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A Sociological Evaluation of a Large Team Science Project: The iUtah Experience

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A SOCIOLOGICAL EVALUATION OF A LARGE TEAM SCIENCE PROJECT: THE IUTAH EXPERIENCE

by

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ABSTRACT

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The problems facing our society today have become increasingly complex (e.g. water sustainability, food security). In an attempt to address complex issues, researchers increasingly undertake collaborative research approaches that seek to integrate knowledge from multiple disciplines and nonacademic stakeholders. This is reflected in the development of large team science projects that bring together both academic and nonacademic researchers to work together on a particular problem. However, these scientific collaborations and large team science projects are complex endeavors that are not yet fully understood, particularly with regards to what makes these endeavors successful and how to make them as effective as possible. Using a sociological perspective, this study assesses a large collaborative science project called iUTAH (innovative Urban Transitions and Aridregion Hydro-sustainability) in order to illuminate the complex dynamics in large collaborative research projects. iUTAH resulted from a 6-year $20 million NSF grant developed to address water sustainability in Utah, USA, and the project involved multiple research institutions and stakeholders throughout the state. This study takes a qualitative approach through the use of in-person interviews to elicit factors influencing the team research experience and overall effectiveness of the iUTAH project. Researchers were asked how they viewed evaluation efforts and success of the iUTAH project, as well as what factors influenced the effectiveness of the overall project. Findings highlight how team size, geographical dispersion, cyberinfrastructure, researcher rank, and research focus area distinctions influence big team science initiatives. Additionally, findings portray the importance of face-to-face meetings to the overall team experience by facilitating social cohesion between researchers. Furthermore, findings illuminate the importance of including various measures of evaluation and success, including both traditional measures of research success (e.g. journal publications, citations), and more abstract indicators of success such as capacity building and relationships. This study contributes to the literature on the science of team science, and can be used to inform future big team science collaborations by offering insight into particular factors that can bolster collaboration within big team science projects, and by illuminating multiple dimensions of project success.

(101 pages)

PUBLIC ABSTRACT

A Sociological Evaluation of a Large Team Science Project: The iUTAH Experience

K. Taylor Dean

Many contemporary scientific research projects are composed of large numbers of researchers working together to provide solutions to social issues that affect our society. In an attempt to understand and address these issues, projects have been implemented where researchers from a wide variety of disciplines come together and collaborate. As this research includes a variety researchers, it requires a unique approach. Questions such as how to make these projects as effective as possible, how to properly evaluate these projects, and how to gauge the quality and success of these projects need to be answered.

These are directly addressed in this research by evaluating a large team science project called iUTAH (Innovative Urban Transitions and Aridregion Hydro-Sustainability). The iUTAH project was established to address water sustainability in Northern Utah, USA, and to bolster the states capacity to address water sustainability.

This research employs face-to-face interviews with researchers involved in iUTAH. Findings from this research highlight the important influence that team size, geographically dispersed team members, the importance of cyberinfrastructure, researcher rank, research focus areas, and in-person meetings have on scientific collaboration. Additionally, findings illuminate multiple dimensions of project success that include traditional indicators of research success (e.g. publications and citations), as well as project specific indicators (e.g. capacity building and relationships) that are unique to collaborative scientific approaches. These findings contribute to the literature and understanding of large team science collaborations, and can be used to inform future projects to ensure they are as effective as possible.

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1 – Introduction

Collaborative research approaches and teamwork in science have increased in frequency as the complexity of problems facing humanity increases (National Research Council 2015; Stokols et al. 2008a). This is exemplified by the development of large research projects that incorporate interdisciplinary and transdisciplinary research approaches in an attempt to ameliorate contemporary social and environmental problems (Stokols et al. 2008a). These initiatives are funded by both public agencies and private foundations, and given the large amount of resources these projects require, it is essential to better understand how to make these initiatives as effective as possible (Masse et al. 2008; Stokols et al. 2008b).

In the last decade, researchers interested in analyzing large research projects quickly realized how complex and difficult these initiatives can be, which led to development of a new field of inquiry referred to as the “science of team science” (Croyle, 2008; Stokols et al.2008a; Fiore, 2008; Fiore, 2013). The field as a whole focuses not on the specific phenomena addressed by a team science initiative (e.g. heart disease, sustainability), but rather on understanding the processes that take place within these projects and the subsequent outcomes (Stokols et al. 2008a). There are many complex factors that create difficulty in achieving successful cross-disciplinary research projects and this complexity stems from the dynamic nature of team science initiatives. This includies large team sizes (often between 50 and 200 investigators), involvement of multiple disciplines (spanning both natural and social sciences), diverse project goals, and the involvement of nonacademic stakeholders (Stokols 2006; Stokols et al. 2008b; Klein 2008; National Research Council 2015). Additionally, there are both individual and group dynamics (e.g. interpersonal and intrapersonal processes) occurring throughout the course of these projects, further increasing the complexity in understanding and studying these initiatives . Furthermore, there are multiple types of cross-disciplinary collaboration attempts (e.g. multidisciplinary, interdisciplinary, transdisciplinary) being implemented in big team science initiatives.

Often at the core of these cross-disciplinary research initiatives is the concept of knowledge integration (Klein 2008). The integration of academic knowledge from different disciplines, and the inclusion of stakeholder knowledge in these initiatives, are often seen as necessary for these initiatives to ameliorate social issues and often touted as the benefit of collaborative research approaches (Stokols et al. 2008a). However, the processes that lead to knowledge integration in the context of big team science initiatives are difficult to achieve and one of the least understood aspects of team science approaches, as integration can occur within a single mind as well as a among a team (Klein 2008; Wagner et al. 2011). It is difficult to create indicators that accurately capture the occurance of knowledge integration and to ascertain big team science project success. Researchers articulate that existing measures of team science products, and indicators of project success such as bibliometrics (e.g. co-authorships, co-inventors, collaborations, references, citations, and co-citations) are not able to fully capture the dynamic nature of knowledge integration and “leave considerable gaps in understanding of the social dynamics that lead to knowledge integration” (Wagner et al. 2011, 14). As the integration of knowledge is often the most important aspect of cross-disciplinary research (Klein 1996; Klein 2008), and is vital in guiding evaluation of these initiatives (Wagner 2011), more work is needed to understand how knowledge integration is achieved in these team science iniatives, and how it relates to project success.

In order to address the complexity of big team science initiatives, and to gain a better understanding of the “social dynamics that lead to knowledge integration” this study incorporates a sociological perspective. This study seeks to shed light on the complexities inherent in cross-discplinary collaborations by incorporating theories pertaining to the construction of knowledge, and how it is produced and transferred, by introducing the Social Construction of Reality (Berger and Luckmann 1966), Modes of Knowledge Production (Gibbons 1994), and the Sociological Imagination (Mills 1959). These sociological theories underpin this study and provide insights into how knowledge integration occurs in complex cross-disciplinary collaborations, and offers insights to how to properly evaluate these iniatives.

Evaluation studies of cross-disciplinary collaboration suggest the combined use of quantitative and qualitative research methods to evaluate team science initiatives, including “surveys and interviews of team members” (Stokols et al. 2008a, S82). This highlights that understanding individual researcher experience in the context of big team science initatives can provide valuable insight to better understanding knowledge integration. Therefore, this research takes a qualitative approach to explore knowledge integration in cross-disciplinary approaches at both the individual and group level. Qualitative methods are useful in this case to examine researchers self-described experiences of cross-disciplinary collaboration and to more fully capture the social dynamics that lead to knowledge integration. I attempt to inform the science-of-team science literature by reporting on how participating individuals view the dynamics and complexity of a large team science initiative, and how these factors influenced their team science experience. Additionally, I seek to understand how the concept of knowledge integration can be used to help evaluate what and how to measure big team science project success.

This research empirically focuses on a big team science initiative called iUTAH (innovate Urban Transitions and Aridrergion Hydro-sustainability). iUTAH was a federally funded NSF project that ran from 2012 to 2018. The overarching goal of the iUTAH project was to understand how to sustain water resources in Utah, USA. The project attempted to build collaborative partnerships between research institutions and public stakeholders regarding water sustainability, and to increase research capacity to expand the state's economic, educational, and research competitiveness (http://iutahepscor.org/ accessed 1/31/2018). The project incorporated 13 higher education institutions in Utah, and involved researchers from physical, engineering, and social sciences to address these project goals.

Evaluation of large interdisciplinary programs like iUTAH requires researchers to be creative and imaginative in their approaches in order to account for the diversity and complexity of large team science projects, including varying meanings of success, and dynamic intrapersonal and interpersonal processes that occur within these initiatives. This study provides insight on knowledge integration and addresses challenges inherent in the cross-disciplinary collaborations in large team science initiatives.

I begin Chapter 2 by introducing the sociological theories that provide the backbone of this study. I also give a brief description of the field of science of team science, which this research attempts to inform. Chapter 3 describes in further detail the study context of the research and the methods employed to address the research question. Chapter 4 describes the findings and how they relate to and inform the literature. Chapter 5 offers a brief conclusion and outlines a future research agenda.

Chapter 2. - Literature Review and Conceptual Framework

As the social and scientific problems that face humanity have increased in complexity (e.g. water sustainability), the scientific community has undergone a shift to try and address them (National Research Council 2015). This shift is reflected by the increase in team science, where researchers work collaboratively with one another on a research question or topic (National Research Council 2015). In the science of team science literature there are several different approaches to team science and scientific collaboration (e.g. multidisciplinary, interdisciplinary, transdisciplinary), but there has been particular emphasis on interdisciplinary and transdisciplinary research approaches to address complex societal problems (Stokols et al. 2008a). While science of team science scholars distinguish between interdiscplinary and transdisciplinary research approaches, the literature often uses these terms interchangeablely, or discusses them in tandem. This is problematic, as the semantics between the two are an important analytical distinction for science of team science scholars who are studying collaboration.

Science of team science scholars distinguish between interdisciplinary and transdisciplinary approaches to differentiate how “science teams and larger groups vary in the extent to which they include or integrate the knowledge of experts from different disciplines or professions to achieve their scientific and, when relevant, translational goals” (National Research Council, 23). In the science of team science literature, interdisciplinary research approaches attempt to combine “information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines… to advance fundamental understanding or to solve problems (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, 2005, 26). In distinction, transdisciplinary research approaches “entail not only the integration of approaches, but also the creation of fundamentally new conceptual frameworks, hypotheses, and research strategies that synthesize diverse approaches and ultimately extend beyond them to transcend preexisiting disciplinary boundaries" (Stokols et al. 2013, 5). Additionally, transdisciplinary research approaches are often oriented around the "translation of research findings into practical solutions to social problems and include societal stakeholders to facilitate this translation" (National Research Council 2015, 23).

Thus, transdisciplinary research approaches are seen as "a promising way to gain new scientific and technical insights on complex phenomena and speed application of these insights" (National Research Council 2015, 24). This is because the transdisciplinary approach offers "the greatest potential to produce highly novel and generative scientific outcomes" due to the integration of expertise from multiple fields, and the inclusion of both academics and practitioners (Stokols et al. 2008a, S79). The promise of transdisciplinary research efforts to address contemporary social problems is exemplified by the development of many large team science programs, funded by both federal and private entities (Stokols et al. 2008a). The large investments required for these initiatives have spurred the need to understand the effectiveness of the intellectual and social output these programs produce (Stokols et al. 2008b). This need led to the science of team science, where researchers are focused explicitly on understanding the dynamics of large team science projects.

Science of team science scholars are focused on the holistic understanding of team science initiatives and they have been tasked with understanding how to make transdisciplinary research collaborations more effective. This includes both working toward a better understanding of the process of collaboration in transdisciplinary research as well as the evaluation of the added value of transdisciplinary project outcomes in order to accumulate evidence regarding transdisciplinary research efforts (Stokols et al. 2005). This is an important research agenda as researchers inquire into the cost-effectiveness and translational outcomes of large team science initiatives to address contemporary social problems (Stokols et al. 2005).

This research seeks to provide an understanding of the individual (intrapersonal) and group (interpersonal) processes that occur in these projects, and to illuminate mechanisms that can be used to facilitate transdisciplinary collaboration within a big team science project. Additionally, this research attempts to understand success in the context of large team science initiatives, and provide a method for evaluating and understanding transdisciplinary knowledge integration achieved in a big team science project.

I draw upon 3 distinct bodies of literature to inform this study. I begin by introducing sociological theories that inform the conceputal framework that guides this study. Second, I review the literature on different types of collaboration found in scientific research and the difficulties that stem from these scientific approaches. I conclude by reviewing the literature on the science of team science, and by explaining the conceptual framework for this study.

