

SOCIAL MECHANISMS OF LEADERSHIP EMERGENCE:
A COMPUTATIONAL EVALUATION OF LEADERSHIP
NETWORK STRUCTURES

By

Daniel Jacob Griffin

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Psychology — Master of Arts

2020

ABSTRACT

SOCIAL MECHANISMS OF LEADERSHIP EMERGENCE: A COMPUTATIONAL EVALUATION OF LEADERSHIP NETWORK STRUCTURES

By

Daniel Jacob Griffin

Leadership emergence is a topic of immense interest in the organizational sciences. One promising recent development in the leadership literature focuses on the development and impact of informal leadership structures in a share leadership paradigm. Despite its theoretical importance, the network perspective of leadership emergence is still underdeveloped, largely due to the complexity of studying and theorizing about network-level phenomena. Using computational modeling techniques, I evaluate the network-level implications of two existing theories that broadly represent social theories of leadership emergence. I derive formal representations for both foundational theories and expand on this theory to develop a synthesis theory describing how these two processes work in parallel. Results from simulated experiments indicate that group homogeneity is associated with vastly different leadership network structures depending on which theoretical process mechanisms are in play. This thesis contributes significantly to the literature by 1) advancing a network-based approach to leadership emergence research, 2) testing the implications of existing theory, 3) developing new theory, and 4) providing a strong foundation and tool kit for future leadership network emergence research.

Dedicated to Lizzy Ann,
My Friend, Confidante, and Love of my Life
... also, my editor.
Thanks for everything.

ACKNOWLEDGMENTS

I would like to express my sincere gratitude to my mentor Dr. Steve Kozlowski for his knowledgeable direction for my research and continuous support of my goals. Thank you for putting up with a barrage of emails and requests for help with some aspect of the thesis or other. Thank you for encouraging me and for enabling me to do my best work.

Secondly, I would like to thank my thesis committee members, Dr. Richard DeShon and Dr. Zachary Neal for invaluable aid on both conceptual and methodological points necessary to this thesis. I am very grateful for both their enthusiastic support for my goals, ideas, and research, as well as their realistic assessments of issues in my work or reasoning.

Thirdly, I would like to thank Dr. John Schaubroeck for his mentorship early on in this process. Thank you for providing some of the initial direction that lead to this work.

Lastly, I would like to thank my wife Lizzy, my parents, and my friends who have tirelessly put up with me, listening as I explained the same idea yet again, talking so fast that I did not finish my sentences. Thanks for smiling and nodding excitedly even when you were bored or had no idea what I was talking about. Thanks for providing critical feedback and helping me to polish my work. Thanks for everything.

TABLE OF CONTENTS

LIST OF TABLES	vii
LIST OF FIGURES	ix
KEY TO ABBREVIATIONS.....	x
Introduction.....	1
Review of the Literature	3
Leadership Networks	3
Theories of Leadership Emergence	10
Social Identity Theory of Leadership.	11
Claiming and Granting Theory of Leadership.	14
Integration of Theories and Hypotheses.	18
Two Process Theory of Leadership Emergence (TPTL)	26
Contextual influence.	30
Correspondence in implicit theories of leadership.....	35
Methods.....	37
Overview of Methodological Approach	37
Evaluating theory.	37
Formalization of theory.....	39
Computational modeling.....	42
Computational Modeling Procedure	43
Formalization.	43
Computerization.....	44
Parameterization.	45
Generative sufficiency.	46
Simulation procedures.	48
Measures of team attributes.	49
Evaluation of Leadership Networks.....	50
Generating unweighted networks.	50
Network measures.....	51
Collinearity with density.....	56
Analysis.....	56
Statistical significance.	57
Results.....	58
Study 1: Comparison of SITL and CGTL.....	58
Study 2: Heterogeneity in SITL	60

Study 3: Heterogeneity in CGTL	63
Study 4: Heterogeneity in TPTL	66
General pattern TPTL.	67
Moderation analysis in TPTL.	68
Study 5: Exploratory Hypotheses	70
Context.....	71
Leadership prototype heterogeneity.....	72
Discussion	74
Limitations	80
Future Work	81
Conclusion	84
APPENDICES	86
Appendix A: Formal Hypotheses.....	86
Appendix B: Representations of SITL, CGTL and Synthesis Model Processes.	90
Appendix C: Formalization Process	92
Appendix D: Generative Sufficiency Test.....	111
Appendix G: Correlation Tables.....	113
Appendix H: Multiple Regression Tables.....	121
REFERENCES	123

LIST OF TABLES

Table 1: Table of network characteristics used as outcome variables for analysis.	53
Table 2: Regression results for Study 1 comparing the differences between SITL and CGTL mechanisms	59
Table 3: Regression results for Study 2 evaluating the impact of group heterogeneity emergent leadership network structures in the SITL based model.	61
Table 4: Regression results for Hypothesis 3 of in Study 3 assessing the relationship between leadership network characteristics and heterogeneity in CGTL teams with a shared schema.	63
Table 5: Regression results for Hypothesis 3 and 4 in Study 3 assessing the moderated relationship between leadership network characteristics and heterogeneity in CGTL teams.	64
Table 6: Regression results for test of Hypothesis 9 in Study 4 assessing the general relationship between leadership network characteristics and heterogeneity in TPTL teams.	67
Table 7: Regression results for Hypothesis 6a and 7a in Study 4 assessing the relationship between leadership network characteristics and heterogeneity in TPTL teams with either a shared schema or hierarchical schema	69
Table 8: Regression results for Hypothesis 6 and 7 in Study 4 assessing the moderated relationship between leadership network characteristics and heterogeneity in TPTL teams.	70
Table 9: Regression results for Study 5 assessing the impact of average contextual pressure to join the group in TPTL teams on leadership network emergence.	71
Table 10: Regression results for Study 5 assessing the impact of the skew in contextual pressure to join the group in TPTL teams on leadership network emergence.	72
Table 11: Regression results for Study 5 assessing the impact of the variability in leadership prototype TPTL teams on leadership network emergence.	73
Table 12: Relationships Described by Hypotheses.....	75
Table 13: List of Formal Hypotheses of the Models	86
Table 14: Variables and Parameters Associated with the Social Identity Theory of Leadership Formal Model.....	97

Table 15: Processes Mechanisms and Equations Associated with the Social Identity Theory of Leadership Formal Model.....	97
Table 16: Variables and Parameters Associated with the Claiming and Granting Theory of Leadership Formal Model.	103
Table 17: Processes and Equations Associated with the Claiming and Granting Theory of Leadership Formal Model.....	104
Table 18: Processes and Equations Associated with the Formal Synthesis Model.	109
Table 19: Tests for Explicitly Encoded Process Mechanisms	111
Table 20: Tests of Theoretical Predictions.	112
Table 21: Means, standard deviations, and correlations with confidence intervals for SITL simulations.....	113
Table 22: Means, standard deviations, and correlations with confidence intervals for CGTL simulations.....	115
Table 23: Means, standard deviations, and correlations with confidence intervals for TPTL simulations.....	118
Table 24: Multiple regression results for each criterion variable predicted by mechanism type, heterogeneity, and leadership schema.....	121

LIST OF FIGURES

Figure 1: Traditional and network perspectives of leadership	5
Figure 2: Example diagram for the processes described by Social Identity Theory of Leadership	8
Figure 3: Example diagram for a longitudinal representation of the processes described by Social Identity Theory of Leadership	9
Figure 4: Figure 4. Example diagram of the complex mechanism described in Social Identity Theory of Leadership.	9
Figure 5: Scatter plot of the relationship between team heterogeneity and variance in influence strength for team simulated from the SITL model.....	62
Figure 6: Graph of interaction between average leadership strength and heterogeneity for team simulated with the CGTL model.....	66
Figure 7: Graph of interaction between average leadership strength and heterogeneity for team simulated with the TPTL model.....	68
Figure 8: Representation of mechanisms described by social identity theory of leadership	90
Figure 9: Representation of mechanisms described by Claiming and Granting theory of leadership.	91
Figure 10: Representation of the synthesis theory of leadership emergence.....	91

KEY TO ABBREVIATIONS

CGTL Claiming and Grating Theory of Leadership

SITL Social Identity Theory of Leadership

TPTL Two Process Theory of Leadership

ILT Implicit Leadership Theory

CM Computational Modeling

Introduction

Throughout the history of organizational and management sciences, leadership has been a topic of supreme interest. Despite its apparent importance, we know relatively little about the mechanisms by which leadership emerges in a team. Specifically, the impact of social context on leadership emergence has often been overlooked in the literature (Shamir & Howell, 1999). Leadership is inherently embedded in a social context (Lord et al., 2017; Parry, 1998), making it imperative that we understand the processes by which this social context impacts leadership emergence. Various theories have proposed social mechanisms driving the process of leadership's emergence (Claims and Grants: DeRue & Ashford, 2010; Group Prototype: Hogg, 2001; Sensemaking: Weick, 1993; Relational Models: Wellman, 2017; Emotional Intelligence: Wolff et al., 2002), however, there is a lack of integrative research capable of evaluating the process of leadership emergence (Acton et al., 2018) described in these theories.

I will directly evaluate the viability of proposed social mechanisms of leadership emergence found in prominent theories of leadership, using computational modeling methods. I will provide evidence supporting the generative validity of the proposed mechanisms and identify areas where the theorized mechanisms may be incomplete or fall short of producing the predicted outcomes. I will further contribute to the leadership emergence literature by proposing a synthesis theory that incorporates mechanisms from different foundations and demonstrate the implications of these social mechanisms interacting. This research will provide a powerful evaluation of social aspects of the leadership emergence processes, provide a theoretical foundation for deeper investigation into the processes of leadership emergence, and produce various predicted outcomes that will help direct future empirical leadership emergence research.

In addition to these theoretical contributions, I make a significant contribution to the organizational sciences by providing a clear step by step directions for developing testing and using a computational model. I provide clear theoretical guidelines for considerations to make when formalizing a theory and developing a computational model, and I demonstrate various uses of computational modeling. This thesis has the high potential to generate various meaningful and impactful contributions to the organizational sciences and management literature.

Review of the Literature

Leadership Networks

Leadership is inherently a social process (DeRue & Ashford, 2010; Hogg, 2001; Lord et al., 2017; Wolff et al., 2002). There are formalized structures and bureaucratic rules that may impact the process of leadership emergence but, in essence, leadership can be defined by influence or power that exists between individuals (Carter et al., 2015). Theoreticians have proposed numerous social-cognitive mechanisms that drive the process of leadership emergence in the social context. The Social Identity Theory of Leadership (SITL) proposed by Hogg (Hogg, 2001), provides an excellent description of how social identities and in-group pressures may be of central importance during the leadership emergence process. According to this social identity-based theory, individuals are “socially attracted” to those that best match the prototype of a given group. Thus, individuals who are most prototypical of a group increase in influence and secure a position of power within the group structure. A second theory, the Claiming and Granting Theory of Leadership (CGTL), proposed by DeRue and Ashford (DeRue & Ashford, 2010) describes how social context drives leadership emergence. CGTL proposes that a process of claiming and granting is central to the development and internalization of leader identities. Individuals each have leadership prototypes that are closely related to the concept of Implicit Leadership Theories (ILT) (Offermann et al., 1994). These prototypes lead them to make grants of leadership when interacting with someone that closely matches their own ILT or make claims of leadership if they feel that they themselves best match their ILT. Both theories are rich with propositions of social mechanisms of leadership emergence, and both theories have helped shape organizational scholars’ understanding of leadership; however, these narrative theories may be better understood and tested through the rigorous evaluation of the proposed mechanisms and

their implications. I will use computational modeling techniques to investigate the mechanism of these two theories and the implications they have on each other.

For example, SITL proposed that leadership emergence is driven by comparisons made with a prototype that is likely to be largely shared and updated regularly due to contextual and social influences. By contrast, CGTL proposes that leadership emergence is driven by comparisons made with personal ILT's. ILT's are somewhat context-dependent (Antonakis et al., 2003) but largely stable (Epitropaki & Martin, 2004). The juxtaposition of a theory based on a shared dynamic prototype and an individual stable prototype has fascinating implications. I will investigate predictions made from formal representations of these two theories, and use this as a foundation for building a synthesis theory of the two processes.

In recent years, there has been a trend to study leadership using non-traditional perspectives (Carson et al., 2007; Denis et al., 2012; Dinh et al., 2014; Fitzsimons et al., 2011). Shared leadership, one of these newer perspectives of leadership, is particularly relevant to research on the social mechanisms of leadership emergence. While traditional leadership perspectives often treat leadership as a characteristic of the group, with one individual influencing the entire team, shared leadership has the perspective that everyone can influence each other either through formal means or informal social structures (Carter et al., 2015). In studying the processes of leadership emergence, a shared leadership perspective has several advantages. Specifically, shared leadership considers dyad-level influence and, notably, this is the level at which mechanisms in many leadership emergence theories (e.g. CGTL and SITL) are described. Shared leadership has tremendous potential for expanding our understanding of team processes and, as Kozlowski et al. (2016) pointed out, there continues to be a need to evaluate the processes of shared leadership. Furthermore, it has been suggested that in a world where

expertise is increasingly important and multi-team systems dominate the workplace, shared leadership may be a more appropriate conceptualization of leadership processes (Bienefeld & Grote, 2014). For this thesis, I will take a “leadership-as-network,” (Carter et al., 2015) approach to represent shared leadership.

