of the project, a graduate student who had been involved with several aspects of the project, working directly with stakeholders, collecting data, conducting data analysis, and building the model, took on the role once she graduated. She had the necessary scientific understanding and the skills as a boundary crosser and skilled communicator to fill this role. She also had the benefit of familiarity with the project and history with the team that created trusting relationships, which has been tied to team performance.

Project management is a role that can be well-filled by a scientist with a master's degree, who understands the scientific program and has the skills to speak to both scientists and community stakeholders. One of the challenges for transdisciplinary teams is defining the job description for these positions and being able to hire for them. These kinds of complex projects need formal project managers, but this career track is often not well defined within universities or in graduate training programs like it is in the translational and clinical sciences. As transdisciplinary science is growing, scholars have been articulating best practices and calling for specific career paths around interdisciplinary research expertise (Bammer 2013; Moore & Khan 2020). Hendren and Ku (2019) have named this professional role the interdisciplinary executive scientist.

There is no doubt that the overall project could have been more successful with a strong and consistent project manager or an interdisciplinary executive scientist, an even higher level of responsibility for team coordination and integration. The lack of a consistent project manager meant that much of the team's efforts were not properly utilized. For example, documents created early on in the project, though they were stored in shared team cloud folders, were forgotten and not leveraged to the extent that they could be. An interdisciplinary executive scientist could have elevated the team's integration processes to an even higher level.

Navigating Collaborative Science Tensions

Participatory team science includes a variety of tensions, including but not limited to:

1. Diverse knowledge and context depth of those involved
2. Varying planning and action timelines across stakeholders
3. Tensions between feasibility of community engaged research and rigorous science and
4. Divergent goals for outcomes and dissemination of research products.

Food systems modelling teams will likely face all these tensions and can only overcome them by developing trusting relationships, developing individual and team awareness, and adopting open communication habits. One of the key capacities that teams need to develop is the ability to have productive conversations and constructive conflict, where differences and issues can be discussed and explored without team members feeling that these discussions are personal attacks or don't result in resolution and common agreement (Bennett and Gadlin).

Participatory team science is a new mode of research, where team members need a broader set of skills and the goals and standards of research are determined by a diverse group of stakeholders. One of the primary tensions to be resolved is the tension between scientists who want to hold the project to the gold standard of scientific research versus team members who see the value of conducting research that is feasible and can meet stakeholder expectations and timelines (Mohammed et al. 2021). Researchers who strive to use perfect data and frontier scientific methods may not be a good fit for team science, unless they are seeking to branch out into more engaged and relevant work. Instead, they are often best engaged as periphery members, brought into specific meetings to determine appropriate methods for more applied studies. Using the characteristics from Table 1 and the model of network team management, teams can help identify members that identify themselves as systems thinking and boundary crossing, and in large teams, there can be room for varying levels of integration and participation of more narrowly focused experts to guide methods.

The usual respect given to rigor and complexity in each team member's discipline can inadvertently be a challenge to relevance and usability of community-driven research. Most understand there is a tradeoff between how the frontier of disciplinary methods can be employed and how transdisciplinary a food systems model must be to allow for a breadth of important biological, social, market and policy dimensions. With a vision to improve relevancy, some modelers (particularly systems thinkers and process innovators) will seek to incorporate more phenomena, more parameters and the context of a larger set of team members and stakeholders. Yet, there are other team members, particularly the rigorous researchers, who will raise concerns about how each variable, metric or interaction in such a multi-faceted model will be specified in an unbiased, representative and/or transparent manner. These two approaches must be reconciled in order for a team to move forward.

For example, in this project we used an agent-based model, which is ideal for simulating complex systems, including emergent behavior that may result from autonomous actions of food system agents.

The interdisciplinary team codeveloped the agent-based model that integrates economic data, nutritional indices, social decision-making factors, biophysical crop data, and life cycle assessment. The purpose of the model was to improve our understanding of complex rural-to-urban food chains among four major Colorado agricultural products. This model simulates potential changes to the Denver food policy environment and observes resulting effects throughout the supply chain, from school purchasing decisions to potential changes in producer cropping regimes. The model enables the team to examine the effects of policy changes on everything from household health to soil health.