Sociological Theories on Knowledge and Scientific Inquiry

Team science has been touted as the remedy to contemporary societal problems due to its emphasis on integrating multiple disciplinary perspectives to produce novel and translational science outcomes (Stokols et al. 2008a). This approach signifies a paradigm shift from a single disciplinary approach to scientific problems, to a transdisciplinary approach, where there is an attempt to integrate multiple scientific disciplines and include stakeholders from the community (Stokols et al. 2005; Stokols et al. 2008a; Klein 2008). The science of team science field developed to better understand and analyze this shift, but still "lacks the conceptual coherence of a more established and widely recognized scientific paradigm" (Stokols et al. 2008a, S80).

This is articulated in a paper by Stokols et al. (2005) discussing the lessons learned from a transdisciplinary research project in order to develop a grounded theory on transdisciplinary collaboration. Klein (2008) suggests transdisciplinary research collaboration should be grounded in the philosophy of constructivism, as she discusses the inherent complexity in transdisciplinary collaboration and the difficulty in evaluating these initiatives, especially as it pertains to the concept of measurement.

This study introduces a sociological perspective to better understand the shift from a unidisciplinary approach to a transdisciplinary approach, especially related to the concept of the production and integration of knowledge in large team science projects. The Social Construction of Reality (Berger and Luckmann 1966) is introduced to provide a backdrop to understanding how a shift from a unidisciplinary research approach to a transdisciplinary team science approach requires a change in how research products are evaluated. The concept of modes of knowledge production (Gibbons 1994) is then introduced to provide a conceptual distinction between the output of unidisciplinary approaches and transdisciplinary team science projects to guide transdisciplinary evaluation efforts. I conclude the sociological theories guiding this evalauation with the The Sociological Imagination (Mills 1959) to provide science of team science scholars a perspective that is able to grapple with the complexities inherent in transdisciplinary research approaches due to its emphasis on creativity. Additionally, it is used to distinguish between objective and subjective factors in big team science projects, one of the guiding concepts in this study.

Social Construction of Reality

The sociology of knowledge can summarized as a sub-discipline of sociology that aims to explain what passes for "knowledge" in a society and how it is transmitted and maintained in social situations (Berger and Luckmann 1966). The sociology of knowledge deals not only with the empirical variety of knowledge in human societies, but also with the processes by which bodies of knowledge come to be socially established as reality (Berger and Luckmann 1966). According to Berger and Luckmann (1966), this transmission of what is deemed knowledge creates a reality that is socially constructed. This means that as individuals interpret and discuss the world around them, they begin to establish agreed upon assumptions as to what reality is. A great example of this context in which social construction occurs is the scientifc community, described by Neuman (2006) as a "collection of people and a set of norms, behaviors, and attitudes that bind them together."

The scientific community is governed by a set of norms, or "a set of informal rules, principles and values that governs how scientists conduct their research" (Nueman 2006). The purpose of this research is not to elaborate on the philosophy of science, or critique any of the scientific enterprise, it is simply to acknowledge that scientific research is guided by socially constructed norms of what constitutes "knowledge" in the scientific community. One such scientific norm is the belief that the "scientific research process is incomplete without publication" (Wagner et al. 2011), because it provides the ability within the scientific community to correct, evaluate, and accept knowledge within the community (Price 1978).

Berger and Luckmann (1966) propose that the central question for sociological analysis should be how subjective meanings become objective facts, or in other words, "how is it possible that human activity should produce a world of things" (pg. 18). In traditional scientific approaches, this is addressed through the process of research and publication, which involve the concepts of disciplines, peer review, and measurement. Disciplines provide researchers with a structure of knowledge and research methods to produce knowledge, scientific peers are concerned with the quality of knowledge being produced and provide feedback to ensure the knowledge being produced meets the criteria of the scientific community, and measurement provides a shared understanding of the knowledge being produced to reduce potential biases (Klein 2008). However, the concepts of discipline, peer review, and measurement become difficult to identify and implement in transdisciplinary research approaches, due to the integration of multiple disciplines and community stakeholders, as well as the varied goals and outcomes of such projects.

Measurement of the publication process has usually been conducted using bibiometric approaches which are commonly used in "policy analysis, evaluation, and the creation of indicators… to track scientific output and productivity" (Wagner et al. 2011, 18). As science of team science scholars address the issue of transdisciplinary project evaluation, especially in regards to project success (including both tangible and intangible research products), a new approach is needed. This is articulated by Klein (2008) where she suggests transdisciplinary project evaluation is "made not given" (pg. S122). She articulates the need for traditional statistical methods (e.g. bibliometrics), but suggests they are not sufficient in understanding knowledge integration holistically in transdisciplinary projects. This sentiment is corroborated by Wagner et al. (2011) who suggest that bibliometrics, such as indicators of co-authorships, co-inventors, collaborations, references, citations, and co-citations, “leave considerable gaps in understanding of the social dynamics that lead to knowledge integration” (pg. 14). This issue is one of the guiding themes of this analysis, as I seek to evaluate project success of a big team science project.

Knowledge Production Modes

The New Production of Knowledge (1994) attempts to explain how knowledge is being produced in contemporary society. It is argued that “major changes in the way knowledge is being produced” are occuring in today’s scientific community that “affects not only what knowledge is produced, but also how it is produced,” and that these changes influence “the context in which it is pursued, the way it is organized, the reward system it utilizes and the mechanisms that control the quality of that which is produced” (Gibbons 1994, 7). He postulates that an evolution has occured in the production of scientific knowledge and differentiates between two types: mode 1 knowledge production and mode 2 knowledge production.

Mode 1 knowledge production is conceptualized as traditional knowledge, or knowledge that is “generated within a displinary, primarily cognitive context” while mode 2 knowledge is “created in broader, transdisciplinary social and economic contexts” (Gibbons 1994, 10). The distinctions between the two are characterized as follows:

> In Mode 1 problems are set and solved in a context governed by the, largely academic, interests of a specific community. By contrast, Mode 2 knowledge is carried out in a context of application. Mode 1 is disciplinary while Mode 2 is transdisciplinary. Mode 1 is characterised by homegeneity, Mode 2 by heterogeniety. Organizationally, Mode 1 is hierarchical and tends to preserve its form, while Mode 2 is more heterarchical and transient. Each employs a different type of quality control. In comparison with Mode 1, Mode 2 is more socially accountable and reflexive. It includes a wider, more temopary and heterogenenous set of practioners, collaborating on a problem defined in a specific and localised context. (Gibbons 1994, 12).

This distinction between mode 1 and mode 2 knowledge production can be useful as science of team science scholars seek a theoretical framework to help guide evaluative efforts of big team science projects, especially as it relates to project success. The distintion between the two types of knowledge production, and an understanding that the two types require different types of quality control can be useful for scholars charged with evaluating large team science projects. Large team science projects are representative of mode 2 knowledge production, and science of team science scholars can use the distinction of mode 2 knowledge to guide evaluative efforts and conceptualize what success means for specific projects. This is due to the characterization of mode 2 knowledge production as involving a transdisciplinary research approach, which Gibbons (1994) conceptualizes as a distinct form of knowledge production with specific characteristics.

Gibbons (1994) outlines 4 distinct features of transdisciplinary research knowledge production: (1) develops a distinct but evolving framework to guide problem solving efforts; (2) comprises both empirical and theoretical components that can’t be reduced to disciplinary structures; (3) results are communicated to those who participated in the process, often bypassing institutional channels such as journal publication; and (4) it is dynamic, where a particular solution can be made and advanced upon, but where and how that advancement will take place is unpredictable, though often in the form of both formal and informal channels. Thus, by understanding these distinct features of mode 2 knowledge production, and how they differ from the traditional mode 1 knowledge production, science of team science scholars can develop interpretive frameworks to help guide evaluations of big team science projects, especially as they address the concept of knowledge integration and project success.

Sociological Imagination

The sociological imagination as proposed by C. Wright Mills (1959) refers to a quality of mind that allows for individuals to shift from one perspective to another – from the political to the psychological to the biological; from historical to contemporary; from the interpersonal to the intrapersonal. Additionally, the sociological imagination allows individuals to distinguish between the 'personal troubles of milieu' and the 'public issues of social structure' (Mills 1959, 8). Alternatively, this can be interpreted as the importance of incorporating both subjective (personal) and objective (structural) factors into social science analysis, because they are contingent upon one another and both exert influence that shapes reality, as suggested by Berger and Luckmann (1966). This understanding provides the conceptual framework for this particular study by recognizing the processes of team science initiatives can be construed as subjective processes that both influence and are influenced by objective factors and outcomes. I postulate that through analyzing indivdiual research experience in big team science projects, science of team science scholars can glean a better understanding of these subjective and objective factors that influence knowledge integration.

Mills (1959) suggested that in every intellectual age, one style of thought becomes a common denominator of cultural life. Highlighting the role of science in society, this focus is exemplified by the following passage:

> During the modern era, physical and biological science has been the major common denominator of serious reflection and popular metaphysics in Western societies. The technique of the laboratory has been the accepted mode of procedure and the source of intellectual security. That is one meaning of the idea of an intellectual common denominator: men can state their strongest convictions in its terms; other terms and other styles of reflection seem mere vehicles of escape and obscurity (Mills, 1958, 14).

Mills went on to suggest that the cultural meaning of physical science is becoming doubtful stemming from secular and humanistic concerns, as well as inability to provide solutions to problems widely known and deeply pondered by both intellectual communities and cultural publics. He proposes that social sciences, specifically the sociological imagination, are beginning to become the major common denominator of cultural life, due to the increasing complexity of social problems.

While this insight is hard to prove empirically, today we are facing challenges that traditional disciplines and methods are unable to grasp or provide solutions to. *Sociological Imaginiation* was quite prescient, because only a few decades later, we see a large increase in collaborative efforts among researchers to address the complexity of social problems by going beyond the physical sciences. This trend has continued, and today we see an increase in collaboration in science, exemplified by increased numbers of authors in scientific publications that span various scientific disciplines, from both the social and natural sciences (Wutchy, Jones, and Uzzi 2007; Fiore 2008), as well as an increase in transdisciplinary research collaborations to address contemporary social problems (Stokols et al. 2008a).

The sociological imagination allows for multiple interpretations of the world and provides a framework that allows the researcher and the researched to use their experience to orient an analysis as “a fusion of both personal and intellectual life” (Mills 1959, 222). This is an important component of the sociological imagination, because it legitimizes using experience as a way to guide scientific inquiry, while still understanding that there are multiple experiences and interpretations of the world that need to be considered. This framework also creates opportunity for a symbiotic relationship between scientists from different disciplines and backgrounds, because it accounts for multiple interpretations of the world and doesn’t give primacy to one perspective over another. This ability can be employed when trying to ascertain how to evaluate mode 2 knowledge production, and provide vital insight into how to evaluate transdisciplinary work that is inherently creative and can’t be reduced to specific disciplinary pieces (Gibbons 1994). Additionally, it legitimizes using the personal experience of team science researchers to guide project evaluation efforts and to better understand project success.

Collaboration to Address ‘Wicked Problems’

The increase of transdisciplinary research efforts is in part due to the increased complexity of contemporary social problems. This is exemplified in an article describing the purpose of team science initiatives:

> Considering the enormous complexity and multifactorial causation of the most vexing social, environmental, and public health problems (e.g., terrorism and interethnic violence; global warming; cancer, heart disease, diabetes, and AIDS; health disparities among minority populations), efforts to foster greater collaboration among scientists trained in different fields are not only a useful but also an essential strategy for ameliorating these problems (Stokols et al. 2008a, S77).

This recognition of the complexity and multifaceted nature of problems facing society today is captured by the concept of 'wicked problems', as proposed by Rittel and Webber (1973). Rittel and Webber identified two types of problems – 'wicked' and 'benign' - that characterize issues facing contemporary society. Benign problems are classified as such due to their relative straightforward solutions. These problems have clear and logical definitions of their nature and problem solvers and researchers know exactly what their mission is and when they have formulated a solution that will solve the problem (Freeman 2000). Finding and providing solutions to benign problems is generally a linear process in which one defines the problems and then seeks the necessary professional expertise to solve them. Wicked problems, on the other hand, are much more complex in nature. This complexity stems from the multiple definitions of the problem and a range of potential solutions. Brown et al (2010, 4) sum up the complexity of wicked problems succinctly:

> A wicked problem is a complex issue that defies complete definition, for which there can be no final solution, since any resolution generates further issues, and where solutions are not true or false or good or bad, but the best that can be done at the time... since wicked problems are part of the society that generates them, any resolution brings with it a call for changes in that society… requiring a new

> approach to the conduct of research and to the decision-making based on that research.