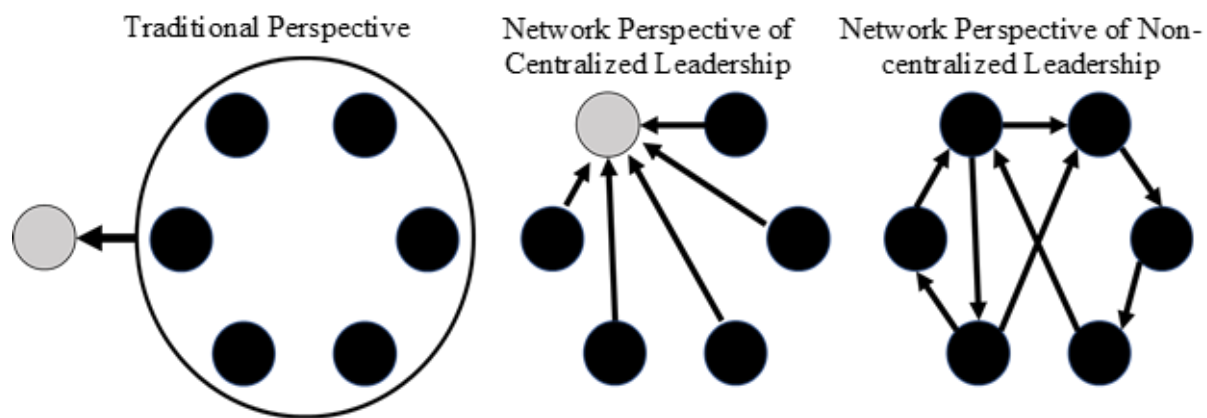


Figure 1. Traditional and network perspectives of leadership. Circles represent team members and arrows represent the dyadic leadership relationships between individuals pointing the source of influence. **Left:** Traditional leadership perspectives have a leader influence the entire team and do not account for the dyad-level relationships that form a leadership network. **Center:** A centralized leadership network where all team members defer to one individual. **Right:** A shared leadership network with no one centralized leader (Carter et al., 2015). Note that the network perspective depicted center and right is able to account for potentially interesting patterns of influence distributed across the team.

Leadership networks formally account for components of leadership traditionally overlooked (Carter et al., 2015; Mehra et al., 2006) and, as recent meta-analysis found (D’Innocenzo et al., 2016), structures in leadership networks are an important predictor of performance outcomes. In a leadership network, dyadic leadership relationships are incorporated into a set of connections between team members where the stronger a connection between two individuals, the stronger the leadership or influence between those individuals (See Figure 1). Leadership networks can be used to describe one-leader teams, multi-leader teams, or even teams with distributed leadership. In these networks, the measure of a group’s or individual’s

leadership can be described in terms of network indices such as an individual's centrality or the overall network's edge-density. When coupled with computational modeling, leadership networks have tremendous potential to enable deeper investigation into the processes of leadership emergence.

Computational Modeling (CM) is a powerful methodology that can augment leadership emergence research (Harrison et al., 2007; Weinhardt & Vancouver, 2012). Harrison et al. (Harrison et al., 2007) provide an excellent discussion of computational modeling, and the various uses to which it can be applied. For example, CM is particularly good for studying processes (Kozlowski et al., 2013), and emergent phenomena (Grand et al., 2016; Guastello, 1998). Additionally, CM may be used to assess the generative sufficiency of a theory (Epstein, 1999); generative sufficiency is a test of a theory's logical ability to produce predicted outcomes based on proposed mechanisms. Likewise, CM can predict patterns or phenomena that a set of proposed mechanisms logically imply, and which theoreticians may not have, themselves, predicted. Furthermore, a CM that is well-validated can also make substantive predictions (Harrison et al., 2007). Organizational science has been somewhat slow to adopt CM as a mainstream research methodology when compared to some other methodologies (Dinh et al., 2014; Harrison et al., 2007); however, CM has been used for decades and continues to be a powerful tool.

Computational modeling is ideal to assess theoretical mechanisms of leadership emergence for at least three reasons. First, leadership emergence is inherently a dynamic, emergent process (Acton et al., 2018). The processes must be evaluated as such. Despite conceptual and methodological advances in our ability to assess dynamic psychological phenomena, it is enormously costly and difficult to prepare a study that could capture the

progress of leadership emergence *in vitro* or *in situ*. This difficulty is compounded when attempting to evaluate the bottom-up, social mechanisms of leadership emergence. For these reasons, to date, most empirical leadership research has focused on top-down processes by which organizational dictums, culture, etc. may guide leadership emergence. This research misses the social processes of bottom-up leadership emergence (Kozlowski et al., 2013). Computational modeling, by contrast, easily can be designed to focus on the dynamic and emergent nature of social mechanisms of leadership emergence. CM does not replace empirical evaluation but provides a way to study implications, gain insight, and test theory, separate from empirical evaluation (Harrison et al., 2007). Secondly, computational modeling can evaluate the logical consistency of proposed mechanisms and proposed outcomes. If a CM can recreate input-output pairings that are predicted by SITL or CGTL, this provides support for the generative sufficiency of the theory in question (Epstein, 1999). Whereas traditional leadership research typically relies on narrative explanation to provide justification for theories, computational modeling provides a way that can systematically test the logic and implications of these theories. Thirdly, CM provides a useful way to explore a theory that is still being developed. Leadership emergence is a field with a vast wealth of phenomena that have not been fully explored. CM is a powerful theory-building tool, enabling the creation of a logical, phenomena-focused theory that future empirical evidence can investigate. CM is an ideal tool for investigating the implications of how SITL's and CGTL's proposed mechanisms may interact.

To illustrate the ability of computational modeling to evaluate mechanisms, consider a typical path model that could be used to represent some process from one of these theories (e.g. SITL: Figure 2). Compared to the rich theory that a path model is based on, a path model is likely relatively simple, incapable of accounting for the dynamic nature of the process or the

feedback relationships inherent in the theory. Even stepping beyond a simple path model to a time-lagged longitudinal model (Figure 3), it is likely that feedback effects are overlooked. Despite its limitations, much of current empirical research on leadership emergence follows the pattern of using simple input-output mediator/moderator relationships that are unable to evaluate the complex interactions between mechanisms. CM can overcome the weaknesses found in a black box style methodology by simulating the complex interactions described in theory (Figure 4). While not replacing traditional methods, CM provides a powerful new perspective on leadership emergence research.

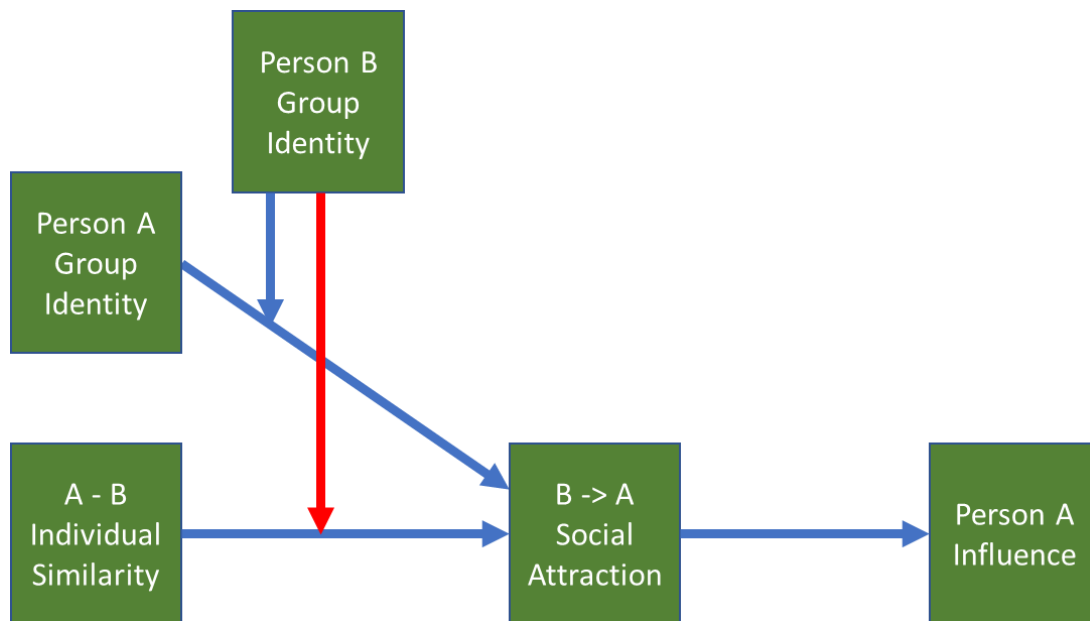


Figure 2. Example diagram for the processes described by Social Identity Theory of Leadership.

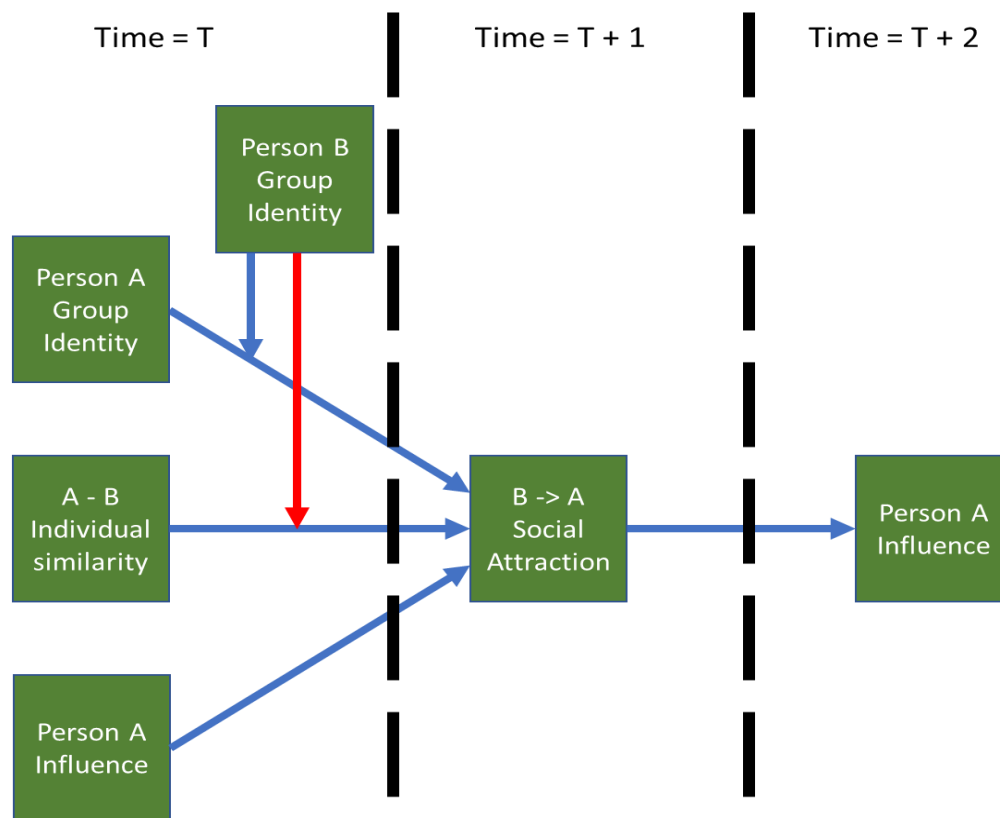


Figure 3. Example diagram for a longitudinal representation of the processes described by Social Identity Theory of Leadership.

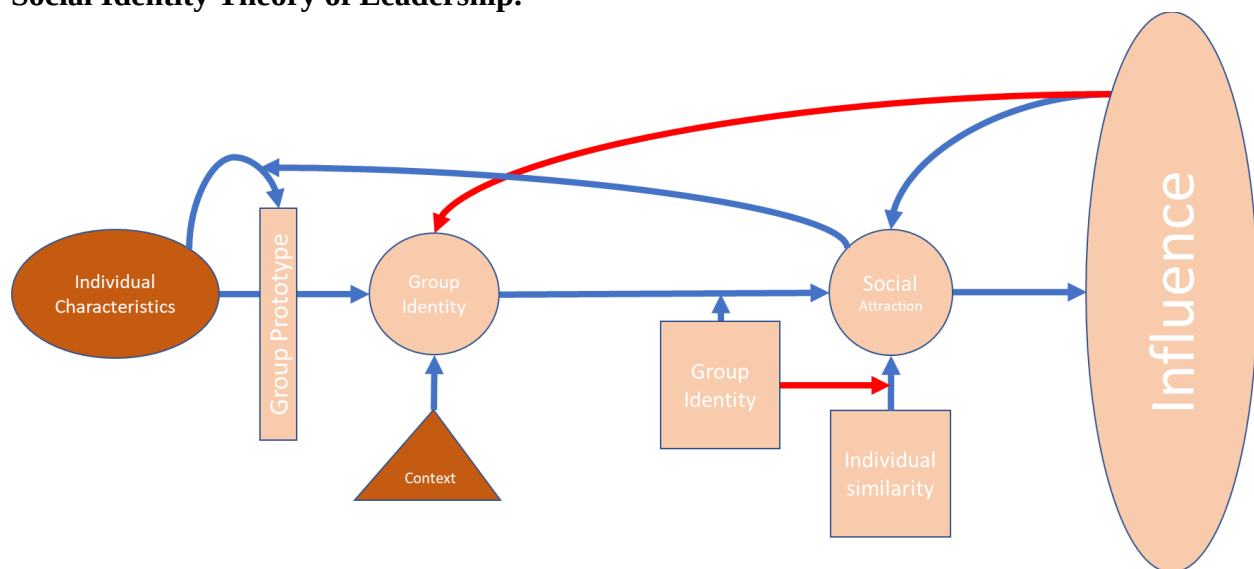


Figure 4. Example diagram of the complex mechanism described in Social Identity Theory of Leadership.