As one might guess, the multi-faceted nature of this model creates an important, necessary, and complex conversation of how to balance the number of parameters needed for such a model with the time needed to estimate them using cutting edge methods and data. Discussions on tradeoffs such as these need to be managed by skilled facilitators and perhaps process innovators or external facilitators who can help the team navigate and resolve these tensions with respect and care. This is the ideal responsibility for an integration executive scientist, who does not have a stake in one of the disciplines and has the skills to help team members integrate diverse considerations. Models such as these need to balance scientific rigor with feasibility and timelines that make the output useful for industry and policy decision-makers.

One of the outcomes of participatory team science is documenting the steps and challenges faced to resolve these tensions. In food systems research, teams should be evaluating the choices of model parameters and choices in the context of the policy or program solutions the target community of concern identified. The content expertise of the domain experts and rigorous researchers is not enough to guide the research direction. It must be informed by the context depth that process innovators and system thinkers have developed. Only when stakeholder concerns, domain expertise, and systems thinkers' views are integrated will such projects offer up relevant outcomes. The tension between rigor, feasibility, and contextual relevance will never disappear. It is up to teams to create a culture and set of processes that allow for productive debates and find an acceptable path forward. The end result is high quality convergent research.

The timing of integration of disciplinary perspectives is another source of tension for transdisciplinary teams. When is the right time to bring in new team members from other disciplines? Upon receiving the Future of Food and Ag Research (FFAR) award, there were a number of practical considerations that set in: a model needed to be built that included quantitative representations of the food supply chain in economic, environmental, and health dimensions. Because economic sciences allow for the standardized valuation of products and supply chains, initial modelling of parameters to include in the agent-based model focused on estimating costs of production, consumer values, and supply chain costs and performance. Unintentionally, this may have signaled less attention to other socioeconomic forces at play in food supply chain decision making.

At that point, the team included some strong sociologists and political scientists, whose disciplinary perspectives were pushed aside: as a result, the team lost one researcher, with others perhaps feeling less valued. Perhaps this was due to the fact that the FST received the FFAR grant before the newly formed team had reached the point where they had a shared vision and language (despite the fact that there was a fairly high level of trust among most members). However, due to the trust among most, the sociologists remained part of the team and actively engaged in meetings. Over the course of the FFAR work, the socio-cultural elements were increasingly seen as more integral to the work than originally conceived. Interestingly, as the modeling work of the FFAR grant comes to a close, the socio-cultural elements that have been integrated into the model are perhaps some of the most innovative elements of the team's collective work. This experience illustrates that those disciplines that are a challenge to initially integrate can also provide the greatest opportunity for innovation. One solution for resolving this tension is prioritize team integration and iteration of visions and specific research plans, especially when researchers have expressed interest and commitment to the team.

One defining characteristic of most interdisciplinary food systems projects is their engaged nature. These projects have additional complexity related to stakeholders. Not only do we need to find ways to coalesce the team around shared research questions, methods, data, and language, we also want to integrate the context-rich knowledge and values of stakeholders. One innovative element of the FFAR call for proposals was a requirement to document and leverage existing local investments in the food system (>$1M in food system investments), and to build bridges across often-disconnected community, government, private-sector and research partners. In Colorado, this meant trying to bring urban and rural stakeholders, diverse scales of agricultural operations, policymakers and government agency leads, supply chain stakeholders, and nonprofit organizations to the table. Most of these partners usually focus on only one aspect of the health, environment, or economic components of the food system. Integration of stakeholders with diverse knowledge and interests poses another challenge to transdisciplinary teams.

Early on in the research, partners in the City and County of Denver determined that they wanted to build the case for the Mayor to adopt the Good Food Purchasing Program (GFPP) for its procurement policy. GFPP is a food system rating metric that integrates a set of well-known, third-party sustainability, food justice, economic, and labor standards. The FST research quickly revealed that there are tradeoffs associated with adopting GFPP. One particular challenge is that GFPP did not necessarily capture the diversity and importance of place as written. So, for example, the FST found that there are tradeoffs associated with organic certifications (one of the priority areas under the "environmental" value of the GFPP) in dryland farming systems as producers cannot practice no till and thus more erosion occurs (Jablonski et al. 2020). Sharing this point, however, led to some tensions across researchers and stakeholders.