Traditional disciplinary approaches to research are not inherently able to grapple with the complexity of “wicked” problems, due to these problems falling largely outside the boundaries of academic disciplines and cultural limitations to the way we think (Brown et al. 2010; Freeman 2000). Wicked problems are also probabilistic in nature, juxtaposed to the deterministic nature of benign problems (Freeman 2000). This means that wicked problems may be viewed from multiple perspectives, and have a variety of potential solutions, where benign problems often have one straightforward approach and answer.

For example, water sustainability across the Wasatch Front in Utah as an example of a wicked problem. This is a complex issue, because it encompasses multiple scales, and interpretations of the problem. What exactly does water sustainability mean? Who does water sustainability affect? Is everyone affected equally? Is it going to require a technological solution, a change in behavior, or some combination of both? And the list goes on. This problem could be addressed through a plethora of different perspectives, and could have a wide variety of different solutions depending on the perspective taken.

I believe this concept can be useful for science of team science scholars charged with evaluating transdisciplinary research approaches. The recognition that transdisciplinary research approaches are wicked problems in and of themselves, due to the many individuals involved, diversity of disciplines represented, and the broad project goals, may allow for relative flexibility and creativity when trying to evaluate these projects.

Types of research collaboration

Kurt Lewin (1946) proposed a new type of research orientation called “action research”, which in this study is understood as synonymous with the transdisciplinary research approach. He proposed this research approach because he and his colleagues had been working on projects with government officials trying to translate psychological principles and findings into practical recommendations for resolving societal problems (Stokols 2006). This required collaboration between researchers from different disciplines and community practitioners was in stark contrast to traditional disciplinary approaches. Action research can be defined as:

> A participatory, democratic process concerned with developing practical knowing in the pursuit of worthwhile human purposes, grounded in a participatory worldview which is emerging at this historical moment. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally the flourishing of individual persons and their communities (Reason and Bradbury 2001, 1).

However, as researchers tried to implement action research, they quickly realized how difficult and challenging it is. This is due to initiatives often requiring coordination among different types and levels of collaboration (i.e., among scholars working together on scientific projects; among the members of community coalitions collaborating to improve conditions within their local community; and among the representatives of organizations, agencies, and institutions spanning local, regional, and national levels who coordinate their efforts to implement and evaluate major public health policies and programs) (Stokols 2006).

Given these challenges and the complexity inherent in ‘action research’ and scientific collaboration, Rosenfield (1992) created a typology of different levels of research collaboration.

She specifically distinguished between three levels of collaboration: multidisciplinary, interdisciplinary, and transdisciplinary. In a recent report commissioned by the National Research Council (2015), a typology of research collaboration building from Rosenfields was established. They differentiate between 4 levels of collaboration: unidisciplinary, multidisciplinary, interdisciplinary, and transdisciplinary, which will guide this inquiry.

- *Unidisciplinary*: Researchers from a single discipline work together to address a common problem
- *Multidisciplinary*: Researchers from different disciplines each make separate contributions in an additive way
- *Interdisciplinary*: Researchers integrate "information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines to advance fundamental understanding or to solve problems.
- *Transdiscplinary*: Researchers integrate and also transcend disciplinary approaches to generate fundamentally new conceptual frameworks, theories, models, and applications. This often includes involving stakeholders from outside academia to participate and incorporate their knowledge into the research process.

As mentioned above, there are multiple inherent challenges when trying to collaborate in scientific research. Therefore, it is not surprising that additional research has tried to systematically identify determinants of successful collaboration projects. This has created a need to establish a systematic science of transdisciplinary action research to better understand factors that facilitate and hinder collaborative research projects, including cogent definitions and theories, methodologies, “lessons learned”, and the development of new strategies for training future transdisciplinary researchers (Stokols et al. 2008a). This research agenda transpired into a new field of inquiry called the science of team science. This study addresses this team science research agenda by providing empirical insights into a transdisciplinary team science project.

Teamwork and The Science of Team Science

Background

There has been progress towards creating a systematic science of transdisciplinary action research. The reconceptualization of collaboration by integrating the concept of teamwork has given researchers a body of literature to draw from that provides theoretical and methodological insight to the study of science collaborations (Fiore 2008). This stems from a recognition within the scientific community that there is an increasing amount of team science taking place. A recent study analyzed the past 50 years of research and nearly 20 million scientific publications and found that the size of authoring groups has steadily increased since 1960 (Wutchy, Jones, and Uzzi 2007). Additionally, they suggest that this has spanned science and engineering, social sciences, arts and humanities and patents, while also finding that team publications had higher impact ratings (Wutchy, Jones, and Uzzi 2007; Fiore 2008). Furthermore, a study by the National Research Council (2015) found that groups of 6 to 10 authors have been the most frequent in scientific publications since 2000.

Fiore (2008) recognized the difficulties in achieving successful collaboration outcomes in big science team. This in part is due to differences in epistemological orientations (e.g. disciplines, methods, fields) and suggested by equating collaboration with teamwork, large strides could be made in the improvement of collaborative endeavors. He states:

> As an area of research, the study of groups has produced a great deal of knowledge in the past 50 years investigating not just cooperation but its more complex counterpart, teamwork. Indeed, it is the science of teams that I submit could be the true catalyst for change, because it has matured into its own area of inquiry producing a rich base of knowledge that has helped us to better understand the complex coordinative processes engaged by teams (Fiore 2008, 253).

Teamwork is a dynamic process that is emergent and can be learned, rather than something that is naturally occurring (Fiore 2008). Therefore, by framing big team science as a process that can be learned, and by focusing on activities that are necessary for teamwork rather than the product that emerges, we are able to mitigate some of the challenges inherent in team science (Fiore 2008; Stokols et al. 2008a).

The reconceptualization of collaboration in science as teamwork led to the establishment of a new field of inquiry: the science of team science (e.g., Croyle, 2008; Stokols et al.2008a; Fiore, 2008, 2013). This field emerged from scientific research on groups and teams, but is unique in that it focuses solely on scientific teams. The field is not oriented toward a particular phenomena addressed by a team science initiative (e.g. heart disease, sustainability), but rather on understanding and enhancing the preexisting conditions, collaborative processes, and project outcomes associated with team science initiatives more generally (Stokols et al. 2008a). However, the field is still in its infancy and lacks the conceptual coherence or theoretical framework of a more established scientific paradigm (Stokols et al. 2008a).

Fiore (2008) understood the importance of focusing on the inherent processes involved in scientific collaboration by introducing concepts of teamwork. Fiore (2008) suggests by focusing on teamwork dynamics, rather than focusing on outputs, we may glean generalizable information that will improve scientific collaboration in the context of big team science projects. This is due to the eclectic nature of big team science projects, all with different goals, topical focus, and intended outputs. Therefore, by introducing concepts of teamwork into research on collaboration processes and big team science initiatives, and by ascertaining how they ultimately influence project success, science of team science scholars can make collaboration research more tractable (Fiore 2008). This leads to the overarching research question guiding this analysis:

- Research Question 1: What factors influence team research experience and effectiveness?

Large strides have been made in research conducted on groups in the past 50 years, as researchers have produced a large amount of knowledge addressing the concept of cooperation (meaning to work together) and teamwork (Brozek and Keys 1944; Fiore 2008). Research on teams and teamwork in the scientific literature has been conducted largely outside the context of scientific collaboration, but offers "knowledge that can inform strategies for improving the effectiveness of science teams and larger groups" (National Research Council 2015, 38). Due to having similar features and processes inherent in collaboration activity, science of team science researchers may be able to glean generalizable insight to inform future big team science research initiatives.

Science teams are characterized by a composition of 2 to 10 researchers working together on a single project with a narrow focus, while big team science teams are usually composed of more than 10 researchers working on a broadly scoped project (National Research Council 2015). Stokols et al. (2008a) identifies team-based projects as larger and more-complex initiatives comprising many (e.g., often between 50 and 200) investigators who work collaboratively on multiple, closely related research projects, and who may be dispersed across different departments, institutions, and geographic locations. Literature on teamwork, which researchers from the science of team science have drawn upon to theorize about big team science projects, has largely focused on small teams composed of 2 to 10 researchers and has been mostly outside the context of scientific research. Researchers studying the science of team science articulate the need to understand collaboration processes specifically in big scientific teams, as they likely differ due to size and being conducted in the context of scientific research (National Research Council 2015).

Processes of team science

A conceptual model put forth by Stokols (2003) has been used widely in science of team science research studying big science teams to identify key antecedent conditions, intervening processes, and outcomes. Subsequent studies using this framework suggest that the intellectual and scientific outcomes of team science initiatives are strongly influenced by both the antecedent conditions of projects, and the interpersonal and intrapersonal processes that occur throughout the course of large team science projects, ultimately affecting project outcomes (Stokols et al. 2008b).

According to Stokols (2003), antecedent conditions are conceptualized as the physical environment of the project, and the bureaucratic and structural issues that stem from the physical environment. This includes the geographic dispersion of group members, often due to individuals working on the same project from separate locations. It also includes making sure the project has an adequate infrastructure to support the activities of the project, such as a functional cyberinfrastructure to faciliate communication in geographically dispersed projects (National Research Council 2015). Additionally, it suggests that personal factors of individual researchers (e.g. values, expectations, goals, research orientaiton, and previous experience of scientific collaboration) are present at the outset of a project and influence processes throughout a big team science project.

In this study, these antecedent conditions are conceptualied as objective factors that influence a big team science project. While these factors are subject to change throughout the course of a project, they usually remain relatively stable due to the “rigidity of environmental and bureaucratic structures” (Hall et al. 2008, 162). The objective factors that will be addressed in this inquiry include the geographic dispersion of researchers, cyberinfrastructure, and researcher rank.

The physical environment of a big team science project is conceptualized in this study as the geographic dispersion of group members. Geographic dispersion creates challenges to the communication and and coordination process within a big team science project, thus is a barrier to overall project effectiveness (National Research Council 2015). When project members are geographically dispersed, it is difficult to collectively understand what each individual's expertise, role, and competencies are, thus creating barriers to a collective understanding of the group (National Research Council 2015). One way to combat the challenges inherent in geographically dispersed projects is cyberinfrastructure, which encourages communication between individuals who are at different locations (National Research Council 2015). It also allows for the sharing of knowledge between members of the project and as can act as a knowledge reserve for the project as a whole. The objective personal factors of researchers that this analysis will focus on are researcher rank and discipline. These can be conceptualized as researcher demographics, and have been shown to influence processes throughout a big team science project. This conceptualization of objective factors that influence big team science led to the following specific research questions:

- Research Question 1a: How does team size influence team experience and effectiveness in a big team science project?
- Research Question 1b: How does the geographic dispersion of a large team science project influence team experience and effectiveness in a big team science project?
- Research Question 1c: How does cyberinfrastructure influence team experience and effectiveness in a big team science project?
- Research Question 1d: How does researcher rank influence team experience and effectiveness in a big team science project?
- Research Question 1e: How does researcher discipline influence team experience and effectiveness in a big team science project?

It has been postulated that as projects advance to later stages, these objective factors can be depicted as determinants of success (Hall et al. 2008). However, this conceptualization fails to account for the dynamic nature of these projects. While objective factors themselves may be relatively stable throughout the course of a project, they influence subjective factors within a big team science project differently at different times throughout the course of the project. For example, while having access to cyberinfrastructure (e.g. communication software) provides the ability for researchers from different geographic locations to communicate, it doesn't imply that these researchers will necessarily use the tools appropriately or reliably to communicate effectively. However, how these factors influence one another and how they evolve throughout the course of a big team science project warrants further investigation and this notion led to the development of the conceptual diagram that guides this analysis, which is discussed in a later section.

The processes in big team science projects are described in the conceptual diagram put forth by Stokols (2003) and are split into two main categories: intrapersonal and interpersonal. The main difference between these two concepts is scale. Intrapersonal processes are conceptualized as processes that take place at the individual level, whereas interpersonal processes occur at the group level. Intrapersonal characteristics are composed of attributes of the individual researcher, such as research orientation, leadership qualities, motivation, trust, and respect (Hall et al. 2008; Stokols et al. 2008b; Nash 2008), while interpersonal characteristics are composed of attributes at the group level, such as group conflict, trust and respect among group members, and diversity of the group (Hall et al. 2008; Stokols et al. 2008b).

Previous research has conceptualized these processes as distinct from one another. However, this fails to illuminate the dynamic and interrelated aspects of the interpersonal and intrapersonal processes that take place throughout a big team science project, as it has been shown group processes influence the behavior individual researchers (Godemann 2008). While it is true team science processes occur at different scales (e.g. individual and group), I believe these processes are interrelated and contingent upon one another. Thus, these subjective individual and group processes are malleable and likely to change throughout the course of the project as the project changes and evolves.