Despite the amount of effort that has been applied to leadership emergence research, and a general proliferation of leadership theory (Dinh et al., 2014), there is a significant need to focus greater attention on the processes of leadership emergence (Kozlowski et al., 2016). Specifically, there is a significant need to understand the mechanisms by which social context drives the processes of leadership emergence. The theories of SITL and CGTL provide an excellent foundation to understand how different aspects of social context, ILT's, and in-group pressures may drive leadership emergence. Notably, both theories are rich with mechanistic predictions of how dyadic relationships of influence may emerge. I will use computational modeling and a "leadership-as-network" (Carter et al., 2015) perspective of shared leadership to further understanding of these social mechanisms of leadership emergence to pursue three main objectives. 1. Evaluate the generative sufficiency of the models thereby providing evidence for the proposed mechanisms' viability, 2. Test implications of emergent network structures made by a synthesis model incorporating mechanisms from both theories, 3. Produce specific predictions that will be the foundation for future empirical research.

Theories of Leadership Emergence

From a shared leadership perspective, leadership emergence can be characterized as a process where individuals in a team develop relationships of influence over others within the team. An individual with a significant amount of influence would be considered a leader. Hogg's (Hogg, 2001) social identity theory of leadership and DeRue and Ashford's (DeRue & Ashford, 2010) Claiming and Granting Theory of Leadership are two prominent theories of leadership emergence that provide descriptions of social mechanisms of leadership emergence. These mechanisms apply well to dyadic interactions, making them an excellent foundation to build off

of in working to building a deeper understanding of the social mechanisms of the emergence of leadership network structures.

Social Identity Theory of Leadership. Social Identity Theory of Leadership (Hogg, 2001) is based on the core concepts of social identity theory (Abrams & Hogg, 1999). Individuals have multiple identities that are differentially activated based on many factors including context. Individuals are motivated by self-esteem (Baumeister & Tice, 1985; Dweck, 2013) and uncertainty reduction (Hogg & Abrams, 1993; Kramer, 1999) to devise prototypes that optimally categorize individuals and distinguish between groups. These prototypes are set up so that one can view themselves in the best way possible, and there is a minimum amount of ambiguity between groups. According to Social Identity Theory, individuals are motivated to promote members of the same group for reasons of 1. self-enhancement and 2. belonging (Abrams & Hogg, 1999). The more one identifies with a group, the more they incorporate other group members into their own self-concept and will, thus, be motivated to actively seek to promote the welfare of other group members as a form of self-enhancement. Similarly, individuals are motivated to belong to the group and will actively seek association with other group members as a way to clarify their place in the group. Hogg built off of these theories, to provide a framework of how social identity drives the process of leadership emergence in a group (Hogg, 2001).

According to Hogg's (Hogg, 2001) Social Identity Theory of Leadership, individuals who are most prototypical of their group will gain and maintain leadership over others, while those who are not prototypical of the group will find it difficult to gain such influence. Hogg did not suggest that SITL was the only process driving leadership emergence, but he claimed that under conditions where group membership is particularly salient and groups are particularly

homogeneous, these proposed mechanisms will be the dominant force determining who will emerge as a leader. In other situations, SITL's proposed process will run concurrently with more trait focused processes of leadership emergence such as DeRue and Ashford's (DeRue & Ashford, 2010) theory.

In addition to describing how outcomes are related to antecedent variables, SITL makes clear claims about the processes that drive these theorized relationships. This rich theoretical foundation can be divided into mechanistic relationships as follows:

1. Individuals form a group prototype, motivated by self-esteem maximization and uncertainty reduction. The group prototype is based on characteristics of group membership, with highly socially attractive individuals and highly salient individuals more strongly influencing the group prototype.
2. An individual's group identity will be differentially activated based on how closely they feel their characteristics match the group prototype. The closer their characteristics match the group prototype the more their group identity will be activated.
3. SITL describes a process of identity internalization and depersonalization whereby individual characteristics and characteristics of others are judged more according to group identity than individual characteristics. The more strongly an individual identifies with the group, the less they will base decisions on individual characteristics, and the more they will base decisions on how closely their characteristics compare with the group prototype.
4. Based on self-esteem, individuals who are similar to each other will be socially attractive, and likewise, those similar to one's social identity will be socially attractive to each other. It is implied that the more strongly one's group identity is activated, the weaker the impact of personal similarities, and the stronger the impact of group similarities will be on social

attraction. In other words, social attraction due to self-similarity is inhibited by group identity (because of depersonalization), and social attraction due to group-similarity is enhanced by one's social identity. Similarly, the more an individual matches the group prototype the more perceived influence they will hold.

5. Socially attractive individuals and those with perceived influence are eventually given greater actual influence. Social attraction represents an indicator of how much individuals identify with each other, and the more they identify with each other, the more they are willing to follow them, help them, or obey their requests.

6. It is implied that as individuals increase in influence, they increase the activation of their leader identity. Potentially, this increase in leader identity may come at the sacrifice of the leader's group identity.

7. Individuals with influence can use their power to increase their social attraction (perceived influence) and visibility which, in turn, maintains or increases their influence.

Each of these proposed mechanisms provides a fundamental building block from which we can assess the theory. Notably, each mechanism can be described as either a dyadic or individual level mechanism. This fact makes a network conceptualization ideal for tracking the implications of these mechanisms because a network can encode all possible dyadic relationships. In addition to mechanistic predictions, SITL makes specific predictions, listed below, about outcomes of the leadership emergence process under given circumstances.

1. Leadership is stable in stable contexts and with stable group membership.
2. Strong contextual pressure encouraging group membership leads to stronger leader influence.
3. Group homogeneity leads to increased leadership strength.

4. Under circumstances of high contextual pressure to identify with the group and homogeneous group membership, the group forms a strongly hierarchical structure with a single central leader who is relatively low in-group identification.
5. Minorities or group outsiders will find it difficult to become a leader.
6. Minorities or group outsiders will find it hard to maintain leadership.
7. Under circumstances with a strong shift in group prototype and increased group membership salience, there can be a sudden shift in who holds positions of leadership.

These predictions are important outcomes for leadership. Understanding how the proposed mechanisms may, for example, inhibit the ability of a minority team member to become a team leader could help researchers develop interventions designed to enable high potential minority leaders to gain and maintain leadership positions. Similarly, the closeness between leaders and followers (i.e., Leader-member exchange) has been linked to performance (Dunegan et al., 2002; Le Blanc & González-Romá, 2012; Martin et al., 2016), less abusive supervision (Martin et al., 2016), and various other outcomes and antecedents. It may be helpful to understand how the proposed mechanisms could produce a distal, strong central leader, to develop an intervention designed to avoid this scenario. Understanding the link between these mechanisms and the proposed outcomes is an important focus of this research.

Claiming and Granting Theory of Leadership. DeRue and Ashford (DeRue & Ashford, 2010) proposed a Claiming and Granting Theory of Leadership emergence (CGTL) which is based on the foundations of Self-Categorization Theory (Turner et al., 1987) and identity theories. Individuals can have role-based identities such as leader or follower identity; these identities serve in a sense-making capacity (Weick, 1993), guiding individuals to know what behavior is appropriate under a given context, and helping establish inter-personal

relationships (Stets & Burke, 2000). CGTL describes an identity-work process by which individuals develop, strengthen, or try out new identities (Brown, 2015). CGTL's proposed process is driven by similar motivations to SITL (e.g. self-enhancement, uncertainty-reduction, belongingness). Individuals stick to known roles for reasons of uncertainty reduction and belongingness but may try out new identities (e.g. a leadership identity) motivated by self-enhancement to take on a more prestigious or less effortful identity.

In tandem with the identity work process, individuals develop a leadership prototype or model. Various forms of leadership prototype have been discussed in the organizational literature including those related to sensemaking (Weick, 1993), relational models (Wellman, 2017) and Opponent processes (Hollenbeck et al., 2015); however, Implicit Leadership Theories (ILT) continue to be a core leadership prototype theory (Dinh et al., 2014; Lord et al., 2017, 2020). Based on its popularity and simplicity I will refer to the leadership prototype as an ILT. This ILT forms a prototype of the characteristics that they associate with leadership (DeRue & Ashford, 2009; Kenney et al., 1996). ILT's update over a lifetime but are fairly stable, although different characteristics of an ILT may be more salient in some situations than others. Research has underlined the importance of ILT's in leadership emergence showing that those who match prototypes of leadership are most likely to be identified as leaders. Notably, characteristics do not need to be predictive of the actual performance of a leader to become highly salient characteristics of an individual's ILT (Epitropaki & Martin, 2004). ILT's represent characteristics, biases, and stereotypes that individuals develop over their life helping them to identify individuals worthy of following. In a recent development, researchers have further proposed that individuals use implicit theories of followership (ITF), in addition to ILT, to identify individuals who match characteristics associated with follower roles (Bastardo & Van

Vugt, 2018; Lord et al., 2020; Oc & Bashshur, 2013; Uhl-Bien et al., 2014). ILT's and ITF's are important in determining what identities individuals will tryout and eventually internalize.

According to CGTL, a process of claiming and granting is central to leadership emergence (DeRue & Ashford, 2010). When individuals interact with each other they will often claim authority or grant authority through their actions. These actions may make up explicit claims of authority such as taking charge of a meeting, or discreet actions such as letting someone else enter a room first. During an interaction, individuals decide to make a claim or grant of leadership depending on how well the person they are interacting with matches their schema of leadership and their own leadership identity. Broadly, the more that claims and or grants are reciprocated, the stronger the relationships of influence will be between the two team members, and, as a consequence, the more the respective leader and follower identities will be reinforced. DeRue and Ashford proposed that people have a schema of leadership (separate from their ILT), that describes expectations of leadership. People with a strong 'hierarchical leadership' schema will expect that relationships of influence should flow in one direction such that there is always a clear leader and a clear follower. These individuals will feel that leader and follower identities are opposing so that activation of a follower identity would be expected to reduce one's leader identity and vice versa. By contrast, people with a strong 'shared leadership' schema will be willing to work in relationships where leadership is shared or ambiguous and do not have this strong negative association between their follower and leader identities.

CGTL, as with SITL, makes clear predictions that can be broken down to mechanism-level theories of how dyadic relationships of influence form. These process mechanisms, derived from the theory, are as follows:

1. Individuals have a leader (follower) identity which is activated based on the comparison between self-characteristics and ILT's (IFT's). Individual identities are also impacted by the actual influence an individual has such that the more influence they gain, the stronger their leader identity.

2. When individuals interact, they compare each other with their own ILT to determine whether to claim a leader identity. The stronger an individual's leadership identity is, the more likely they are to claim leadership.

3. Perceptions of others are based on how well they match personal ILT and the influence they control.

4. When claims of leadership between two individuals have been reciprocated in the past, claims are more likely to be made and reciprocated in the future.

5. Reciprocated claims also lead to increased dyadic influence.

6. Credibility, clarity, and visibility of a claim increase the chance of a claim of leadership being reciprocated.

7. Contextual rewards and risks for leadership and formal leadership positions add impact to the strength of an individual's leader identity. These contextual influences could include things such as the prestige associated with being a leader.

8. Individuals have a schema of leadership that is on a continuum between shared leadership and hierarchical leadership. For individuals with a hierarchical schema of leadership, the influence that others have over one's self diminishes one's influence. Similarly, individuals with hierarchical schema's are less likely to grant leadership if their own leadership identity is strong. Additionally, claims of leadership will negatively impact an individual's leader identity.

These negative feedback paths by which other's leadership negatively impacts one's own are ameliorated by shared schemas.

Similarly to SILT, CGTL makes specific outcome predictions based on the mechanisms described. CGTL's predictions are based on the impact of leadership schema as follows:

1. Teams, where individual's schemas are shared in nature, will have strong bi-directional relationships.
2. Teams, where individual's schemas are hierarchical, will have strong unidirectional relationships.
3. Teams, where individual's schemas are divergent, will have weak overall relationships.

The implications of the predictions of CGTL are very important to practical problems such as team assignment, and leadership training. Specifically, if disagreement in leadership style can cause teams to fail to establish leadership structures this could have drastic consequences for team performance. Similarly, the differences in leadership structures that are assumed to be produced by teams with shared or hierarchical leadership-schemes could have very important implications to how information flows through the team, and under what circumstances a team will fail or succeed.