One way to navigate potential tensions is by integrating an advisory team. The goal of the advisory team is to include diversity in all realms that are relevant for a project. Commonly that includes stakeholders across geography, institution type, food system sector, scale of organization, etc. Building a culture of inclusion begins with aligning values and emerges from processes of repeated interaction. A core research team should agree on relevant criteria for diverse and inclusive membership, and appropriate activities during the planning phases. To be authentic when the aim is to be transdisciplinary and inclusive, the focus should be on building new partnerships and inviting broad participation, while also allowing for the leadership team to grow and integrate new members (HALL et al). Leveraging past work with stakeholders and communities adds credibility to the co-creation process, will expediting trust building as partners see their past efforts valued and provides a catalyst for work to start from and build momentum more quickly. In the case of the FST, a GFPP coalition was established to help integrate diverse stakeholder perspectives as well as research findings. This coalition has been effective in providing a platform for sometimes difficult conversations.

Discussion

Participatory team science is new paradigm of knowledge creation and thus deserves a roadmap for new ways of conducting research in complex teams. We have offered three contributions towards this roadmap: 1) description of several unique characteristics of team members, 2) exploration of the team development process, and 3) a framework for team management drawing on network characteristics. The study of two cohorts of PreCIP and CIP teams revealed that transdisciplinary teams need new roles—project managers and decisions teams—to support team success. This case, and other CIP teams, also illustrate that development of participatory team science teams takes time to build trust and collaborative capacity. Teams benefit when they receive capacity building grants that allow them to spend time on Phases 1 and 2 of the team development ladder, without the pressure to produce specific research products. Universities as well as the National Science Foundation offer planning grants that are designed to support teams in accomplishing these team development tasks. Teams can benefit from thinking of them as team development support rather than seed funding to start pilot research projects.

As mentioned above, the time invested to participate in successful interdisciplinary or transdisciplinary food systems teams is significant. The rewards generally do not begin to be felt for years down the road. There are a number of things that make participating in these teams rewarding:

1) Anyone who spends significant time in the "field" working with stakeholders or trying to affect policy knows that there are no silver bullets. No individual discipline has *the* answer. If the focus is on understanding a policy that is going to reduce GHG emissions, for example, it may be at the expense of the long-term viability of agricultural businesses. Thus, it is only through working together, acknowledging, and discussing tradeoffs that we can begin to address the many wicked problems across the food system. Ultimately, decisions will not be made just based on the science but based on values. Hopefully, however, understanding tradeoffs can help community members and policymakers better understand how to craft policies that are best in line with their values, vision, and goals.
2) If you are fortunate enough to participate on a strong food system team, the process of better understanding work of your colleagues from different disciplines should help to improve your disciplinary work through better recognition of the complex ways stakeholders make decisions, how other disciplines perceive issues, and the tools and data that they use for analysis. In other

words, in the best situations, participation in interdisciplinary teams can help to inform and improve your disciplinary research.

3) Working in teams can be personally fulfilling as teams allow us to tackle complex problems and make substantial impact in the world. Academia can be a frustrating or lonely profession, and team science offers the opportunity to forge positive relationships with colleagues outside your department to be a valued expert and to contribute to impactful work.

Finally, we want to offer a few specific recommendations to anyone planning food systems research. It is important to get to know people and their working styles. Good teams will work together for years, so you need to know who plays well in the sandbox; being brilliant is not as important being good at teaming. Know that it is OK for the team roster to change and shift each year. If you adopt a Shared Authentic Leadership model, you'll be able to attract and keep good teammates. As you invite new team members and work to integrate them, remember that you are looking for more characteristics that domain expertise, you are also looking for hidden skills (e.g. the ability to make brilliant figures or maintain meticulous data records) and characteristics of transdisciplinary scientists (e.g. systems thinkers and process innovators). You can maintain high performance with regular assessments of team roles and responsibilities, making room for team members to shift roles and responsibilities and looking for new members to fill gaps in the team. Finally, teaming includes time to socialize and share stories which builds the trust required to work on challenging problems, so take time to celebrate success or just hang out.

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