Therefore, the interpersonal and intrapersonal factors that influence big team science projects can be conceptualized as subjective factors. These factors are a dynamic interplay between the individual and the group, and each team member experiences them differently. They do not remain the same throughout the course of a project, as they are "malleable human factors whose qualities change over time as a result of the collaborative process" (Hall et al. 2008, 162). These subjective factors culminate in the overall subjective experience of team science as perceived by the individual researcher. The culmination of these individual experiences lead to the social cohesion of the group, which has been suggested as the main precursor for groups to achieve their goals and achieve the highest levels of integration (National Research Council 2015; Godemann 2008). As science of team science scholars seek to understand how to make these team science initiatives more effective, I suggest these subjective processes and individual researcher experience need to be better understood, leading to the following research question:

- Research Question 1f: What subjective interpersonal and intrapersonal factors influence team experience and effectiveness in a big team science project?

With a better understanding of subjective researcher experiences in team science initiatives, and how experience is shaped by objective factors, mechanisms can be developed that facilitate a positive experience by researchers. Additionally, researcher experience and how it relates to social cohesion can provide science of team science scholars with insight on how to best facilate this cohesion, thus providing insight on how to make future big team science projects more effective.

Outputs of team science

Identifying the output of big team science projects can be quite difficult and complex, as outputs of big team science projects are often context specific and depend on project goals (Stokols et al. 2008a; Stokols et al. 2005; Croyle 2008; Klein 2008). Klein (2008) illuminates this complexity by portraying how big team science projects differ in knowledge domain, goals and objectives, institutional location, and intended outcomes. This makes the evaluation of big team science projects a complex task, and the methodology and experiences guiding big team science initiatives are still in the early stages of development (Trochim et al. 2008; Klein et al. 2008).

One of the main challenges when evaluating big team science projects relates to the concept of knowledge integration, including integrating concepts, techniques, and/or data from legitimized disciplinary fields, which is often the goal of team research (Porter et al. 2007; Wagner et al. 2010; Klein 2008). Traditional evaluation methods of science have focused on the use of bibliometrics (Wagner et al. 2011). Bibliometrics represent the methods and measures employed to study communication among scholars and the structure developed from that communication, often in the form of publishing in journals accessible by others in a particular scientific network (Borgman and Furner 2001; Wagner et al. 2011), and are often used by team science scholars as indicators of project success. However, knowledge integration is a difficult concept to measure, as it takes place at both the individual and group level. Wagner et al. (2011) articulate this barrier well by stating, "The process of integration – whether cognitive or social – is more difficult to observe (and measure) than are the results of the process… which may explain why more literature has focused on the outputs of research rather than the processes" (pg. 16). They conclude assessments of transdisciplinary projects need to progress beyond traditional bibliometric output in order to capture the dynamic processes involved in big team science projects that lead to project output. Therefore, bibliometrics are quality indicators of project productivity, but fail to fully holistically capture the concept of knowledge integration, and more importantly project success.

Many transdisciplinary project indicators of success build off this concept of knowledge integration, and quality research is often determined by patents, publications, and citations (Klein 2008), while the most common bibliometric analysis often consist of the statistical analysis of article citations (Wagner et al. 2011; Borgman and Furner 2001). However, in the context of big team science projects, which take a transdisciplinary research approach, and where the integration of knowledge is often the main goal, it has been suggested these methods are limited (Klein 2008; Wagner et al. 2011; Stokols et al. 2003).

Transdisciplinary research projects often aim to combine knowledge from different fields, thus methods that assume rigid disciplinary structures are limited in their ability to provide useful information on project quality. Additionally, these methods often involve the need of “identifying experts who fit the problem space” to meed the criteria of peer review (Klein 2008, 121). This can be extremely difficult in the context of big team science projects as they often have distinct project goals and aim for the inclusion of both academic and public stakeholders. Measurement is the final concept that creates difficulty for traditional bibliometrics to illuminate the quality of a big team science project, as the level of knowledge integration isn’t able fully captured in these methods.

In order to evaluate big team science projects, new measures and indicators of success are needed that capture their dynamic nature. Stokols et al. (2008a) highlight this and suggest methods should include the “combined use of survey, interview, observational, and archival measures in evaluations of team science initiatives for a more complete understanding of collaborative processes and outcomes” (pg. S82). Additionally, Wagner et al. (2011) articulates the need to implement qualitative measures to “detect integration in research processes, to assess the value of the outcomes of collaborative work, and to develop causal inferences about the factors that influence highly valued outcomes” (pg. 17). This is illustrated in recent research conducted by Roche and Rickard (2017), where they found that researchers involved in a collaborative science project distinguished between two specific constructs of success. One group of researchers articulated that their perception of project success was related to traditional scientific output, such as publications and citations, while the other group discussed success in terms of the capacity the project built regarding researcher relationships, and a better understanding of knowledge outside their disciplines.

Drawing on the literature above, I propose that project success is a complicated concept in the context of big team science projects, that should be composed of both knowledge integration and the sustained effort for scientific collaboration, while still factoring in traditional research products (e.g. publications, citations, additional grants received).

In this study, knowledge integration can be defined as “going beyond a normative focus to encompass a new way of knowing that grows out of shifts in epistemics, institutional structure, and/or culture” (Wagner et al. 2011, 15). The process of knowledge integration includes 5 aspects as outlined by Godemann (2008): a) exchanging information, b) achieving integration, c) creating a common knowledge base, d) achieving awareness of the frame of reference, and e) developing group mental models (pg. 637).

These concepts embody success as they facilitate and support the ability to address the complexity of contemporary ‘wicked’ social problems. In order for science to play a leading role in addressing and ameliorating social problems, which is often the goal of big team science projects, evaluation and assessment methods also need to be grounded in real-world contexts and experience. As mentioned, the translation of big team science project outputs in addressing social problems is extremely difficult to measure, and indicators of success have yet to be established, which is why researchers are inquiring about new evalation methods (Klein 2008; Wagner et al. 2011; National Research Council 2015). The infancy of the science of team science, and the call for ascertaining the best practices of team science projects, has made success an abstract concept that has yet to be agreed upon in the literature. As the science of team science seeks to legitimize itself as a field of study, how researchers involved in team science conceptualize success can provide valuable insight and “lessons learned” for scholars to build upon. This led to the development of a second set of research questions:

- Reseach Question 2a: What do researchers involved in big team science projects view as success?

- Research Question 2b: How do researchers involved in big team science projects think success should be evaluated?

To address these collective research questions, I propose a new conceptual model (Figure 1) that adapts the original team science concept model put forth by Stokols (2003), the collaboration readiness factors and determinants of success put forth by (Hall et al. 2008), and factors of teamwork suggested by (Fiore 2008).

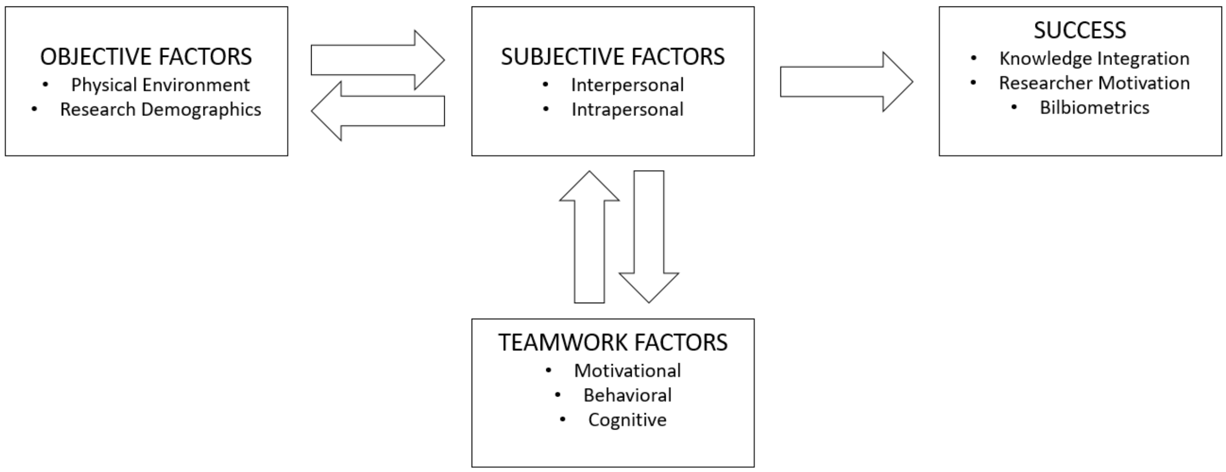

Figure 1. Conceptual diagram of factors influencing team science success.

Better understanding of how objective and subjective factors influence team effectiveness and experience will enable better understanding of team processess in big team science. This analysis seeks to elucidate if and how these factors influence the experience of researchers in the context of a big team science project. Additionally, this research seeks to understand what researchers view as success in the context of a big team science project and how it should be evaluated. This information will allow researchers and funding agencies of future big team science projects to create mechanisms to effectively facilitate team processes in future projects at both the individual and group level, and provide empirical insight on project success to guide future evaluations.

Chapter 3. – Methods

Introduction

This study seeks to illuminate researcher experience in a big team science collaboration to better understand how objective and subjective factors influence the overall team science experience and team effectiveness. Additionally, this study seeks to inform the concept of knowledge integration in team science collaborations, and to understand how researchers view success in the context of big team science projects. To do this, I apply these ideas in the context of a big team science project called iUTAH (innovative Urban Transitions and Arid-region Hyrdo-sustainability). This chapter outlines the methodological approach for this study, including the study context, sampling and interview methods for data collection, and analytical methods. The research questions for this study are reiterated here as follows:

- Research Question 1: What factors influence team research experience and effectiveness?
- Research Question 1a: How does team size influence team experience and effectiveness in a big team science project?
- Research Question 1b: How does the geographic dispersion of a large team science project influence team experience and effectiveness?
- Research Question 1c: How does cyberinfrastructure influence team experience and effectiveness in a big team science project?
- Research Question 1d: How does researcher rank influence team experience and effectiveness in a big team science project?

- Research Question 1e: How does researcher discipline influence team experience and effectiveness in a big team science project?
- Research Question 1f: What subjective interpersonal and intrapersonal factors influence team experience and effectiveness in a big team science project?
- Reseach Question 2a: What do researchers involved in big team science projects view as success?
- Research Question 2b: How do researchers involved in big team science projects think success should be evaluated?

Study Context

To address the above research questions, I chose to evaluate the iUTAH (innovate Urban Transitions and Aridrergion Hydro-sustainability) Program, which was a large team science project funded by the National Science Foundation's (NSF) EPSCoR Program (Established Program to Stimulate Competitive Research) from 2012 to 2018. iUTAH was established as a research and training initiative aimed at building research capacity and infrastructure for water sustainability in Utah, USA (http://iutahepscor.org/ accessed 1/8/2018). As the second driest state in the nation, water is a valuable and scarce resource for Utah. Compounding the problem of water scarcity is the fact that Utah is projected to double in population by 2050, thus creating a 'wicked' problem in the state oriented around water conservation that could ultimately influence the wellbeing of Utah citizens.

The iUTAH project addressed water sustainability in Utah by integrating physical, chemical, biological, and social systems. The project involved researchers and students from all of the research universities in the state (Utah State University, the University of Utah, and Brigham Young University) as well as most of the primarily undergraduate institutions (Dixie State University, Salt Lake Community College, Snow College, Southern Utah University, Utah Valley University, Westminster College, and Weber State University). The iUTAH project had three Research Focus Areas (RFA) to address water sustainability in Utah. RFA1 examined ecohydrology, RFA2 focused on the social and engineered water system, and RFA3 addressed coupled human-natural systems. These RFAs clustered over 100 researchers representing a diverse set of academic disciplines from the physical, engineering, and social sciences. iUTAH also emphasized outreach, education, and diversity and involved collaborations with many external partners and stakeholders representing both local and state governments and NGO's.

Qualitative Methodological Approach

A qualitative approach was used for this research using semi-structured interviews with iUTAH researchers to collect data in order to address research questions. Qualitative methods often emphasize the importance of context and treat individual experience as data (Neuman 2006). Science of team science scholars postulate that interviewing researchers involved in big team science projects could provide valuable insight into the processes in team science by illuminating similar and divergent perspectives (Stokols et al. 2008a). Additionally, semi-structured interviews are especially useful when trying to elicit comprehensive and detailed information on a particular topic (Rapley 2001), such as changes in research capacity due to team science (National Academy of Sciences 2005), and changes in research philosophy (Stokols et al. 2005).