Integration of Theories and Hypotheses. Both Hogg's and DeRue's theories of leadership emergence are centered around the social-cognitive processes of leader identification where individuals in a group make judgments that determine who they will follow. In both theories, the status of being a leader is part of a self-reinforcing feedback loop. Influence in SILT leads to one's ability to maintain social attraction and group salience which in turn leads to

influence; in CGTL, increased influence increases one's leader identity. This also increases the likelihood of future claims of leadership being reciprocated, thus, leading back to sustained leadership. Additionally, both theories are particularly applicable to informal leadership network emergence. Both theories describe a bottom-up social process of leadership emergence that only tangentially incorporates formal roles. Another similarity is that both theories would predict that highly salient individuals who match expectations of a leader will emerge more quickly than an individual with identical qualifications who are less salient.

On the other hand, the two theories have many differences. Possibly the most notable example is in the nature of the prototypes used to assess others. SITL proposes that judgments about who to follow are based on a largely shared prototype that is very dependent on context. By contrast to this shared, group-based, transient prototype, CGTL proposes that judgments about who to follow are based on an individual, leadership-focused prototype that theoretically is stable. Additionally, both theories make different explicit and implicit predictions about leadership emergence. For example, processes predicted by SITL are hypothesized to be strongest when group membership is considered highly salient, whereas CGTL would likely predict that the process of leadership emergence is strongest when the importance of the task or situation is more salient. SITL is internal in nature, in that social attraction is increased because of internalization of group identity, whereas CGTL is driven/motivated primarily by external factors ("this person will help us succeed", "I think this person looks like a leader", etc.).

In comparing SITL with CGTL, it is meaningful to consider the different general patterns of influence implied by the two theories. First, generally speaking, SITL describes mechanisms of leadership emergence that create bidirectional relationships. For example, the individuals most likely to be socially attracted to a highly group-prototypical individual are others who are highly

group-prototypical themselves. Thus, the most socially attractive individuals are likely to be attracted to each other. This will lead to bidirectional relationships. CGTL has no such bidirectional mechanisms, and in fact, individuals with hierarchical schemas will prefer unidirectional leadership relationships. Another point where the two theories imply different patterns is in the distribution of leadership. CGTL explicitly describes a process where leadership gained by another can impede one's own ability to secure influence; SITL, by contrast, does not describe any such interference. Under CGTL's mechanisms, when compared to SITL, the interference is likely to lead to a pattern of leadership that has few individuals holding most of the power in a hierarchical orientation (the team's distribution of influence is right-skewed). Additionally, it is reasonable to assume that there will be less overall strength of influence across the entire team because of the interference. One last way in which these models could differ significantly is the pattern of transitivity in influence for a team. CGTL describes a process where different individuals could have vastly different implicit theories of leadership (ILT's); differences in ILT's may imply non-transitive leadership patterns (i.e. if person A follows person B and person B follows person C, transitivity implies A follows C). By contrast, in SITL, groups of individuals with the same prototype will all use the same metric to determine leadership (i.e. the group's prototype). This implies a more strongly transitive pattern of influence.

Hypothesis 1a: Under CGTL mechanisms alone, when compared with SITL mechanisms alone, influence will more strongly follow a pattern where few individuals have most the power, and most individuals have little power (i.e. the distribution of influence will be right-skewed).

Hypothesis 1b: Under SITL mechanisms alone, when compared with CGTL mechanisms alone, the overall strength of leadership across the entire team will be greater.

Hypothesis 1c: Under SITL mechanisms alone, when compared with CGTL mechanisms alone, influence relationships will more strongly follow a pattern reciprocal influence such that if some individual (A) has influence over another individual (B), B will be more likely also have influence over (A).

Hypothesis 1d: Under CGTL mechanisms alone, when compared with SITL mechanisms alone, influence will more strongly follow a hierarchical pattern such that individuals are most likely to follow those who have the most followers.

Hypothesis 1e: Under SITL mechanisms alone, when compared with CGTL mechanisms alone, influence relationships will more strongly follow a pattern transitive influence such that if some individual (A) follows another individual (B), and B follows a third (C), under SITL mechanisms A is more likely to follow C than under CGTL mechanisms.

While each theory provides a powerful perspective of the social mechanisms of leadership emergence, neither is complete. SITL explicitly states that under certain circumstances a trait-based process of leadership emergence may be more dominant (Hogg, 2001). Considering that both social identity, and implicit theory-based mechanisms of leadership are important, it follows that understanding how these two theories may interact is important. Additionally, these theories may not be entirely capable of explaining all hypothesized results separately. If both processes are truly active at the same time, as SITL suggests, combining the two mechanisms may produce powerful insights and predictions that neither theory can produce on its own.

One of SITL's main predictions provides an example of how the two theories appear to be somewhat insufficient on their own, in terms of the mechanisms they describe. SITL proposes

that when group membership is particularly salient, and the group is particularly homogeneous, a single dominant leader will emerge with a very strong hierarchical pattern producing a steep pyramidal leadership structure. The mechanisms described in SITL appear to be insufficient to produce this distribution of influence as hypothesized by SITL. Specifically, there is no clear mechanism described in Hogg's theory that would explain why individuals with similar levels of prototypicality to the central leader would not emerge with proportional levels of influence, instead of developing into essentially a winner takes all hierarchical system as described in the theory.

SITL describes mechanisms by which a highly socially attractive individual becomes more salient to the group prototype and thus the group prototype drifts toward the given leader increasing the ability of the influential to maintain influence; however, individuals close in characteristics to the central figure would implicitly gain proportional influence. Furthermore, SITL proposes that individuals with significant power become less prototypical (and by implication would be less important to the group prototype). Considering this negative feedback influence, it seems likely that the distribution of influence within a strongly homogeneous group will not develop so that one person has most the influence and most other members have little influence as described by Hogg (2001). In fact, under conditions where leadership is particularly antithetical to the group prototype, the distribution of influence within the network would likely become strongly left-skewed such that most individuals have a relatively large amount of influence and a few outliers have less influence.

Hypothesis 2a: Under SITL mechanisms alone, increased homogeneity in characteristics of group members will lead to a pattern of strong influence with most individuals having a relatively large amount of influence and few individuals having very little influence (the

distribution of influence will be left-skewed), such that no clear individual bears the majority of the influence in the group.

Additionally, there are no explicit mechanisms that would prevent individuals from reciprocating influence. In fact, both the impact of self-similarity and prototypically would be expected to cause social attraction to be largely reciprocal in homogeneous groups. I would predict the influence relationships formed in a highly homogeneous group to be largely bi-directional.

Hypothesis 2b: Under SITL mechanisms alone, increased homogeneity of characteristics of group members will lead to a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.

CGTL, by contrast, implies very different outcomes for homogeneous groups depending on the leadership schemes of a team's members. In a group where individuals' leadership schemas converge on shared leadership style, homogeneity would lead to individuals likely having little opinion on who is the leader because both individuals in any given interaction match the ILT's to a similar degree. Either a claim or a grant would likely be reciprocated. These teams should form strong relationships of influence across the entire group with no clear central figures. The distribution of influence would be expected to be left-skewed with many individuals influencing many others, and few individuals having less influence. (This is similar to the distribution that would be predicted by the mechanisms of SITL). Additionally, these strong relationships are predicted to be bidirectional.

Hypothesis 3a: Under CGTL mechanisms alone, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of strong influence where most individuals have a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.

Hypothesis 3b: Under CGTL mechanisms alone, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.

In a group where individuals' leadership schemas converge on hierarchical leadership, homogeneity leads to ambiguity over who the best leader. Who is the best leader may be unclear to both individuals in any given interaction (as described previously). Because of the hierarchical nature of the team's leadership schemas, either a claim or a grant would have a high likelihood of not being reciprocated. These teams should form very few, weak relationships of influence across the entire group with no clear central figures.

Hypothesis 4: Under CGTL mechanisms alone, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with very weak relationships of influence.

In a group where members have divergent leadership schemas, homogeneity means that individuals will be almost equally likely to make a claim or grant. Individuals will follow the patterns described above between any one pair of individuals with similar schemas. Thus, those with shared schemas will form a strongly connected group and those with hierarchical schemas

will be separated from each other. The ambiguity between those with shared and hierarchical schemas will furthermore inhibit the formation of relationships between individuals with different schema types.

Hypothesis 5: Under CGTL mechanisms alone, in groups with divergent leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of leadership, such that individuals with shared schemas will form a clique with strong and bidirectional influence-relationships, but individuals who have a hierarchical schema will have weak influence-relationships with all other group members.

In two of three cases, CGTL on its own would suggest the influence within a highly homogeneous group would be low or non-existent. In the third, CGTL would predict a distribution of influence similar to what I predict the SITL mechanisms will produce. Neither the mechanisms described by CGTL or SITL appear to imply SITL's proposed strong hierarchical pattern. The apparent contradiction between what the mechanisms described by CGTL and SITL appear to imply will happen, and the explicit prediction of SITL regarding the impact of homogeneity, illustrate a place where a synthesis theory built off the two theories may help to explain discrepancies. It is important to note that the interpretations of SITL and CGTL's mechanisms described here are not necessarily a perfect representation of the author's initial intent. This fact, however, further illustrates the value in revisiting these narrative theories to provide crystal clear, formal interpretations of the mechanisms. A synthesis model will represent a combination of the two models, but necessarily add novel elements to the combination of these established theories, clarifying how the two processes will interact. To this end, a synthesis theory will provide a contribution to the literature both by combining mechanisms described by the two models and by describing ways in which these theories can be extended. Not only will a

synthesis theory be able to address mechanisms that appear to be insufficient, but the synthesis theory will also be able to suggest various predictions about patterns of leadership emergence and possible situations where one process may be dominant.

Two Process Theory of Leadership Emergence (TPTL)

Process mechanisms proposed by both Social Identity Theory of Leadership and Claiming and Granting Theory of Leadership are not contradictory. At any given time both processes may be independently active in helping to guide the emergence of leadership. As stated previously, SITL explicitly discusses this possibility, stating that a trait-based process could also be concurrently active. Differences in team structure, context, and environmental factors may largely drive the differential activation of the two leadership emergence processes. Importantly the combination of the trait focused CGTL processes and the social identity-focused SITL processes can explain phenomena that neither theory independently can explain in isolation.

I propose that a combination of the mechanisms originally described by both SITL and CGTL are active in the process of leadership emergence. Thus, dyadic influence is increased both through a process of social attraction and reciprocation of claims (grants) of leadership. In addition to the original mechanisms, I propose two additional changes. The first change is a clarification on the impact of influence on group identity. SITL suggests that the more influence an individual gains, the less they identify with the group. CGTL describes, on the other hand, a process by which an individual's leader-identity is strengthened as they gain leadership influence over others. I propose that leader identity is negatively related to group identity in certain contexts. The negative feedback between influence and group identity as described in SITL can be explained as a mediated path through leader identity. Increased leader identity leads to

decreased group identity (and vice versa), and increased influence leads to increase leader identity. Gains in influence have a positive relationship with leader identity (as predicted by CGTL), but the negative relationship with group identity (proposed by SITL) is mediated by leader identity (Appendix B).

The second change to the original mechanisms that I propose is based on the depersonalization process described in Social Identity Theory. Activated group identity leads to a process of depersonalization which impacts how individuals assess themselves and others. Specifically, they tend to see themselves and others more in terms of the prototypes for the active identity than individual characteristics. I explicitly propose that in addition to impacting how social attraction develops, this process of depersonalization will impact assessment of ILT match. An individual with a strong group member identity will likely largely overlook individual characteristics in favor of group membership-based characteristics when assessing how one's ILT matches the individual's characteristics (Appendix B). Both changes are consistent with the original theory, and simply make up explicit statements of how certain mechanisms may directly interact with each other.

Homogeneity and heterogeneity. As discussed previously, both the mechanisms of SITL and CGTL make interesting predictions about outcomes associated with homogeneity of a team and these are partly contradictory. When the mechanisms are combined, a novel pattern is implied that serves to clarify the contradiction predictions.

When team members have shared schemas, both SITL and CGTL have very similar predicted outcomes. I predict that under the synthesis model the same general pattern described previously will still hold, although the two processes may amplify each other causing an increased skew in the distribution of influence. Specifically, I predict that in teams with a

convergent shared leadership schema, influence will be shared by the majority of the individuals. This pattern will encourage largely bidirectional leadership relationships.

Hypothesis 6a: Under TPTL mechanisms, in groups with convergent, shared leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of strong influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that no clear single individual bears the majority of the influence in the group.

Hypothesis 6b: Under TPTL mechanisms, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.

Largely homogeneous teams where individuals have hierarchical schemas pose an interesting case. The SITL process will push the team toward having many people share a large amount of influence with a few individuals holding very little influence. By contrast, the CGTL mechanisms are largely pressuring the team to have minimal influence relationships. When combined, I predict that an entirely new pattern will emerge. The hierarchical schema causes individuals that may otherwise become leaders under the SITL process to back off in favor of someone who they identify as a leader either according to the influence they hold or their match to one's ILT. This negative feedback will serve to develop a distribution of leadership where one (or a few) clear leader holds significantly more influence than the rest of the group. This is significant because it is the patterns that SITL predicts for homogeneous groups and suggests that both SITL and CGTL mechanisms may be required to produce the hypothesized pattern.

Hypothesis 7a: Under TPTL mechanisms, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with a hierarchical pattern of influence such that one (or a few) individual has significantly more influence than the rest of the group (this will be a heavily right-skewed distribution of influence).

Hypothesis 7b: Under TPTL mechanisms, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of influence that is unidirectional, such that if some individual (A) has influence over another individual (B), B will not have influence over A.

As predicted previously, teams, where the schema is divergent, will segment into a group of individuals with strong shared leadership schemas and a group of individuals with strong hierarchical schemas. Each of these sub-groups will follow the patterns predicted previously. Furthermore, there will be very little internal connection between the two groups because of ambiguity over leadership. The influence of SITL will likely cause these differences to be relatively flattened compared with the outcomes predicted by CGTL alone. This is because the divergence of schemas will weaken CGTL process impact while not influencing SITL's process impact.

Hypothesis 8: Under TPTL mechanisms, in groups with divergent leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of influence such that individuals with a shared schema will form a clique that has a strong and bidirectional influence-relationship and a group of individuals with a hierarchical schema that has a hierarchical pattern of influence. There will be very weak leadership relationships between the two groups.

Because of the ambiguity that forms in CGTL, homogeneity leads to weaker overall CGTL processes, whereas it leads to stronger group identification and so stronger SITL-like processes. By contrast, heterogeneity in group characteristics leads to an overall lack of ambiguity, thereby strengthening the CGTL process. This will lead to weaker group identification and thus weak SITL process

Hypothesis 9a: The more homogeneous a group is, the more the network that is established will be similar to the pattern of leadership that emerges based on SITL. Including high reciprocity, density, and transitivity, low hierarchy, and a negative skew to leadership distribution (see hypothesis 1).

Hypothesis 9b: The more heterogeneous a group is, the more the network that is established will be similar to the pattern of leadership that emerges based on CGTL. Including low reciprocity, density, and transitivity, high hierarchy, and a positive skew to leadership distribution (see hypothesis 1).

Contextual influence. Both SITL and CGTL explicitly discuss the impact of contextual pressures, including those encouraging or discouraging group membership, taking the lead in a given situation, or being a follower. As with homogeneity in team membership, the implications of various distributions of contextual forces encouraging an identity are somewhat contradictory and even counter-intuitive. The synthesis model may be able to shed new light and help direct future research in this area.

Contextual influence promoting group identity will strengthen the processes described by SITL compared with those described by CGTL. There are two reasons for this prediction. First, increased contextual influence promoting group identity will generally increase group identity

and decrease leader/follower identities. Thus, the group identity-based process will be promoted. Secondly, increased pressure to be part of the in-group will generally lead to stronger group identities, which leads to stronger social attraction. Thus, the mechanisms described by SITL will be amplified as compared to CGTL mechanisms. Leadership in teams with strong contextual group membership influence will develop a pattern more similar to the pattern predicted by SITL, compared to identical teams with weaker group influences. Notably, strong influences encouraging group membership may overshadow the impact of differences in prototypically. These teams then may develop so that almost everyone has strong relationships of influence with almost everyone else with few outliers.

Hypothesis 10a: Increased contextual influences encouraging group membership are associated with patterns of influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.

Hypothesis 10b: Increased contextual influences encouraging group membership are associated with increased overall network influence.

The increase in group membership pressure will increase the overall social attraction between members of the team and, thus, increase the overall strength and number of relationships of influence. Because this increase extends across the entire group without regard to prototypically, it is more likely that individuals defer to each other such that existing influence relationships are more likely to be bi-directional (as compared to an identical team with less group membership pressure).

Hypothesis 10c: Increased contextual influences encouraging group membership are associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A

As with group contextual pressures, contextual influence promoting leadership identity will lead to a pattern of leadership produced that is similar to the pattern produced by CGTL. These pressures amplify leader identities which, in turn, inhibit group identities. With group identities weakened, the processes of social attraction-based leadership will be inhibited. Unlike group contextual influences, however, the increase in leader identity associated with increased contextual influence encouraging leader identities may not promote CGTL's mechanisms. Even though patterns of leadership emergence will be more similar to those of CGTL, all individuals will generally be more likely to make claims of leadership and generally fewer grants of leadership. This will increase the likelihood of bidirectional influence when relationships are established, but this does not imply stronger relationships overall. Specifically, for teams with convergent hierarchical schemas, the increased likelihood of all individuals making claims will increase ambiguity in the leadership emergence process and, thus, be associated with decreased overall relationship strength for the team. For teams with shared schemas, this will simply increase the bidirectional flat leadership patterns similar to that described by increased group membership influence.

Hypothesis 11a: Increased contextual influences encouraging leadership identity are associated with a pattern of influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.

Hypothesis 11b: Increased contextual influences encouraging leadership identity are associated with increased overall influence in the leadership network for teams with a convergent, shared leadership schema.

Hypothesis 11c: Increased contextual influences encouraging leadership identity are associated with decreased overall influence in the leadership network for teams with a convergent hierarchical leadership schema

Hypothesis 11d: Increased contextual influences encouraging leader identity are associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.

In the scenarios described above, it is assumed that contextual influences impact the entire team equally. This may not always be a reasonable assumption. DeRue and Ashford (DeRue & Ashford, 2010) explicitly discuss the fact that formal leadership roles will place contextual pressure to identify as a leader. This type of role does not impact the entire team. It is possible that, for various reasons, contextual pressures to identify with the group or as a leader will be significantly different for different team members. The shape of the distribution of contextual influences promoting an identity may be very important in defining the characteristics of leadership in the team the emerges. Consider a team where a few members find group identity much more important than others. These highly group focused individuals will have a significantly amplified group identity and will form strong relationships with others who have similar contextual group pressures. This amplified group pressure will likely lead to other group members also being more socially attracted to the group-focused individuals based on their own social identities. Thus, these individuals that have stronger contextual pressure to identify with the group will likely develop more influence in the group. Because only a few members of the

group would have this amplified influence, this will likely increase the overall hierarchy pattern in the group.

Hypothesis 12: The more strongly the contextual influences encouraging group identity are distributed with a positive skew (such that group membership is very strongly reinforced for a few members and more moderately reinforced for most members), the more strongly leadership is distributed in a hierarchical pattern, and the more strongly the distribution of leadership in the team will form a positively (or less negatively) skewed distribution with few individuals holding significantly more influence than the most the group members.

Teams where a few members who find leadership much more appealing than others, will likely follow a similar pattern. These individuals are highly motivated to claim leadership and, thus, are more likely to have claims reciprocated overall. In this scenario, as with group identity pressures, the individuals most encouraged to identify as leaders will likely form a central hierarchy hub of leadership. This is not necessarily associated with a greater overall strength of leadership relationships within the team, but the strength of the hierarchy is likely to be stronger than teams with a more even distribution of leadership striving influences. The reason the strength of leadership relationships is not necessarily increased is the fact that those that may have a hierarchical leadership schema are more likely to find leadership ambiguous with the increased claims.

Hypothesis 13: The more strongly the contextual influences encouraging leader identity are distributed with a positive skew (such that group membership is very strongly reinforced for a few members and more moderately reinforced for most members), the more strongly the leadership is distributed in a hierarchical pattern.

Correspondence in implicit theories of leadership. A last area where the two theories leave room for interesting implications is correspondence in ILT's. Specifically, the impact of correlation and divergence between team member's ILT's could lead to interesting patterns of leadership structures.

Although ILT's are developed individually over a lifetime, it is likely that some characteristics of ILT's correlate. When ILT's are correlated, individuals will tend to agree in the assessment of who is a leader in any given interaction. This will cause the reciprocity of claims and grants to be greatly increased and consequently, the overall strength of leadership relationships will be increased. Under these conditions, the team will generally agree on a rank order of leadership causing relationships to be largely unidirectional.

Hypothesis 14a: Convergence of ILT (so that individuals have similar ITLs) leads to increased influence across the network.

Hypothesis 14b: Convergence of ILT (so that individuals have similar ITLs) leads to an increased pattern of unidirectional influence relationships such that if some individual (A) has influence over another individual (B), B is unlikely to have influence over A.

When ILT's are largely divergent across the team, individuals that have similar in ILT's will be most likely to have stronger connections with each other (See hypothesis 13a). This will lead to a pattern of cliques that are more strongly connected within than between the cliques. The overall structure of leadership within teams with divergent ILT's will be more random in nature than other teams, implying that, across the board, structural influences on the leadership pattern produced in such teams will be weaker. These effects will be mitigated or completely counteracted if the team has a convergent shared leadership schema. This is because the

ambiguity found when ILT's do not correlate will not necessarily hurt leadership relationships between individuals with a shared schema of leadership.

Hypothesis 15a: Divergence of ILT (so that there is no strong agreement on what makes a leader) leads to segmentation of group into highly connected cliques (based on similarity in ILT) that influence each other, but do not influence individuals in the other groups as strongly.

Hypothesis 15b: Segmentation of influence network due to a divergence of ILT will be moderated by leadership schema such that groups that have a convergent, shared schema will have more influence-relationships and be less segmented by clique than groups with less convergent schemas or groups with a convergent, hierarchical schema.

Hypothesis 15c: Divergence of ILT leads to a more random pattern of leadership so that the structure of leadership is not significantly reciprocal, transitive, or hierarchical.

See Appendix A for a complete list of Hypotheses.

Methods

Overview of Methodological Approach

I use Computational Modeling (CM) and network analysis to study the social mechanisms of leadership emergence. Specifically, I assess the implications and predictions made by three theories of leadership emergence. These theories are the Social Identity Theory of Leadership, The Claiming and Granting Theory of Leadership, and the Two Process Theory of Leadership proposed in this thesis. I use a CM in computerized experiments to simulate the emergence of team influence networks. I then use social network analysis and traditional regression techniques to test the hypothesized relationship between team-level characteristics and influence network indices. This work allows me to test the hypothesized implications of the theories and evaluate the causal explanations for theoretical hypotheses. I additionally used this simulation as an exploratory tool to understand the relationship between team characteristics and influence network structure.

Evaluating theory. To understand the computational modeling approach taken in this thesis it is important to briefly discuss the theory-building process. Theories often make two types of propositions. First are the basic relationships, and simple mechanisms the theory is built upon. For example, SITL proposes that individuals who are prototypical increase in social attractiveness. CGTL proposes that individuals decide to claim or grant leadership based on comparisons between individual characteristics and individually held leadership prototypes. I refer to these simple base propositions as *process mechanisms*. These propositions make up the fundamental unit level building block of theory and can be presented as individual formal propositions or simply logical steppingstones to a more complex proposition.

The second form of proposition that should be discussed is the more complex form of propositions to which these simpler propositions often lead. For example, SITL suggests that highly homogeneous teams can lead to the emergence of a single powerful leadership figure. This proposition builds on various other process mechanisms described in SITL including the processes of social attraction and depersonalization. Similarly, CGTL proposes that teams with similar leadership schemas will have stronger relationships of influence. Again, this is a compound proposition that builds on various process mechanisms described in CGTL including those that describe the leadership evaluation process and the claiming process. The key distinction from the base level process mechanisms is that these propositions are established in the narrative theory as the logical outcome implied by the combination of process mechanisms. I will refer to these propositions that build on various base-level process mechanisms as phenomenon-based propositions. These are often referred to as hypotheses when they are being tested. For further clarification, I refer to the logical justification for how a set of given process mechanisms work together to produce a phenomenon-based outcome as a *theoretical explanation*.

While the distinction between process mechanisms and phenomenon-based propositions is subjective, I submit that this distinction is very informative. According to this nomenclature, I would suggest that the vast majority of empirical organizational research is more focused on evaluating a phenomenon-level theoretical proposition than the process mechanisms or theoretical explanations that were used to derive them. Empirical work is most often built around some phenomena predicted by theory with less regard for the process mechanisms. Consider the case of an empirical evaluation of SITL that would likely focus on the broader propositions regarding the phenomena of leadership, taking less regard for the process mechanisms that the

phenomenon-based propositions are built upon. A researcher may test some of the mechanism level propositions, but many will likely be ignored. For example, a researcher may be interested in the implications of homogeneity on leadership emergence but would likely not have any way to test the process mechanisms of social attraction or depersonalization that form the logical foundation for these hypotheses. Under the present prevailing research norms, most effort focuses on the broader phenomenon-based propositions; less work is done to evaluate the actual process mechanisms proposed by theories, and next to no work evaluates the theoretical explanations that link these process mechanisms and the phenomenon-based outcomes.

I do not question the merit of the hypothesis-centric approach to research. If one can find substantial support for a broader proposition, this likely suggests support that the general idea of the proposed process mechanisms was right if not completely accurate. Furthermore, the broader outcomes are often the more actionable ideas, making this phenomenon-level focus reasonable if not ideal in many circumstances. However, I suggest that there is value in and need for research that can focus on evaluating not only the phenomenon-based propositions but also the theoretical explanations, and process mechanisms as well. To this end, formal theorizing and computational modeling have emerged as a powerful tool capable of evaluating theoretical explanations and assessing the process mechanism level of theory. I suggest that formalization of theory, accompanied by a rigorous computational evaluation of these formal representations provides the key to moving beyond phenomenologically focused research that tests hypotheses without assessing the theory that they are based on.

Formalization of theory. Theories can be formalized by establishing rigorous, consistent, representations of the theory (Adner et al., 2009; Vancouver et al., 2020). Formalized theories often establish mathematical equations or rules that define how various constructs relate

to each other and interact. In formalizing a theory with process mechanism and phenomenon-based propositions as described previously, one or more process mechanisms are likely combined to make equations or rules for each of the core theoretical variables of interest. Phenomenon-based propositions would typically describe the hypothesized outcome of these equations or rules.