Sampling and Interview Methods

This study emphasized gathering perspectives from iUTAH researchers. The sampling frame for this study included researchers who collaborated on scientific research activities as part of the three research focus areas involved in iUTAH. Originally, a list of iUTAH researchers was obtained from the iUTAH program office. The list contained 116 individuals that participated in iUTAH's research focus areas at some point over the course of the project. A criteria of involvement for inclusion in this study was established to include professors of all rank and post-doctorate researchers from Utah State University, the University of Utah, and Brigham Young University who were involved with iUTAH for at least two years. Those excluded from the study were researchers from primarily undergraduate institutions, graduate and undergraduate students, researchers who participated for less than two years, and external stakeholders involved in research. This criteria was established mainly due to time constraints of the researcher, and the time and cost it would have taken to address all the different participants in the project. Therefore, as the analytical focus of this project was on team experience and team science collaborations, only researchers from the institutions of the iUTAH principal investigators were addressed in this study.

With the help of the iUTAH program director, the total list of 116 researchers was culled to a sampling frame of 36 individual faculty and post-doctoral researchers. The sampling frame was structured to represent each of the three research focus areas in the iUTAH project, each university institution, and two categories of rank (full and associate professors in one category, and assistant professors and post-docs combined in the other) (Table 1). Semi-structured interviews were conducted with individual researchers involved in the iUTAH project to ascertain their perception of their experience collaborating within a big team science project. Participants were asked a series of questions stemming from the conceptual diagram to address the specific research questions. The interview protocol is shown in table 2.

Table 1. Number of researchers by rank, institution, and research focus area and number and percentage of researchers interviewed.

		RFA1: Ecohydrology		RFA2: Social/Engineering Water System		RFA3: Coupled Human/Natural Systems		TOTAL		
		Full or Associate Professor	Assistant Prof or Post Doc	Full or Associate Professor	Assistant Prof or Post Doc	Full or Associate Professor	Assistant Professor or Post Doc	Full or Associate Professor	Assistant Prof or Post Doc	Combined
USU	# of Researchers	4	1	4	2	4	0	12	3	15
	# of Researchers Interviewed	4	1	2	2	1	0	7	3	10
	% of Researchers Interviewed	100%	100%	50%	100%	25%	-	42%	100%	67%
U of U	# of Researchers	9	3	1	2	0	2	10	7	17
	# of Researchers Interviewed	4	1	0	1	0	1	4	3	7
	% of Researchers Interviewed	44%	33%	0%	50%	-	50%	40%	43%	41%
BYU	# of Researchers	3	0	0	1	0	0	3	1	4
	# of Researchers Interviewed	2	0	0	1	0	0	2	1	3
	% of Researchers Interviewed	66%	-	-	100%	-	-	67%	100%	75%
TOTAL	# of Researchers	16	4	5	5	4	2	25	11	36
	# of Researchers Interviewed	10	2	2	4	1	1	13	7	20
	% of Researchers Interviewed	63%	50%	40%	80%	25%	50%	52%	64%	56%
	Combined %	60%		60%		33%		56%		

Table 2. Interview Protocol
1. How would you describe your iUTAH experience? What did you do? 2. Was this project different then how you normally conduct your research activities? What do you feel your role was with the iUTAH project? Did this change over the course of the project? 3. Do you identify with a particular RFA? 4. Did being involved with a particular research focus area influence your research activities? 5. How was the experience collaborating with other researchers in your RFA? In iUTAH? Did this change over the course of the project? 6. Did you feel like part of a team from working with a particular RFA? iUTAH? Did this change of the course of the project? 7. Were there any factors or mechanisms that made working with other researchers more effective? created barriers? 8. Did being involved in iUTAH change how you will conduct future research? 9. Did being involved in iUTAH change your career trajectory? 10. What important collaborative successes have occurred because of iUTAH? 11.Were there any ‘‘missed opportunities’’ for collaboration in iUTAH? 12. Considering the successful outcomes that have occurred to date, what do you consider the added value of the iUTAH project?

13. If you were to participate in a similar large project again, what are some things you would do similarly? Differently?

14. How do you believe big team science projects should be evaluated?

15. How would you define “success” of a big team science project?

A purposive sampling technique was implemented, which has been recommended when selecting a difficult-to-reach, specialized population (Neuman 2006). This is an especially useful technique as it allows for the “judgement of an expert to select cases or when selecting cases with a specific purpose in mind” (Neuman 2006, 222). Additionally, this technique was used because it is valuable when analyzing types, and for comparisons across groups (Neuman 2006). Researchers were categorized based on their primary research focus area, their university affiliation, and their career rank.

Institutional Review Board approval was obtained for this research with human subjects and each participant was presented with an informed consent form stipulating that participant identity would remain confidential. Interviews were conducted with researchers between March 2018 and June 2018. Researchers in the sampling frame were solicited by an email from the researcher to see if they would be willing to participate in the interview process. Emails provided a brief description of the project and inquired about the availability and willingness of the researcher to particpate in an interview at a time and location of their choosing. All 36 researchers composing the sampling frame were invited to participate. If researchers didn’t respond within one week to the initial email, up to two reminder emails were sent. Ultimately, 20 researchers agreed to participate in an interview, for a participation rate of 56%. Interviews were mostly conducted in-person, with the exception of two researchers who had moved out of the state and were interviewed by phone. In-person interviews took place at the researchers institution in their office. Interview length ranged from 15 minutes to over an hour, with the average interview lasting just over 30 minutes. Interviews were audio recorded and transcribed for subsequent analysis.

Analytical Methods

The conceptual diagram described in Chapter 2 established the basis for analyzing the interviews. A thematic coding process was conducted by the researcher using Nvivo 12 pro, a qualitative research software program. The thematic coding process was done in two separate phases in order to capture findings regarding specific research questions as well as emergent findings. In the first phase of analysis, themes regarding the specific objective factors addressed in research questions were analyzed. Specifically, interviews were analyzed for findings regarding team size, geographic dispersion, cyberinfrastructure, researcher rank, and researcher discipline. This initial phase also included grouping interviews to represent the 3 categories of the sampling framework: RFA, instituion, and rank. In the second wave of analysis, interviews were analyzed for emerging themes that represented the objective and subjective processes inherent in a big team science project as well as information on what constitutes success in a big team project. The first phase emphasized the specific research questions that emerged from the literature, while the second phase was more exploratory in nature.

One limitation of this approach is the inability to measure and quantify the differences between factors and their specific influence on individuals and the group, making specific causal inferences hard to discern. However, due to the exploratory nature and ultimate aims of the research, this qualitative analysis illuminates useful insights in the inherent processes involved in big team science projects that can be used by future evaluations of big team science projects and by researchers involved in these projects. It is possible that on the basis of this study, survey instruments could be developed to enable more robust quantifiable interpretations.

The author acknowledges limitations in the collection and analysis of the project. Data collection was conducted at the end of a 6 year project, thus making it difficult to know how insight might have differed and fluctuated throughout the course of the project. Future studies could potentially benefit from taking a longitudinal approach, where researchers involved in collaborative research projects are interviewed at the onset of the project, and at periodic intervals throughout the project. This would help illuminate the dynamic nature of these projects, and to ascertain how researchers experience change over the course of the project. Additionally, due to how the sampling frame was developed, it is possible that those interviewed are only the researchers who had a positive experience in the iUTAH project, exemplified by their continued involvement to the end of the project. However, because the main research questions ask what processes ultimately lead to successful big team science outcomes, these individuals provided the necessary information and experiences to inform future interdisciplinary research endeavors.

Chapter 4 – Research Findings and Discussion

Factors Influencing Research Team Experience and Effectiveness

The overall objective of this study was to ascertain how objective and subjective factors influence the team research experience and team effectiveness. These factors were outlined and detailed in Chapter 2. Additionally, this study addressed the concept of knowledge integration and how this relates to project success and evaluation. This study provides science of team science scholars, and those interested in transdisciplinary research, a better understanding of the processes and outcomes in team science initiatives.

Team Size

The size of iUTAH as a whole created both challenges and benefits to team effectiveness as articulated by researchers involved. The nature and scope of the project required a variety of different individuals from many different institutions and disciplines to be involved in the project. Overall, there were over 100 researchers involved in the iUTAH project over the course of its existence from all 13 higher education institutions throughout the state. However, these researchers did not participate in the project equally, with some researchers only peripherally involved or only involved in the project for a short amount of time.

The sampling procedure and criteria of inclusion for participants in this particular study revealed how the large size of this project created substantial difficulties when it comes to teamwork. With the help of the program director, the list of all research participants (n = 114) was culled to meet the sampling criteria of the study, which was non-student researchers from the University of Utah, Utah State University, and Brigham Young University who were involved in iUTAH research activities for at least 2 years. This seemingly simple criteria cut the number of potential research participants by close to 70% (final n=36). This possibly indicates that social cohesion, which prior research has identified as a way to improve team effectiveness (National Research Council 2015), was low in this particular initiative.

The large size and scope of the project created barriers to teamwork in the context of the iUTAH project. As the size of team membership grew, so did the challenges involved in conducting collaborative science. This difficulty stemmed from what one researcher simply articulated as there being *"a lot of cooks in the kitchen"(University of Utah Researcher)*. As the size increased, so did the barriers to effective communication and goal alignments as articulated by the following quotes:

> *"There's no question that this project, because it was such a huge one, involved a whole lot of time over it. And that's my biggest complaint about it, but that's not anyone's fault. I mean, there were 100 plus people involved in iUtah and anytime you've got something that's that big, there's going to be a lot of meetings" – University of Utah Researcher*

> "*So the ecohydrology team was bigger, like 20 people. Then you have the social and engineering science, which was another 20 people. And then you have coupled human*

natural systems, which was another 20 people, and trying to get them all to articulate was a challenge." – Utah State University Researcher

"As soon as you get more than say 10 P.I.'s and their students it's a mess." – Utah State University Researcher

These findings reflect previous research discoveries, where the advantage of larger research groups declines over smaller groups as heterogeneity in disciplines and institutions increases (Cummings et al. 2013). Thus, while the large size of team science initiatives are often touted as one of the positive benefits of transdisciplinary research efforts, they also often create barriers to effective team research that are difficult to overcome. This is because in order for science teams to be effective, they must have a certain degree of group cohesiveness to facilitate communication and trust between researchers (Stokols et al. 2008b). Researchers involved in the iUTAH project articulated that the large team size and scope of the project created a barrier to the cohesiveness of the project, as represented in the following quotes:

"I felt like I was nominally on the team, but nobody was telling me or sharing what the plays were, or you know, what the game strategy was. It's like put on the uniform (name), and you know, sit on the bench." – University of Utah Researcher

"I would say both of them were a bit too big, at two different scales, but still too big to be really cohesive, and collective, or collaborative inclusively over the course of the project" – Utah State University Researcher

Many of the benefits of iUTAH articulated by the researchers seemed to accrue through the interactions in smaller groups of working researchers. Researchers continually articulated the one of the biggest benefits of iUTAH, and the large project size, as the facilitation of smaller working networks that allowed them to work with other like-minded researchers.

> *"There was really an integral group of people within RFA1, maybe as many as 10, that were really involved and really engaged and awesome. And then there were a bunch of others that would kind of come in and out here and there, and weren't as useful." – University of Utah Researcher*

Thus, while big team science initiatives may promote scientific collaboration, the iUTAH project highlights that benefits are realized in the form of smaller working collaborations. This is because the large team size and broad project goals of the initiative made it difficult for researchers to understand their specific roles in the project. Additionally, it created difficulty for researchers trying to understand who had what scientific expertise in the project, and how they could meaningfully collaborate. This was illustrated as researchers sought to contribute to the overall project, and find meaningful participation, as highlighted in the following quotes:

> *"You know, that was a great experience to see how these big projects work and to realize that, you know, the key is to find your niche, how can you contribute to the project, and then realize there are limitations. I mean, I probably was too, maybe a bit*

impractical in thinking how I could contribute in the beginning. Maybe having too many objectives, trying to accomplish too much"- Utah State University Researcher

"But then also trying to find ways where I could actually have some value added. Where I could contribute." – Utah State University Researcher

This insight can be useful as science of team science scholars and those involved in transdisciplinary collaboration try to find ways to make these initiatives more effective by targeting activities and research questions that facilitate smaller science teams. Additionally, clearly identifying researcher roles from the outset of the project, rather than having researchers try to find their own role and area of participation within the project could facilitate better collaboration in big team science projects.

Geographic Dispersion

The geographic distance between researchers was conceptualized as an objective factor that ultimately influenced team effectiveness. Geographic dispersion was continually mentioned by researchers as a challenge to collaboration that adversely affected team effectiveness. The collaboration between research institutions that were geographically distributed throughout the state of Utah created difficulty in communication by causing researchers to have to set aside additional time and resources for travel. This was especially burdensome in the context of large team project, because of the many individuals and meetings that were required in the project:

> *"Well, because our group was spread all over the state, we definitely had to adopt, succumb to, the idea of virtual collaboration, right? So, GoToMeetings, Zoom, whatever the collaboration software of the day was. We spent a lot of time on the phone doing teleconferences, video conferences, just because we couldn't always travel from point A to point B. So, we had to find ways to be effective in collaborating even though we couldn't be sitting in the same room with each other all the time." – Utah State University Researcher.*

In addition to communication issues, the geographically distributed nature of the project created a burden on research activities. The scope and aim of the iUTAH project encompassed areas all over Northern Utah, requiring a lot of travel in order to conduct and collaborate on research activities. *"Like having to go to a different campus is always difficult. So, that was certainly our biggest barrier" (University of Utah researcher).* Similarly, it created a difficult collaborative environment for researchers trying to collaborate on similar projects, for example, *"I was the only one up in Logan. So that was a barrier of me working with the other (researchers), just that physical barrier, the geographical barrier" (Utah State University researcher).*

In sum, the geographically dispersed nature of the project created a barrier to research collaboration by impacting the ability of researchers to communicate effectively, thus influencing team effectiveness. The geographic dispersion made it difficult for iUTAH researchers to participate in aspects of the project that required face-to-face interaction, such as attending in-person meetings as required for the project. This burden was especially noticeable by researchers when they were required to travel between different campuses in different parts of the state. However, researchers did find ways around this barrier, mainly by the use of cyberinfrastructure subscribing to the idea of “virtual collaboration”, as well as participating in infrequent large in-person meetings throughout the course of the project, which will be discussed in the following section.

Cyberinfrastructure

As articulated above, cyberinfrastructure was important for facilitating communication between researchers. This communication can be conceptualized as a subjective process that ultimately influences team effectiveness. Without the use of cyberinfrastructure and software platforms such as Skype, Zoom, and GoToMeeting, a project of this size and magnitude would not have worked well due to the large team size and geographic dispersion of team members, supporting the National Research Council’s (2015) suggestion on the importance of cyberinfrastructure for large team projects. Researchers continually articulated the benefits of having software and cyberinfrastructure available to them, especially due to the frequency of interactions and meetings, where researchers were often times participating in monthly online meetings as part of the iUTAH project. Furthermore, iUTAH provided the funding and resources necessary for these communication platforms that may not have otherwise been available to some researchers due to lack of resources. Researchers also articulated how the dynamic of online meetings was different than in-person meetings, especially in the context of large meetings with multiple team members, changing some of the dynamics of communication:

"Certainly, I mean being able to teleconference with people. There was I think kind of an expensive thing, software, that was purchased by iUTAH for subscription for a while called GoToMeeting and then there was one called Zoom and those were actually pretty effective. Zoom especially was really good, so you could get, you know, 25 different faces on your computer screen and you could hear each other and you could share the screen and show people a presentation. That's really critical if you've got people on the other side of the state. In my own research, because we don't have access to that software, I end up using skype for things like that. And it's okay. But it doesn't really work. Facetime is better for that, but not everybody has an apple computer and so seeing how professional teleconferencing works that actually costs money, comparing that to skype was an eye opener." – BYU Researcher

"*Well as like I said proximity really does help. You know I walk down the hall and knock on the door of colleagues all the time, so proximity helps. Now that we have video conferencing it made it quite simple, you know multiple people sitting there. The dynamic of that is different from when you're in the room. I think research shows that people behave differently on video conferencing than when they do when they're in the room. It's harder to kinda sense where the conversation is going, or read someone's body language, or you know jump in and interject a statement." - University of Utah Researcher*

The dynamic of online meetings was beneficial in some instances because it forced researchers to communicate due to the structured nature of the meetings. These online meetings were often scheduled in advance, allowing researchers the ability to schedule in structured time to communicate with team members, which has been shown to be one component contributing to team effectiveness as it facilitates collaboration and feedback links between team members (National Research Council 2015).

Rank

In this analysis, researcher rank was represented by two different categories. One consisted of post-docs and assistant professors (non or pre-tenure researchers), while the other combined associate and full professors (tenured faculty). There were considerable differences between the two groups and how they participated in the project, but the categorization also made it hard to disentangle the cause and effect of specific researcher rank on team participation. Nevertheless, there were some general themes that emerged pertaining to researcher rank that support previous literature on the topic, suggesting that participation may be influenced by the "career stage and training needs of members as well as the research goals of the team or group." (National Research Council 2015, 35).

An emergent theme regarding researcher rank was unique to the position of post-docs across all of those individuals interviewed. The post-docs interviewed seemed to perceive their role in the project as one with considerable freedom to pursue questions and collaborations that may not have been available to researchers of other rank on the project. This was due to the full-time nature of their position with iUTAH as well as the understanding they were only on the project for a short amount of time:

"Yeah I think I was in a privileged position as a post-doc, because I felt like I was more free to move, to work with the researchers that I wanted to work with. And I had more freedom to go to [another research institution] for example, and that was written into my job description, it gave me a lot more leeway to be able to do it." – Post-Doc

"Well, one nice thing is that I had flexibility, I mean, considerable flexibility within the balance of the project to sort of do what I want to do and go knocking on people's doors to try too, you know, kind of even make efforts at starting this kind of work. But, I think that it's really tough, now as I see it as a faculty member right, it's really tough to engage in those kinds of activities when you have all of your other responsibilities. So, I think, you know, I think … the post-docs in the project really had a nice opportunity and I think played a pretty key role in terms of developing that interdisciplinarity." – Post-Doc

These findings suggest that post-docs in large team science projects are likely fundamental in developing and driving collaborative research activities that may be unique to their position. Additionally, the aforementioned quote portrays the importance of understanding that general faculty participating in these large projects have a multitude of additional factors affecting their ability to participate fully in large team projects. Faculty, particularly junior faculty, are often under constraints relating to institutional structure, such as the need to publish and teach, that ultimately influence participation, portrayed by the following quote:

"Well a whole range of things. For junior folks its concern about getting proper credit for the work that they do. Some academic departments that are… exist largely in the

stone age want to see sole author, first author publications by the faculty member, and that's their only metric." – University of Utah Researcher

The experience of junior faculty members can be either positive or negative. The structure of a large team project can provide additional resources to newer faculty members in the form of funding and research collaborations, thus providing incentive to participate in team science. This incentive to participate has been shown to enhance collaboration in the context of big team science projects, ultimately having positive influence on team effectiveness (National Research Council 2015). This is reflected in the following statement:

"Yeah. It was kind of like, you know like I said, it was hard to know at the beginning what I should focus on, cause it's kind of a gamble deciding what you focus on, but what you choose actually pays off… you're able to get research funding, and grants, and papers. And so with iUTAH is was like okay here we go I have already got this research infrastructure in place, I'm just going to go for it, and it definitely worked out really well." – BYU Researcher

However, the structure of big team science can also create barriers for junior faculty members looking to advance their careers, ultimately de-incentivizing their participation in big team science projects as portrayed by the following quote:

"So I kind of left the whole thing going, "gosh" you just can't do that when your young, you don't have time to invest and not have anything to show, because the people who count beans, all the people up on campus, they don't care that you spent the last two

years figuring out how to talk with other groups. Right. So I was left going, "the idea is great… what comes out of it is too long sighted for a university system with young faculty." – USU Researcher

Faculty of all rank have additional job requirements that create barriers to be able to participate fully in team research activities. This includes additional teaching and administrative responsibilities that make participation in team research activities much more difficult to achieve, as portrayed in the following quote:

"*You know… you can't make a meeting because you got two other things or you're just meetinged out. So, you have to decide, well, this is not a high enough priority for me. You know, I've got to read these, or whatever else it is." – Utah State University Researcher*

Researchers are often involved in multiple research projects all requiring additional time. This balancing of additional responsibilities beyond iUTAH was captured in some degree throughout all interviews with researchers across all ranks, thus making any generalizable insight related to research rank between assistant, associate, and full professors hard to discern. Variability more likely stemmed from individual researchers and their relative workload outside of the context of iUTAH, as well as their willingness to invest fully into iUTAH projects. This supports previous literature suggesting that researchers act as "free agents" due to their relatively autonomy to participate in team science, and commitments such as funding, teaching and other research commitments, and personal interest in the particular project (National Research Council 2015, 35).

Discipline

There were no identifiable differences between particular researcher disciplines and the influence on team research experience and effectiveness. My study did not reveal any particular patterns regarding specific disciplines and their effect on team experience and effectiveness. This portrays the same phenomenon as outlined above in researcher rank, where researchers have the ability to act as “free agents” in these research projects. Thus, the variability in these projects is not reducible to specific researcher disciplines. However, researchers did articulate that one of the benefits of the iUTAH project was its ability to group together researchers from a diverse set of disciplines, thus exposing them to individuals and ideas outside their current collaborative networks.

Research Focus Area

One finding that emerged from this study was the effect that Research Focus Areas had on team experience and effectiveness of participating researchers. Participants articulated the benefit of the research focus areas as providing an organizational structure for such a large project. This structure was necessary for the budgetary logistics of the project, as well as providing researchers an overall research topic to guide their research activities. Researchers articulated both positive and negative effects related to research focus areas, and these responses varied by individual, thus suggesting it was not the research focus area influencing these responses, but rather individual researcher perception of the research focus area.

Some researchers used the research focus areas to guide their specific research activities and mainly collaborate with others within their particular research focus area as exemplified in the following passage:

> *"I think that it allowed me to just be focused on data collection, rather than the modeling, even though I am a modeler… Where with (RFA) we were able to focus on let's just collect some good data, and see what we can make from that. And it's turned into some really interesting [products]…"- Utah State University Researcher*

Thus, research focus areas provided the topical structure needed to guide research activities in such a large initiative. However, these also created some artificial barriers to collaboration, as some researchers only worked and collaborated within their particular researcher focus area. This is shown in the following quote:

> *"Yeah almost everything I did was RFA1, so that's who identified with. Okay yeah, so I guess the bigger picture… the things that maybe didn't work out… for me personally, the interactions from RFA1 to RFA2, and then especially with RFA3, never really panned out... like we tried a couple of times to talk about that, but it was almost like speaking different languages." – BYU Researcher*

However, some researchers were able to break this barrier created by the research focus areas and collaborate with individuals outside of their affiliated research focus area:

"It probably influenced me in ways that I was not conscious of, for example I was on the RFA2 email list serve, so I only received messages from RFA2. Despite that, so I probably only received information on what was going on in RFA2, but despite that I also worked with people from RFA1 and RFA3, so beyond what I didn't know about, I don't think it influenced me very much." – Utah State University Researcher

Additionally, my findings suggest that research focus areas posed an initial barrier to collaboration that, once overcome, led to integration between researchers. This integration was achieved as researchers became affiliated with more than one specific research focus area through being involved with multiple projects, and collaborating with multiple researchers. Many researchers articulated they felt affiliated with more than one research focus area, and that it was hard to keep track of what projects fell into what particular research focus area. The integration of focus areas took time, and occurred near the end of the project as exemplified:

"I think really towards the end of the project, the way we talked about it also, things were starting to become so interactive among the RFA's we really even stopped talking about the project in terms of RFA's towards the end. I think the way we wrote our reports, we had milestones specific to RFA's, but things were really starting to become more integrated, so over time… if there was ever a time I felt connected to the RFA3, it was early in the project, and then towards the end of the project everything was really integrated iUTAH" – University of Utah Researcher

Research focus areas can provide the structure needed to organize large team science projects by guiding specific goals and research activities. However, these artificial boundaries can hinder the ability for researchers to collaborate across research focus areas and thus decrease overall integration in the project. Researchers can overcome these barriers through targeted interaction between researchers affiliated with different research focus areas, or among researchers who feel they have an affiliation with more than one research focus area. The research boundaries seemed to become less of a barrier as the project evolved over time and as collaborations matured. The variability in collaboration between the research focus areas highlights the different individual researcher experiences, as some researchers felt the research focus areas were not a barrier to collaboration, while some felt hindered by the perceived constraints of affiliation with a particular research focus area. Thus, this suggests that projects that involve large research focus areas are beneficial in grouping experts from diverse backgrounds together, and increasing the diversity of expertise, which ultimately increases the possibility for collaboration. However, in regards to actually conducting research, researchers fragmented into smaller working groups within and across the RFA's.