Notably, the formal representations of a given narrative theory are not necessarily unique. There are, for example, many non-equivalent ways to formally adequately describe a given theory or theorized phenomenon. Because narrative theory rarely specifies precise mathematical relationships, it is not always clear how a given aspect of a theory should be formalized and there are likely many options. For example, SITL suggests that those most similar to a group prototype will be more socially attractive. This suggests a formal representation of social attraction as a function of prototypicality (i.e. $S_i = f(P_i)$, where S_i is the social attraction of person i and P_i is prototypicality of person i). While the theory is clear that increased prototypicality leads to increased social attraction, it is unclear the exact nature of this hypothesized functional relationship. Is the function additive, multiplicative, logarithmic, exponential, etc.? Many of the distinctions that can be made when formalizing a theoretical relationship may be inconsequential; however, other distinctions may have very strong implications. Thus, a formalization of the theory is by its nature more specific in its logic and claims than its source narrative.

Narrative theory often describes concepts in oblique, or somewhat ambiguous terms which make the logic difficult to follow. Of necessity, proper formalization makes claims and propositions clear in such a way that they can be readily understood in a consistent manner. Thus, a formal theory has the effect of reducing ambiguity found in narrative theory. As a

consequence, formalized theories inherently make predictions stronger and more testable (Adner et al., 2009). For this reason, it is much easier to test and consequently discredit a formalized theory than a narrative theory. Importantly, this is not a drawback. This is incredibly useful. The increased testability of formal theories is a huge boon. Theory that cannot be tested is of questionable value, and thus formalization allows us to evaluate theory that would otherwise be too complex to be directly testable. Formalized theory has tremendous potential to enable the rigorous investigation of the causal explanations that organizational research has often overlooked.

A formal representation of narrative theory without any additional changes is a substantial theoretical contribution, which increases the specificity, consistency, and testability of the theory (Vancouver et al., 2020). That is not to say that formalized theory is superior to more traditional narrative theories. Narrative theory has an important and distinct role from formalized theories. I do not suggest narrative theories are obsolete or should not be used. They simply serve different purposes. In many ways, narrative theory is better at clearly communicating complex concepts in a readily understandable way. For most people, a clear description of an idea is easier to learn, assess, and think about than some complex equation. Narrative theory also benefits from the lack of rigidity afforded by their format. A narrative theory can describe a complex or ambiguous concept while still providing meaningful description and insight. A formal theory, by contrast, is much more rigid, making it difficult to convey ambiguous ideas. However, their rigidity enables them to be used to evaluate propositions and relationships more objectively and consistently. Thus, narrative and formal theory can play distinct and complementary roles in research.

Computational modeling. CM is a modern method that can provide a powerful way to evaluate formalized theory, discover implied outcomes of the theory, and support the viability of phenomena-based proposition (Vancouver et al., 2020). CM can test a theory by evaluating the processes described in the theory (Harrison et al., 2007). While the ability to produce a theory's predicted outcomes is not necessarily strong evidence that the proposed mechanisms are actually at work, a CM that is consistently able to produce hypothesized results using proposed process mechanisms provides evidence for the viability of the underlying theory. Likewise, when a CM is unable to produce hypothesized results, this does not prove the theory wrong. It does, however, provide evidence that either the process mechanisms incorporated into the model are incomplete, that the formal interpretation of them is inaccurate, or that the original theoretical explanation for the given hypothesis is flawed or incomplete.

One prominent class of computational model is an agent-based model. Agent-Based Models (ABM) have individual agents that follow pre-prescribed rules (formalizations of the mechanisms of the theory) interacting and simulating the given theory (Bonabeau, 2002; Epstein, 1999; Fioretti, 2013). Because these models allow us to formally represent the rules of behavior and organization of the simulated agents, ABM is particularly relevant for psychological research. In the present CM, agents will represent individual team members. These agents will interact, assess their leader and group identities, and develop dyadic social-attraction, and dyadic leadership relationships according to the formalizations of the three theories (i.e. SITL, CGTL, and TPTL).

There are numerous approaches to computational modeling research (Vancouver et al., 2010, 2020; Vancouver & Weinhardt, 2012). I follow a simple five-step process. These steps are 1) Formalization, 2) Computerization, 3) Parameterization, 4) Tests of Generative Sufficiency, 5)

Simulated Experimentation. Each of these steps is described in detail in the following sections. In addition to these five steps, future directions for this research will include two more steps described in the discussion of future directions. These are 6) Empirical Validation of the Model, and 7) Predictive Application of the Model.

It should be noted that the first four steps are an iterative process more than a linear process. Some minor details of the formalized representations may be adjusted during the computerization process to be compatible with the constraints of the computational model. When tests for generative sufficiency fail, I adjust the code, and the formalization so that the computational model is adequately representing the process mechanisms. Ideally, code is debugged, formalizations are set, the tests for generative sufficiency are passed, and tuning parameters are fixed before moving onto step 5 - Experimentation.

Computational Modeling Procedure

Formalization. I first developed formalized representations of each of the three leadership emergence theories presented previously (i.e. Social Identity Theory of Leadership, Claiming and Granting Theory of Leadership, Two Process Theory of Leadership). I read through the original papers proposing SITL (Hogg, 2001) and CGTL (DeRue & Ashford, 2010) identifying all important variables, process mechanisms, and phenomenon-based propositions. I then incorporated these process mechanisms and variables into mathematical equations that represented the theorized dynamics. The process is described in more detail in Appendix C. Because of their testability and potential for making precise predictions, these formalized theories are in of themselves, a significant contribution to the theory of leadership emergence.

As mentioned previously, the first four steps of the computational modeling process are iterative and during the computerization, parameterization, and generative sufficiency steps I occasionally made minor adjustments to the original formalized model to make it more compatible with the technology and to address inconsistencies that arose. Three slight adjustments were made to the original formalization. These are described in Appendix C, along with a complete description of the formalized theories, including equations and their explanations.

Computerization. I developed three separate agent-based computational models from formalizations of the three leadership theories (i.e. SITL, CGTL, TPTL). In these ABMs, each agent's perceptions, attitudes, and social standing evolve over time as the agents assess each other and interact. The model thus represents a computerized realization of formalizations for each of these three theories. The computational models were programmed using REPAST 2.7 (North et al., 2013), a powerful agent-based modeling platform developed in Java.

The general architecture of the model is that of a typical agent-based model. In every time step, each agent assesses all other agents. This is done in parallel, so at each time point, each agent assesses all other agents simultaneously. Each agent has various individually held characteristics, attitudes, and memory. In each simulation, one attribute was systematically varied for simulated experimentation; all other variables were either randomly generated or set to a constant value. This systematically varied variable was the heterogeneity of the team in all but three simulations. In two simulations the systematically varied characteristic was the variance in leadership schema (one for CGTL model and one for the TPTL model). In the last simulation, variance in individually held leadership prototypes was the systematically varied characteristic.

Parameterization. The three original formalized theories collectively used fifteen parameters. Twelve tuning parameters encode the relative strengths of individual process mechanisms. For example, one parameter represents the relative strength of social attraction's impact on influence while another represents the relative strength of reciprocated claims on influence. Two parameters described the size of the team and number of characteristics measured. The last parameter described the decay rate of memory for the team members. I tested the impact of various parameter values to establish fixed values for these tuning parameters. Parameter values were established based on three criteria. First, the model needed to be able to produce the basic behaviors predicted by the theories (i.e. generative sufficiency). Secondly, following the philosophical contribution of Ockham's Razor, where possible I used the simplest values that could pass the tests for generative sufficiency and removed as many parameters from the formalized equations as possible. Thirdly, where other considerations were met, parameters were selected to provide the clearest distinctions in model output (Vancouver et al., 2020).

After developing the CM, and testing various combinations of parameter values, I was able to reduce the number of tuning parameters from twelve to two. These represent: 1) the ratio between the impact of SITL and CGTL processes, and 2) the relative importance of claim history on future claims vs. leadership identity and current assessment of the other team member. All other tuning parameters appeared to only have qualitatively meaningful impacts on the leadership structures when set to extreme values and were therefore removed from the final formalized models. The team size was set to ten agents and the number of characteristics was set to four. Originally the plan was to keep ten characteristics, but the large number of characteristics washed out many of the emergent processes because it essentially increased noise. From a theoretical standpoint, this suggests that salience has a powerful role to play in leadership

network emergence. Where there are not salient characteristics, the process would theoretically become random and thus less adaptive in general. Four characteristics seemed to be a reasonable number with loose ties to notions of the limits of working memory (Baddeley, 1992).

Generative sufficiency. After parameterizing the models, I tested each model's ability to simulate the proposed mechanisms and produce outcomes predicted by the theories. This is referred to as tests for generative sufficiency (Epstein, 1999; Harrison et al., 2007; Horn, 1971; Naylor et al., 1967; Sargent, 2013; Vancouver et al., 2020). Generative sufficiency represents evidence that the CM is a valid interpretation of the given theory and that the proposed process mechanisms are adequately represented. I distinguish between two types of tests. First are tests of individual process mechanism-level predictions made by the theories. These process mechanisms are explicitly included in the formalization and computerization process. As such, these process mechanism tests will be focused on assessing the implementation of the model, not the theory itself. A computational model is only able to explore the implications and make predictions regarding relationships and mechanisms that it can reproduce. Failure to produce process mechanism behavior could indicate inherent contradictions in theorized process mechanisms, but likely only suggests faults in the code or formalized equations. The second set of tests are focused on the phenomena-level propositions as described previously. These tests assess the ability of the model to reproduce broader patterns theorized to emerge from the mechanism-level processes. These hypotheses theoretically arise from the process mechanisms that are directly coded into the model and will not themselves be explicitly included in the model code. As such, this second set of tests can serve to assess the formalization and theory itself. While failure to produce hypothesis-level propositions could represent a fault in the code or equations, this is less likely if the model can demonstrate expected process mechanism-level

behavior. Thus, these issues represent evidence that there is some inconsistency in the narrative theory logic or fault in the formalized interpretation thereof.

All tests are based on the qualitative evaluation of expected and hypothesized behaviors. I followed up any failure to simulate a process mechanism test with an evaluation of the code and formal equations. I followed up any failure to simulate phenomenon-level propositions by first evaluating it as a possible indication of a problem in the code or formalization. Any predictions that could not be reproduced after a thorough evaluation of code and equations was reported and possible explanations for these failures will be provided. The qualitative evaluation confirmed that in the final form, the models were able to reproduce all process mechanism level behaviors that are within the scope of this model.

One phenomena-level test of generative sufficiency partially failed. This was a test of the impact of contextual influences. The results indicate that the contextual influences, as encoded in the model, had very weak relationships with leadership structures as proposed in the two theories. This likely indicates that how contextual influences were included in the models was not entirely representative of the original theories. Although this may be due to a faulty formalization, this is likely since the theory does not provide a clear description of the process mechanisms for contextual influence to impact the theorized outcomes. Whether the result was due to unspecified process mechanisms from the original theories or faulty interpretations thereof, the role of contextual factors is relatively unimportant to the main focus of this thesis and has little impact on the rest of the model. For this reason, I deemed it more appropriate to dramatically reduce the impact of the contextual factors to ensure that they did not confound other results and move forward. Context is valuable to study, and future research should address these considerations.

One additional hypothesis-based test of generative sufficiency failed regardless of parameterization. This was the proposition made by Social Identity Theory of Leadership, that under high contextual pressures to join a group, and high levels of homogeneity, there would be a propensity to form strong hierarchical, cult-mentality-like influence networks. It is possible that my interpretation of Hogg's proposition was inaccurate and the test for generative sufficiency did not correctly represent the proposed hypotheses found in SITL. It is also possible that the formalization of SITL is incomplete. If the CM is missing a crucial aspect, that would explain why this hypothesis cannot be reproduced. However, this consistent failure to reproduce the hypothesized phenomenon where extremely homogeneous groups form steeply hierarchical structures supports my assertion that the process mechanisms described in SITL are insufficient on their own to explain the emergence of hierarchy out of extreme homogeneity and group pressures. Notably, as I proposed, when combined with CGTL process mechanisms, the model was able to pass the test for generative sufficiency under specific circumstances. Further review of this finding is found in the discussion. For a complete list of tests and test notes, see Appendix D.

Simulation procedures. Simulated experiments were run using the REPAST 2.7 platform (North et al., 2013). Each experiment randomly generates a team of agents that each have one or more attributes systematically varied. The team's members are initialized with no prior knowledge of each other. As described previously, the simulation takes place in discrete time steps. During each time step, all agents assess each other simultaneously. In the CGTL and TPTL models, each agent additionally randomly decides to make claims and grants of leadership to other agents based on the probability equation described in the formalization (Appendix C). The model then updates their attitudes, behavior, and memory accordingly. After twenty such

increments, the model data, including both network and individual-level data, is recorded and the simulation terminated.

I ran five simulation studies. Study 1 assesses the relative differences in leadership network structures that emerge as a result of SITL and CGTL mechanisms (H1). Study 2 tests the impact of team heterogeneity on the network structures that emerge due to SITL mechanisms (H2). Study 3 tests the impact of team heterogeneity on the network structures that emerge due to CGTL mechanisms for teams with shared (H3) and hierarchical (H4) leadership schemas. Study 4 tests the general impact of team heterogeneity on the network structures that emerge due to the combined SITL and CGTL mechanisms (H9) in addition to testing how this relationship differs between teams with shared (H6) and hierarchical (H7) schemas. Lastly, Study 5 assesses exploratory relationships between emergent leadership network structures and group contextual influences (H10, H12), leadership contextual influences (H11, H13) and convergence in leadership prototypes (H14, H15). Results for Study 1 through 4 are seen collectively in one set of models in Appendix H.

Measures of team attributes. Aggregate values of the following variables are used as predictors of emergent leadership network structures and were either systematically varied or randomly assigned during simulations. These variables are as follows: group homogeneity, leadership schema, contextual pressure to lead, contextual pressure for group membership, and heterogeneity of individual leadership prototypes. These values are set at the beginning of a simulation and do not vary during the simulations. The first two (i.e. group homogeneity and leadership schema) are the primary predictors, the final three are used to test the exploratory hypotheses in Study 5.

Evaluation of Leadership Networks

The focal outcome in this study is the emergence of leadership network structures. This thesis aims to assess theoretical underpinnings that explain differences in emergent leadership network structures. It is known that leadership network structures may emerge due to differences in leadership emergence processes (D’Innocenzo et al., 2016), but as of yet, we know little more than the existence of structural emergence. This work will let us assess precise structural distinctions that will theoretically arise based on distinctions in the theoretical mechanisms at play in each situation. As such, characteristics of emergent leadership networks are the dependent variables associated with each hypothesis of this thesis. In the following section, I provide an overview of the process used to generate unweighted networks, then describe generally the six network indices assessed (See Table 1).

Generating unweighted networks. Networks that are simulated from the CM are weighted. This means the connections in the network are characterized by some value which represents the strength of a given dyadic connection. The simulated leadership networks have positive weights between 0 and 1. When equations produce a negative influence value, it is replaced by 0. Most social network analysis tools and indices are built on binary, or unweighted networks (Barrat et al., 2004; Wasserman & Faust, 1994). In these networks, a connection either exists or doesn’t, and has no weight associated with it.

I employ a simple mean threshold algorithm to calculate a threshold for each team. Any network connection that is stronger than the grand mean of all weighted network connections is recorded as a connection and any connection weaker than the threshold is set to 0. Properly selecting a thresholding algorithm to generate an unweighted graph is not straight forward. I chose to use a simple mean threshold that was unique for each team because this made the

observed network structure less dependent on the relative influence for a given network. Because I used three different models, under a broad array of team characteristics, there was significant variability in the total amount of influence for any given team. Using a mean threshold for each team increased my ability to pull out network structures from relatively low influence teams.

Network measures. Numerous indices have been used to characterize network structures (Barrat et al., 2004; Otte & Rousseau, 2002; Wasserman & Faust, 1994). I have chosen to focus on eight characteristics that are relevant to the theory. Two of these are based on the original simulated influence relationship strengths and are weighted. The remaining six are derived from the unweighted networks. Note that these two weighted network characteristics correspond to unweighted versions. I include both the weighted and unweighted versions because each address different issues that can arise. For example, the thresholding procedure described helps address discrepancies in the level of influence that SITL and CGTL mechanisms produce. However, this has drawbacks when comparing between teams simulated using the same model. These values were assessed using the R package igraph (Csardi & Nepusz, 2006).

It is important to acknowledge that these network characteristics are highly correlated. There is significant overlap in these network characteristics, however they are each conceptually distinct. As such, even though they are treated separately in following analysis, they should be considered collectively. Future work is needed to investigate the nature of the overlap in these network structural characteristics.

Density. Density, in a network, is the ratio of network connections that are present to the total possible number of network connections (Wasserman & Faust, 1994). This is a network (or team) level index that in basic terms encodes the overall strength of connections in a network. For leadership networks, density is a measure of how much overall inter-personal influence

exists in a team. It is assumed that conditions where networks have overall strong leadership relationships will have relatively high network density.

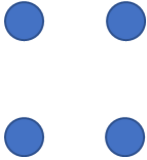
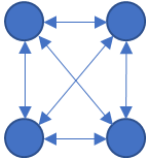
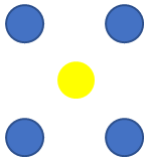
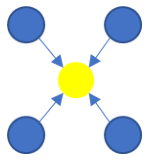
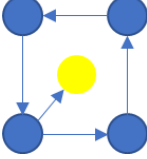
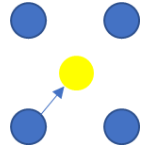
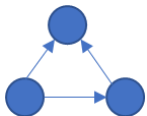
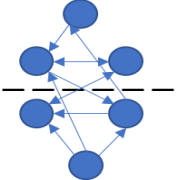
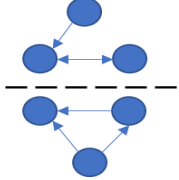
Due to the losses of meaningful variance caused by deriving an unweighted network, I evaluated the weighted density which I refer to as average influence strength. This is reported in addition to the unweighted density. Note that average influence strength is the average of all influence relationships (including relationships with a strength of 0). In the extreme case, where all relationships were either full strength with a value of 1 or empty with a value of 0, both density and average influence strength would be identical.

Degree centrality. Centrality can be measured in various ways, but it is generally conceptualized as an individual-level measure of importance within a network (Wasserman & Faust, 1994). Degree-centrality is a commonly used form of centrality and is simply a count of the total number of edges a node is connected to within a graph. In directed graphs, such as leadership graphs where the direction of a relationship is meaningful (i.e. one person influences the other), degree-centrality can be calculated using in-degree which is the number of edges that connect to the node in question. This is the number of team members that recognize one individual as a leader or the count of followers a specific leader has.

Degree centrality is an individual level index, not a network-level index. My primary theoretical interest in in-degree centrality is in the structure and distribution of influence. In this regard, I am most interested in when influence is distributed such that one person, or a few, have relatively little influence compared to one person who has a lot of influence. As such, I calculated the skew of in-degree centrality. A positive value indicates a team where there are few outliers with significantly more influence than the rest of the team. A negative skew indicates a team where most of the team has a similar level of influence with few outliers significantly less

Table 1

Table of network characteristics used as outcome variables for analysis.

Criterion	Equation	Description	Minimal Example	Maximal Example
Density	$D = \frac{\sum E_{ij}}{n(n-1)}$	Number of total connections		
Degree Centrality	$C_i = \sum_j E_{ij}$	Measure of the total influence a single individual (yellow)		
Reciprocity	$R = \frac{2r}{n(n-1)}$	Propensity for individuals to have reciprocal influence		
Hierarchy	$H = \frac{\max_i C_i}{\sum_j C_j}$	Proportion of influence in the network held by the most central figure		
Transitivity	$T = \frac{6t}{n(n-1)(n-2)}$	How strongly the network forms a consistent ordering		
Modularity	$M = \frac{w}{\sum_j \sum_i E_{ij}}$	How strongly the network forms two distinct groups		

Note. C_i is the centrality for person i . n is the number of team members. E_{ij} is the connection between person i and person j . It is 1 if person i influences person j and 0 otherwise. It is just the weight of the given connection for the weighted versions. r represents the number of reciprocal dyads. t represents the number of transitive triads. w is the number of within-group connections.

influential than the rest of the team. As with density, I calculated this value using both an unweighted and weighted index.

Degree centrality is an individual level index, not a network-level index. My primary theoretical interest in in-degree centrality is in the structure and distribution of influence. In this regard, I am most interested in when influence is distributed such that one person, or a few, have relatively little influence compared to one person who has a lot of influence. As such, I calculated the skew of in-degree centrality. A positive value indicates a team where there are few outliers with significantly more influence than the rest of the team. A negative skew indicates a team where most of the team has a similar level of influence with few outliers significantly less influential than the rest of the team. As with density, I calculated this value using both an unweighted and weighted index.

Transitivity. Transitivity is essentially a measure of how well a ranking order is preserved (Barrat et al., 2004; Wasserman & Faust, 1994). For network members A, B, and C, if A is connected to B and B is connected to C, transitivity is A's propensity to connect to C. In a perfectly transitive network, A would always connect to C; in a perfectly intransitive network A would never connect to C. Transitivity could be described as directed or undirected. I use a directed form of transitivity. Note that some of the notions of transitivity referred to in the hypotheses may be better described in terms of an undirected form of transitivity. Directed transitivity is a measure of rank-ordering, while undirected transitivity is more of a measure of social transference. Future work may find comparing these two metrics informative. In a leadership network, the directed concept of transitivity I use could be expressed in the idea that the leader of one's leader is the original person's leader. Transitivity is defined here as the proportion of triads that are considered transitive. This is calculated by evaluating all possible

sets of three-team members. If among three team members two of them are indirectly connected ($A \rightarrow B$, $B \rightarrow C$ is an indirect connection from A to C), and they are also directly connected ($A \rightarrow C$) then the triad is transitive.

Hierarchy. As with transitivity, there are many definitions and measures for the notion of hierarchy. I use a centrality-based definition. Hierarchy could be described as representing the extent to which one influence on a given level is dominated by one or a few people. When considering the distribution of centrality scores (Chen et al., 2013) for each member of a team, teams where one person's centrality score is much higher than the rest, would be considered strongly hierarchical. Based on this notion, I define hierarchy as the proportion of the sum of all degree-centrality scores across a single team that is held by the single individual with the highest degree centrality score. In cases where all individuals are influenced by one central individual and no one else, hierarchy would be maximized. In cases where hierarchy is evenly distributed, hierarchy would be minimized.

Reciprocity. Reciprocity is a measure of how likely it is that a team member has influence over those that influence them (Wasserman & Faust, 1994). A highly reciprocal scenario happens when every time a team member has influence over another, the second team member influences the first. In other words, when one network member A, is connected to a second member B, reciprocity is the propensity for B to connect back to A. Formally, reciprocity is the ratio of reciprocal dyads to the total number of dyads. In leadership, high reciprocity implies that leadership relationships tend to be bidirectional, representing shared authority.

Modularity. A network's modularity is a measure of how well the network can be divided into subgroups (Clauset et al., 2004). A highly modular network is divided so that most network connections are within nodes in the same groups, and very few connections are between

nodes from different groups. Modularity is calculated by first identifying the optimally disconnected groups. Modularity is defined as the fraction of connections in this optimal grouping that fall within the groups (i.e. not between the two groups) minus the theoretically expected value. Modularity is maximized when all connections in a graph are from team members to other team members in the same group, with no connections between the two members of different groups. In terms of influence, this would represent essentially a two-party system where you have completely separate leadership hierarchies that have minimal cross-influence.

Collinearity with density. All network measures described are closely influenced by density (Anderson et al., 1999). A completely connected network (i.e. with every possible edge present) would always be perfectly reciprocal, and transitive. This is one reason that it was useful to use a different threshold for each team. This interdependence with density makes it difficult to distinguish between the differences in the network structure that are due to changes in the overall number of connections and the changes that are due to an underlying shift in the propensity for networks to form transitive, modular, reciprocal, etc. relationships. While it is possible to statistically control for density effects, due to high multicollinearity between antecedent team characteristics and density, estimations derived from this approach would be potentially dramatically inaccurate. Though various authors have worked to address these limitations, at this time there is no clear method for accurately handling potential collinearity with density. Thus, all outcome variables could be partly confounded by relationships with density.

Analysis

All relationships were tested using OLS regression models to assess the relationships between hypothesized team characteristic predictors, and network index-based dependent

variables. For the hypothesis comparing between shared and hierarchical schemas, I used a simple OLS regression with a schema interaction term.

Statistical significance. As a simulation study, statistical significance has limited practical meaning. This is because the sample size can hypothetically always be increased to a point where significance is found even if the relationship is trivial in nature or erroneous. Despite its limitations in the given context, significance testing remains an informative method to approach analyzing data, so long as the limitations are appropriately acknowledged. I focus on a discussion of effect sizes, but I include confidence intervals for reporting purposes and ease of decision criterion.

Because the data was all simulated from a computational model, large effect sizes, and significant results do not establish the existence of a given phenomenon. These results, instead, establish the viability of the theory. As discussed previously, computational modeling results help to test the causal explanations linking the process mechanisms of a theory to its proposed hypotheses. When the simulated results indicate a large effect size, that suggests that the theoretical explanation for the given hypothesis was valid and the formalization adequately captures its process. Traditional empirical research is still required to test the hypotheses themselves. This work thus complements future empirical research by testing the logical viability of a theory and serving as a foundation for empirical research. Results from the analysis should be considered accordingly.

Results

Study 1: Comparison of SITL and CGTL

In the first experiment, I simulated patterns of leadership emergence in teams based on the SITL model and the CGTL model with group homogeneity varied systematically. There were 4001 teams simulated for SITL included in this experiment. The CGTL simulations were split between 2001 teams with a shared leadership schema, and 2001 teams with a hierarchical leadership schema, and 2001 teams with randomly varied leadership schema values. Standard statistics and correlations are presented in Table 2. These sample sizes were selected arbitrarily to be a large enough number to ensure small standard errors. Because of this strategy, significance has trivial meaning and is reported only as a convention. More focus should be given to the point estimates and confidence intervals.