In-person Meetings

Researchers regularly articulated the benefit of having in-person meetings with everyone involved in the project in order to facilitate better communication and understanding of what was being done by different researchers in the project. These in-person meetings facilitated individual interactions between researchers that catalyzed emergent research products and collaborations that otherwise may not have been established, thus ultimately contributing to overall team effectiveness as captured by the following quotes:

"When we had all-scientists meetings, it made sense. In part because often times I think these all science meetings, or all participant meetings, it was sharing what had happened, and they were incredibly productive, and it was awesome to see sort of how connections were being made."- BYU Researcher

You know, I do…as much as I, you know, whine a little bit about the Zoom thing, I think it made a difference. It forced us to talk. And then, same thing with the all hands meetings and the, you know, other kinds of activities that we would engage in. You know, we got to know each other. You know, I've made a lot of trips to Salt Lake City and, you know, and some to Provo as well, you know, to engage with people, because of iUtah. – USU Researcher

"I think also the fact that we had 3 all-hands meetings a year, that bring people face to face was helpful." – Utah State University Researcher

The aforementioned quotes also highlight the importance of face-to-face interaction, and social interaction in general. As science of team science scholars look for ways to make collaboration more effective, the importance of having researchers spend time together cannot be overstated. In-person interaction is a precursor to social cohesion that leads to team effectiveness. This is highlighted by a researcher who was skeptical of all the time and interaction required in these projects when asked about mechanisms that helped working with researchers more effective:

"I hate to say it, but you… I'm sure you know it's true… spending time with people is critical. Time communicating your science, time learning how people think, if you want to work well with somebody, you learn how they think, and when you're dealing with somebody who thinks about social sciences vs. natural sciences, the thought processes are very different, so the only way to overcome those barriers is by spending time, and by talking, and talking, and talking, and talking, and talking..." – Utah State University Researcher

This quote portrays the importance of interaction and communication between researchers in order for team science to be effective. It also highlights the different thought process encompassed in big team science initiatives that can create a barrier to effective team science, especially between those representing different disciplines. However, this barrier can be overcome through frequent communication, and often a precursor to knowledge integration, which will be discussed in the following section.

Defining and Measuring Success

As discussed in chapter 2, success is a difficult concept to understand in the context of big team science collaborations. This stems from the diversity of projects, and the concept of knowledge integration, which is a difficult concept to measure, partly due to the process taking place at multiple levels, including both the individual and group. This analysis highlights and provides examples of what researchers view as success and how success is framed differently depending on the indivdiual. However, there were some general themes that emerged through discussion with research participants that reflect the success of the iUTAH project. Researchers involved in the project discussed how success occurred at multiple scales, including both the individual and institutional level.

In regard to evaluating the iUTAH project, findings from the interviews suggest the need to distinguish between two indicators of project success. These two categories relate back to the transdisciplinary research approach, where the outcomes of these initiatives differ by project goals and the problems they attempt to address. This distinction can be summarized as the need to evaluate both the tangible research products generated by the project (e.g. publications, additional grants, students graduated, etc.), as well the more intangible aspects of the project (e.g. building relationships, addressing broad project goals), which in the context of iUTAH was the building of social and physical infrastructure to address water sustainability in the state of Utah.

Researchers involved in iUTAH commented on the need to address research output in a traditional sense: *"Papers. Proposals. Funding. The things its supposed to be producing" (University of Utah Researcher).* However, some commments by the researchers portrayed the understanding that these types of metrics alone didn't quite capture the dynamic process of conducting transdisciplinary collaboration as captured by the following quote:

> *"It's very difficult to assess a project based on paper counts, even conference proceedings, etc. So I am not sure how to assess a project like this one, because it should be on collaborations, but how do you count collaborations? If you wait until a product comes out, well there are plenty of proposals that are developed that take 4 years to get*

funded, or papers… data collected for papers where it takes 5 years to get it published.” – Utah State University Researcher

This quote portrays the difficulty of the timelines of big team science projects, and how it creates difficulty in properly evaluating the project as a whole. This sentiment is also captured in another interview:

“Success of a project like this can only be defined 5 or 10 years down the way. I mean there are a whole bunch of metric, indicators, that we put together and NSF agrees, and these are the metrics that we will use, and that’s because they have to have something.” – University of Utah Researcher

While researchers understood the importance of using traditional indicators of project success, there was also the recognition that these didn’t fully capture the entire scope of what was done in the project. This was referred to as *“bean counting”* by multiple researchers, and while being helpful in some instances, in the context of big team science, may need to be supplemented by additional indicators as represented in the following statement:

“And that’s always going to have a certain bean counting aspect to it. Were always going to be counting how many publications, how many grants – new grants, how many students were trained, how many meetings were held with partners, how many… you know I can’t imagine that were ever going to get away from trying to quantify the output of these big projects as part of an evaluation. That said, I think that we, you know, there’s

> *got to be more to it than that, because … the whole is greater than the sum of its parts, and if all you do is count the parts you're just going to add up to something that is just less than this whole." – Utah State University Researcher*

This need to broaden project indicators of success stems directly from the approach of transdisciplinary collaboration, as indicators need to be developed that address both individual and group contributions. Traditional project output measures, such as research products, are usually indicative of individual level contributions, and fail to encompass some of the broader dynamics of knowledge integration occurring at the group level. This sentiment was captured in the following quote:

> *"The community as a whole will see that there are metrics, there are ways to evaluate group contributions as well as individual, and so it's a changing of the culture of science." – University of Utah Researcher*

These findings articulate how conducting transdisciplinary research is going to require a change in research culture surrounding how these projects are going to be evaluated. In addition to the difficulty for traditional indicators of project quality to capture group level knowledge integration between researchers in transdisciplinary research efforts, these indicators fail to show the knowledge integration achieved between researchers and stakeholders involved in the project. The inclusion of stakeholders from outside academia is one of the touted benefits of transdisciplinary research approaches, and this recognition was articulated by some researchers when discussing proper ways to evaluate projects like iUTAH:

"If there is any way to evaluate the total impact on stakeholders and, in addition to papers and proposals… that would be nice to know. Like I don't know how to do that, but that would be something I would be real interested to know. It's like okay so what new interactions came out of this." – BYU researcher

"I would not define success, that's the stakeholders. We should co-define, co-produce, definitions of success." – Utah State University Researcher

As science of team science scholars' work to define success in terms of big team science projects, they need to take a flexible approach and realize it is going to be project dependent. Traditional indicators of project success need to be broadened beyond the individual level to incorporate group level knowledge integration. In order for this to be achieved, these expectations must be recognized not only by individuals participating in these projects, but also by the institutions and departments where these projects are located. This is due to the fundamental difference in pursuing a big team science project that seeks to incorporate a transdisciplinary science approach, where project goals are often broadened beyond just academia.

Individual level knowledge integration

One of the main objectives of iUTAH was to facilitate the interaction between researchers from an array of diverse backgrounds, representing both the physical and social sciences. Many researchers articulated the interactions they had with researchers representing different backgrounds was one of the largest benefits derived out of participating in the iUTAH project, ultimately influencing their research activities. These interactions facilitated the process of knowledge integration, as captured in the following comment by a natural scientist discussing how he and his student integrated a social science concept through interaction and discussion at a project meeting with a social scientist:

> *"I loved seeing it, cause it is outside of what I typically do, and so it was really powerful to see their approach, and to see the links right. And so it really fundamentally changed the way that we were doing some of our stuff… And so her project, which is published and out, is exactly a reflection of me stealing ideas from the social scientist." – BYU Researcher*

The above quote portrays a direct example of how knowledge integration translated to a specific research product in the form of a journal article. However, the concept of knowledge integration can manifest in ways at the individual level that aren't captured in traditional scientific forms such as journal publication. Researchers involved in the iUTAH project articulated that by just being involved in a big team science project itself was an experience that translated directly to how they conduct research as shown in the following comments:

"I learned a lot, and I continue to use my experience from iUTAH when working with my colleagues here at (institution) and also with stakeholders… I am constantly talking about oh well in [iUTAH] I did this and this is how it is informing my current projects." – Utah State University Researcher

"And so, I learned a lot about the different ways people do research, the different types of data people produce, what people's ideas and perceptions are about what is data and what is not data, what can be shared, what can't be shared, what's public and what's not public. You know, all of these kind of things. So, in terms of my personal experience, I learned an awful lot" – Utah State University Researcher

"So, those were really useful conversations. And I learned a lot from them about other people's research and their discipline and how they saw their research and how conceptualized their research." – University of Utah Researcher

These personal interactions allowed for knowledge integration at the individual level manifesting in research collaborations that were facilitated by the iUTAH project. Furthermore, these collaborations were established between researchers representing diverse and distinct backgrounds. There didn't seem to be any particular pattern to the collaborations between disciplines, as researchers articulated a variety of different collaborations that spanned both related and seemingly disparate disciplines.

Previous transdisciplinary collaboration studies identified an adapted form of the "Mars-Venus effect" (Originally written to highlight the grouping of individuals by gender preferences)

(Gray 1992), in which particular groups of investigators work together based on scientific perspectives, collaborative orientations, and experiences (Stokols et. al 2005). In their study, Stokols et al. (2005) found significant differences in perspectives between neuroscientists and behavioral scientists involved in a transdisciplinary research effort regarding the collaborative processes and outcomes they experienced, including scientific integration. This effect was somewhat captured in some of the interviews as participants brought up the difficulty of trying to produce collaborative science, especially when trying to integrate between the physical and social sciences as captured by the following:

> *"You're working with geologists, hydrologists, to soil scientists… some kinds of ecologists, studying microbes or plants or whatever. And so that scale, that is a very interdisciplinary undertaking. And then I feel like iUtah tried to make that further leap to bring engineers and social scientists into the mix… it's challenging enough just to get kind of the biological or physical scientists working together" – University of Utah Researcher*

However, this limiting effect articulated above seemed to be overcome in some other instances of collaboration as outlined by a biophysical researcher discussing the efforts to collaborate between the social and the physical sciences, *"it's something that you can't disconnect, so I learned to appreciate the need for social science research and the value of that in the natural sciences." (Utah State University Researcher)*. Additionally, this integration of seemingly disparate disciplines was captured as one researcher articulated one of the benefits of their experience in iUTAH:

"I did learn more about the engineering, and in the end that was probably one of the most fulfilling parts of being involved in iUTAH, because I love this interdisciplinary space, and so finding ways to create new questions and see how the engineering sciences and the social sciences could fit together… is probably one of the most exciting things" – Utah State University Researcher

Previous research on collaborative science suggested the tendencies of collaborative initiatives may result in greater separation and fragmentation between disciplines representing different areas of research (e.g. natural vs. social sciences), but the iUTAH experience suggeests that these gaps can be overcome to achieve fruitful collaborative efforts and experiences.

Institutional level knowledge integration

Knowledge integration at the individual level was facilitated and developed by researchers' involvement in the iUTAH project. This individual level integration translated into broader institutional level knowledge integration that was described by the iUTAH participants as one of the main components of added value of the project. The development and benefit of the research collaborations across institutions was heard across all of the interviews. These collaborations occurred both within and between the institutions involved as captured by the following quote:

> *"Collaborative success of iUTAH are the three universities are much more closely linked together, and there is a much greater awareness both within and between the universities of the strength and expertise that's available for projects. People that were just down the hall from each other, or in one building next to each other on campus now know that, hey wow, I didn't know there was someone here who did that. By the same token, people as USU now know that there are folks at BYU and UU and vice versa." – University of Utah Researcher*

The increase in collaborations, and understanding where particular research expertise can be found across the state, are primary examples of knowledge integration at the institutional scale. This sentiment was captured in many of the interviews, and portrayed well by a research who said, *"when I have a problem, I know who to call." (BYU Researcher)*.iUTAH facilitated the understanding for participants of where particular research expertise is located throughout the state, as well as fostered relationships between individuals that may not have occurred otherwise. This resulted in many second generational projects developed by iUTAH researchers that were directly related to participation in the iUTAH project, but that may not be treated as explicitly linked to iUTAH project success. Multiple researchers articulated that their current projects were catalyzed by relationships formed in the iUTAH project, although not necessarily oriented around iUTAH topics.

CHAPTER 5 – Conclusion

One attempt to mitigate contemporary social problems has been the implementation of large team science programs. These initiatives have been recognized as having the potential to address complex issues (i.e., wicked problems) through transdisciplinary research collaboration. That is, these projects usually involve expertise from a wide variety of disciplines and incorporate knowledge from relevant stakeholders. This integration of knowledge from a myriad of experts is the often the main goal of transdisciplinary research efforts, as it offers the greatest potential to be able to grasp and provide solutions to complex problems. However, the wide variety of knowledges present in these large team science initiatives also create challenges to successful transdisciplinary collaboration, especially with regards to knowledge integration.

The challenges inherent in big team science projects, and the attempt for transdisciplinary research collaboration more broadly, led to the development of the field of the science of team science. Researchers in this new burgeoning field have been interested in better understanding how to make these big team science projects more effective. This is especially prudent, as big team science projects often require substantial funding and time. Specifically, scholars in the field have called for a better understanding of the individual and group (e.g. intrapersonal and interpersonal) processes that lead to successful knowledge integration, and a better understanding of how to best assess and evaluate team science initiatives (Hall et al. 2008; Stokols et al. 2005; Stokols et al. 2008a).

This study addressed this research agenda by incorporating a sociological perspective to assess researcher perspectives on being part of a big team science project called iUTAH, established to address water sustainability in Utah, USA. Guided by a sociological perspective and social theories regarding knowledge integration, this research applied a conceptual diagram adapted from a prior conceptual model put forth by Stokols et al. (2003). This study's conceptual diagram split the factors influencing team experience and effectiveness into objective and subjective factors, and used individual researcher experience to illustrate how these factors influenced individual and group processes in transdisciplinary collaboration. Additionally, this research used individual researcher experience to illuminate and highlight the concept of project success.

Findings from this analysis illustrate the challenges inherent in large team size in terms of overall team experience and team effectiveness in the context of transdisciplinary science collaboration. Large team size challenges the social cohesiveness of the team, which is one factor that has been shown to improve team effectiveness (Godemann 2008). Researchers in the iUTAH project articulated the difficulty large group size posed for communication within the project, as well as on understanding of their roles within the project, thus undermining the social cohesiveness in the project. Researchers often discussed the benefit of the iUTAH project as facilitating smaller working groups of researchers that were then able to collaborate effectively on team research. Previous literature on team size and overall team effectiveness illustrates that large team sizes helps address complex issues, along the lines of “more hands make light work” (National Research Council 2015, 33). However, this study illustrates the difficulty team size creates for meaningful collaboration. Future big team science projects need to find ways to facilitate social cohesion among all team members or design projects around smaller research teams.

The geographic dispersion of the iUTAH project was another factor that created difficulty for researchers and had negative implications for overall team experience and effectiveness. While the geographic dispersion of the initiative allowed for multiple institutions to participate in the iUTAH project and increased the overall expertise in the project, it also created challenges for effective collaboration. The distance between researchers hindered the ability for researchers to collaborate within the project and decreased the ability to interact face-to-face with other team members. However, this challenge was somewhat mitigated through the implementation of virtual collaboration or cyberinfrastructure, and the use of communication software such as Zoom and GoToMeeting. This verifies previous literature on the importance of virtual collaboration and the use of communication technologies to increase team effectiveness (National Research Council 2015). Future team science collaborations that involve team members from different geographic locations must ensure the proper amount of funding is available to support virtual collaboration and ensure researchers have access to virtual collaboration software programs.

Previous literature has shown that tenure criteria and ranked promotion are barriers to transdisciplinary research (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine 2005), as researchers are often worried that pursuing team science will hurt their chances at promotion due to institutional requirements and criteria. Findings from this analyses are mixed, with some junior researchers reporting that participating in iUTAH facilitated a working network and provided structure and resources that allowed them to flourish, while others reported the difficulty it created for them as junior faculty worried about the tenure process. Additionally, this research highlights the important role post-docs can play in big team science projects, as they have the freedom to pursue questions and research activities that junior and senior research faculty do not have. Post-doctoral researchers can specifically focus on the project unencumbered by institutional constraints such as teaching responsibilities. Future team science collaborations would benefit from funded post-doc positions, as these positions allow researchers to be creative and pursue questions that other research faculty may avoid.

The separation of the project into specific research focus areas was both beneficial and challenging. Research focus areas gave structure to the overall project that was necessary for budgets and for researchers to identify with a particular group. However, this separation created barriers that sometimes hindered collaboration opportunities. Future projects would benefit from separating into particular research focus areas, but the goals of each focus area should be clearly articulated to the researchers, and guidelines for how the research focus areas should collaborate between themselves should be outlined. Activities that attempt to integrate research focus areas should be emphasized throughout the project, and researchers from all focus areas should have the opportunity to interact face-to-face and pursue opportunities to collaborate.

To increase team experience and overall team effectiveness, the importance of in-person meetings cannot be overstated. Conducting science that is oriented towards integration requires researchers to be familiar with and trust one another, which influences overall team effectiveness (National Research Council 2015). This reflects in overall group cohesiveness, which has been articulated as the "sum of all the forces binding the group together" (Godemann 2008, 635). Researchers in the iUTAH project emphasized the importance of face-to-face meetings on their overall experience and understanding of the project. These face-to-face meetings catalyzed research activities and research collaborations that were integral to the iUTAH project as a whole. Additionally, these collaborations catalyzed many second generation projects that grew from researchers

Regarding the knowledge integration in the iUTAH project, this study highlights the need to distinguish between two scales: individual level knowledge integration and institutional knowledge integration. The use of the qualitative approach, specifically in-person interviews, elucidated how the iUTAH project facilitated knowledge integration among researchers who participated in the project. Findings highlight the nuanced nature of knowledge integration and how previous metrics attempting to measure this concept (e.g. bibliometrics) may not capture the entire process.

Individually, researchers articulated the benefit of the iUTAH project as catalyzing research networks by introducing them to researchers throughout the state. These networks facilitated knowledge integration at the individual level by exposing them to previously unknown concepts and methods, and through interacting with researchers outside their primary disciplinary affiliation. This translated to research products such as journal publications, which bibliometrics address. However, this also translates into more nuanced integrative products, such as co-developing classes and multi-institutional committees for graduate students.

This individual level knowledge integration then culminates in institutional level knowledge integration, as researchers throughout the state attempt to work more collaboratively. This is portrayed by multiple institution grant proposals, and even the more nuanced understanding that researchers now know who in the state to call when they have a problem regarding their research. Additionally, this is portrayed through the involvement with external stakeholders in both state and local government, as well as local NGO's. The iUTAH project facilitated the sharing of datasets between university researchers and community partners that will bolster the capacity for these partners to conduct research and inform decisions. It also facilitated the interaction and subsequent relationships between university researchers and local stakeholders that could prove beneficial for future research collaborations.

These types of multi-institutional collaborations, both among universities, and between universities and external stakeholders highlight the importance for the distinction between interdisciplinary and transdisciplinary research approaches to be made explicit in collaborative research. This analysis illuminated how researchers involved in these big team science projects feel the projects should be evaluated. Researchers distinguished between the more traditional indicators of project success, such as research publications, and grants and more nuanced, context-specific measures or evaluations such as meeting project goals. This sentiment is captured in the following quotes:

> *So, I think a large research project should be evaluated on the standard federal grant method like publications and presentations, but it should also in this case have a heavy emphasis on the capability that we developed in the state because of products we didn't have before. – University of Utah Researcher*

> *[B]ut if you have changed the way a lot of faculty, especially stakeholders do things, and have trained a lot of students who are successful in going out and now have a different vision that you don't only have to be a sole investigator, or its okay and valued to work with stakeholders, and you don't just disseminate information to stakeholders, you engage with them early. If you've hit all of those things and those people continue to do that… then it's successful. – University of Utah Researcher*

The involvement of external stakeholders is the key distinction between interdisciplinary and transdisciplinary research approaches that needs to be made explicit in the literature. However, the iUTAH project portrays how big team science projects can involve both types of collaboration under the umbrella of one project, as there are projects that involve only academic researchers, as well as projects that incorporate stakeholder involvement. Therefore, this distinction should be made clear from the outset of the project, because involvement of stakeholders outside of academia requires a fundamentally different approach to how science should be conducted and evaluated, and the time necessary to be successful.

Findings highlight big team science collaboration is indicative of mode 2 knowledge production as described by Gibbons (1994). Gibbons (1994) described mode 2 knowledge as being produced in the context of application, and contrasted mode 2 with mode 1 by suggesting that mode 2 is more socially accountable and reflexive. The social accountability and reflexivity was captured in responses by iUTAH researchers, who understood their science was meant to inform and bolster local stakeholder decision-making. This is captured in the following quote:

> *We've driven water conservation throughout the state with various water agencies… those were vastly strengthened by the iUTAH project and continued our motivations for the research that we do, and also continue resources by providing data sets and guidance for the work that we do. And then related to the stakeholders, stakeholder engagement, there was information that was given to stakeholders. So the decisions-makers in the state now have quantitative guidance on potential difficult decisions they need to make in regard to water over the next 30 years. – University of Utah Researchers*

This sentiment illustrates the understanding that the work generated within the iUTAH project was largely oriented toward the public and external stakeholders. Therefore, science of team science scholars and those participating in transdisciplinary research approaches need to develop methodology and evaluation methods that account for this type of knowledge production, because as one researcher succinctly puts it *"I would not define success, that's the stakeholders. We should co-define, co-produce, definitions of success" (Utah State University Researcher).*

The findings in this analysis illustrate some of the nuance in big team science and created an impetus to revise the original conceptual diagram guiding this study. Findings illustrate the dynamic and difficult nature of separating out the dynamic objective and subjective factors independently. Instead, the individual researcher experience evolves over the course of a project and through participation and experience with the larger group. The iUTAH project started with individual researchers who brought particular expertise to the project. Throughout the course of the project, and by navigating through objective group factors, researchers became more familiar with one another, portraying a degree of social cohesiveness that then facilitated effective team collaboration. Each individual researcher experience within the iUTAH project was unique and influenced by a variety of factors that are difficult to capture in one overall conceptual diagram. Individual researchers navigating through the iUTAH project had aspects that were unique to them, and it is difficult to capture this variation in one monolithic conceptual diagram. Therefore, the original conceptual diagram was modified and corrected to allow for variability and unique researcher experience in participation in the project. Additionally, the concept of knowledge integration is better articulated as its own category, with both individual and group levels. Furthermore, the concept of knowledge integration is a precursor to project success, instead of an indicator of project success. The revised conceptual diagram is portrayed as follows:

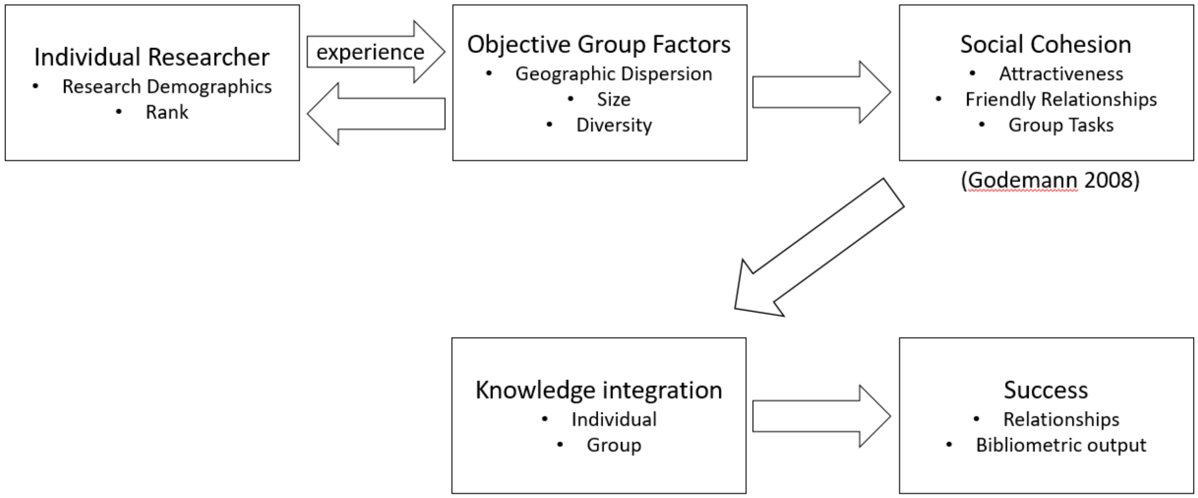

Figure 2. Revised conceptual diagram of factors influencing team science success

This analysis contributes to the science of team science literature by highlighting factors that influenced team experience and effectiveness in the context of the iUTAH project. These findings are based on a particular team science project and may reflect unique features of the iUTAH project. However, findings from this study did support previous science of team science findings and highlight new areas for future investigation.

Future studies evaluating big team science projects would benefit greatly by employing this qualitative interview method to address the concept of knowledge integration. However, it is recommended that this be technique be employed at the onset of the project, and continue in stages throughout the course of the project. This would capture the changes that occur throughout the course of a big team science project, instead of limiting it to just a cross section at the end of a project. Additionally, findings from this study highlight the need to involve external stakeholders in the evaluation process, specifically how involved stakeholders activities were influenced by the research findings. Future studies could employ techniques that address and involve stakeholders to gain a better understanding of the knowledge integration and success of the project for all those involved, including how various stakeholders implemented findings into their day-to-day activities and how they spefically used the project to better inform their decision-making.

As transdisciplinary collaboration and big team science projects continue to be developed and implemented to address contemporary social problems, researchers participating in these projects need to understand uniqueness of this type of scientific approach. Additionally, institutions where this type of collaboration is supported and occurring, may need to change institutional reward structures to encompass the broad ranging outcomes of these large big team science initiatives. This includes rewarding both tangible (e.g. papers and grants) and intangible research products (relationships and increased capacity) that these projects produce.

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