Results are strongly supportive of Hypothesis 1. Skew in the leadership distribution (measure by skew in degree centrality distribution and weighted mean influence relationship strength) are stronger for CGTL than SITL mechanisms. Similarly, CGTL generated team leadership networks were more strongly hierarchical. By contrast, SITL generated team leadership networks that had a higher degree of density and reciprocity. Transitivity was the only hypothesized network characteristic that did not follow the expected pattern. This is likely because transitivity was measured as directed transitivity as opposed to undirected transitivity, and is closely related to the hierarchical structure. The original hypothesis was based more on an undirected conceptualization of transitivity. That is to say that the index of transitivity used in this study indicates the presence of a clear chain of command; this is more consistent with the structures we hypothesized would emerge from CGTL than SITL based leadership networks.

Table 2

Regression results for Study 1 comparing the differences between SITL and CGTL mechanisms

Criterion	Predictor	<i>b</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Individual Strength	(Intercept)	-0.50*	[-0.52, -0.48]			
	Mechanism	1.01*	[0.99, 1.04]	0.64	[0.63, 0.66]	$R^2 = .415^*$
Skew Degree Centrality	(Intercept)	-0.31*	[-0.33, -0.29]			
	Mechanism	0.76*	[0.74, 0.78]	0.54	[0.52, 0.56]	$R^2 = .291^*$
Average Strength	(Intercept)	0.35*	[0.34, 0.35]			
	Mechanism	-0.16*	[-0.17, -0.16]	-0.65	[-0.66, -0.63]	$R^2 = .421^*$
Density	(Intercept)	0.51*	[0.51, 0.51]			
	Mechanism	-0.31*	[-0.31, -0.30]	-0.91	[-0.92, -0.90]	$R^2 = .829^*$
Reciprocity	(Intercept)	0.90*	[0.90, 0.90]			
	Mechanism	-0.64*	[-0.64, -0.63]	-0.90	[-0.91, -0.89]	$R^2 = .812^*$
Hierarchy	(Intercept)	0.16*	[0.16, 0.16]			
	Mechanism	0.09*	[0.09, 0.09]	0.61	[0.59, 0.62]	$R^2 = .366^*$
Transitivity	(Intercept)	0.68*	[0.68, 0.69]			
	Mechanism	0.15*	[0.15, 0.15]	0.62	[0.60, 0.63]	$R^2 = .381^*$

Note. The mechanism variable is dummy coded with 0 for SITL and 1 for CGTL. A significant *b*-weight indicates the beta-weight is also significant. *b* represents unstandardized regression weights. *beta* indicates the standardized regression weights. R^2 represents the zero-order correlation.

* indicates $p < .05$.

Collectively these results indicate that the influence networks that are generated by SITL are highly shared, flat leadership structures where everyone has a strong influence on everyone else. This is the sort of leadership or influence structure we would expect to lead quick responsiveness but also to groupthink and cliquishness. By contrast, CGTL mechanisms would predict the emergence of a more structured hierarchy with clear central leaders and a clear chain of command. The vertical nature of these leadership structures is reminiscent of more traditional pyramid style leadership structures.

Notably, the relative strength of CGTL and SITL mechanisms was a tuning parameter used to balance leadership outputs from these two computational models. Notably, because each team network structure was thresholded using a unique team average influence threshold, it is reasonable to compare network structures between the two models. However, the unweighted variables (i.e. skew in individual influence strength or average team influence strength) which are related to the original, threshold values are not necessarily meaningful to compare between the two mechanisms. Results for skew in-degree centrality and density represent the threshold values and are thus more reasonable for cross mechanism comparison, and both indicate results consistent with Hypothesis 1.

Study 2: Heterogeneity in SITL

I used the data simulated in Study 1 to evaluate the impact of group homogeneity on a subset of these characteristics under the SITL model. There were 4001 simulated SITL teams used for this analysis. See Table 3 for regression statistics.

Results are supportive of Hypothesis 2. There is a clear, positive relationship between the heterogeneity and the skew of both individual influence distributions and degree centrality distributions, with a strong negative intercept. This indicates that highly homogeneous groups will have a very flat influence structure with few individuals who are essentially outcast or ostracized. Under SITL mechanisms, as there is increased heterogeneity in the group, the team will have a more evenly spread distribution of influence where there are some strong leaders and some weak, but most are somewhere in the middle. Similarly, density is an average influence strength; both have positive intercepts with strong negative slopes for heterogeneity. The more similar the group the more influence is present within the group. Under SITL mechanisms, diversity heavily reduces a group's total internal influence.

Table 3

Regression results for Study 2 evaluating the impact of group heterogeneity emergent leadership network structures in the SITL based model.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Influence Strength	(Intercept)	-0.80*	[-0.86, -0.75]			
	Heterogeneity	0.44*	[0.37, 0.51]	0.19	[0.16, 0.22]	$R^2 = .037^*$
Skew Degree Centrality	(Intercept)	-0.56*	[-0.61, -0.51]			
	Heterogeneity	0.36*	[0.29, 0.43]	0.16	[0.13, 0.19]	$R^2 = .024^*$
Average Strength	(Intercept)	0.63*	[0.63, 0.63]			
	Heterogeneity	-0.40*	[-0.40, -0.40]	-1.00	[-1.00, -1.00]	$R^2 = .996^*$
Density	(Intercept)	0.52*	[0.52, 0.52]			
	Heterogeneity	-0.01*	[-0.02, -0.01]	-0.08	[-0.11, -0.05]	$R^2 = .006^*$
Reciprocity	(Intercept)	0.69*	[0.68, 0.70]			
	Heterogeneity	0.30*	[0.29, 0.31]	0.75	[0.72, 0.77]	$R^2 = .556^*$
Hierarchy	(Intercept)	0.15*	[0.15, 0.15]			
	Heterogeneity	0.02*	[0.02, 0.02]	0.26	[0.23, 0.29]	$R^2 = .066^*$
Transitivity	(Intercept)	0.66*	[0.65, 0.66]			
	Heterogeneity	0.04*	[0.03, 0.05]	0.12	[0.09, 0.15]	$R^2 = .015^*$

Note. Heterogeneity is the standard deviation of individual characteristics for team members.

* indicates $p < .05$.

Results for reciprocity were indirectly supportive of Hypothesis 2c. Counter to H2c, increased heterogeneity leads to increased reciprocity in the SITL model. However, this is unsurprising because of how the undirected networks were generated. A distinct threshold was used for each team based on the mean team influence. Because of this, teams with very low variability in influence develop ambiguous structures. Notionally homogeneous SITL teams are highly reciprocal in their influence relationships; however, this is not necessarily represented by the reciprocity index of the unweighted networks generated for this analysis. In the present model, when teams are highly homogeneous, the slight variance in influence is dominated by contextual influences. Specifically, Individuals with higher contextual group membership influences are likely to be slightly more socially attracted to others in the group. This typically

generates a minimally reciprocal structure, even though these individuals all have similar levels of influence with each other. Thus, the structures generated from highly homogeneous teams are unlikely to accurately represent their true level of reciprocity. In this case, variance in influence may conceptually be a better measure of reciprocity. Post-hoc, a test of the relationship between variance in individual influence and team heterogeneity indicated that homogeneous teams had extremely little variance in influence relative to heterogeneous teams despite having more overall influence (Figure 5). This supports the explanation provided above and is consistent with H2c.

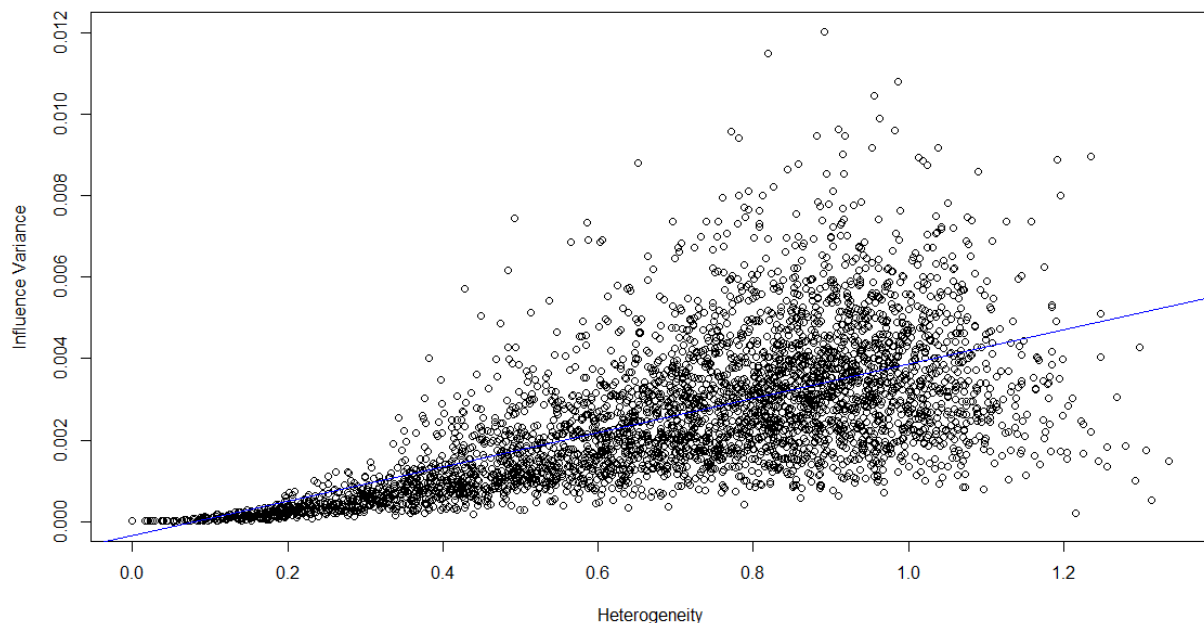


Figure 5. Scatter plot of the relationship between team heterogeneity and variance in influence strength for team simulated from the SITL model. The regression line is significant at a $p = .05$ level with $b = .004$, $SE = 8e-5$.

Collectively, results for Study 2 provide evidence in support of Hypothesis 2. While results did not directly support H2c, the minimal variance in influence for homogenous teams is consistent with this Hypothesis.

Study 3: Heterogeneity in CGTL

I tested the same relationship as tested in Study 2 for the CGTL model with the inclusion of leadership schema as a moderating factor. This analysis was directed at testing Hypotheses 3 and 4. The simulated sample comprised 4002 simulated teams drawn from the original sample used for Study 1. This includes 2001 CGTL teams with shared leadership schema and 2001 CGTL teams with hierarchical leadership schemas.

In this analysis, I focused on testing the moderating impact of schema on the relationship between group heterogeneity and leadership network characteristics. Results and statistics are presented in Tables 4 and 5. Results support Hypothesis 4 but only partially support Hypothesis 3. In general, the shared schema appears to function quite differently than expected, as will be discussed below.

Table 4

Regression results for Hypothesis 3 of in Study 3 assessing the relationship between leadership network characteristics and heterogeneity in CGTL teams with a shared schema.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Influence Strength	(Intercept)	0.65*	[0.58, 0.72]			
	Heterogeneity	-0.38*	[-0.47, -0.30]	-0.18	[-0.23, -0.14]	$R^2 = .034^*$
Skew Degree Centrality	(Intercept)	0.58*	[0.51, 0.65]			
	Heterogeneity	-0.35*	[-0.43, -0.26]	-0.17	[-0.21, -0.13]	$R^2 = .029^*$
Reciprocity	(Intercept)	0.35*	[0.33, 0.37]			
	Heterogeneity	0.05*	[0.02, 0.07]	0.08	[0.04, 0.13]	$R^2 = .007^*$

Note. Teams all had shared schema for this analysis.

* indicates $p < .05$.

Table 5

Regression results for Hypothesis 3 and 4 in Study 3 assessing the moderated relationship between leadership network characteristics and heterogeneity in CGTL teams.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Influence Strength	(Intercept)	0.65*	[0.58, 0.72]			
	Heterogeneity	-0.38*	[-0.48, -0.29]	-0.17	[-0.21, -0.13]	$R^2 = .096^*$
	Schema	-0.03	[-0.13, 0.06]	-0.03	[-0.11, 0.06]	
	Heterogeneity X Schema	0.52*	[0.39, 0.65]	0.35	[0.26, 0.44]	$\Delta R^2 = .013^*$
Skew Degree Centrality	(Intercept)	0.58*	[0.51, 0.65]			
	Heterogeneity	-0.35*	[-0.44, -0.26]	-0.16	[-0.20, -0.12]	$R^2 = .075^*$
	Schema	-0.08	[-0.17, 0.02]	-0.07	[-0.15, 0.02]	
	Heterogeneity X Schema	0.50*	[0.37, 0.63]	0.35	[0.26, 0.44]	$\Delta R^2 = .013^*$
Average Strength	(Intercept)	0.26*	[0.25, 0.26]			
	Heterogeneity	0.00	[-0.01, 0.01]	0.01	[-0.02, 0.04]	$R^2 = .586^*$
	Schema	-0.20*	[-0.21, -0.19]	-1.07	[-1.13, -1.02]	
	Heterogeneity X Schema	0.09*	[0.07, 0.10]	0.37	[0.31, 0.43]	$\Delta R^2 = .015^*$
Density	(Intercept)	0.27*	[0.26, 0.28]			
	Heterogeneity	0.00	[-0.01, 0.01]	0.01	[-0.02, 0.04]	$R^2 = .582^*$
	Schema	-0.19*	[-0.20, -0.18]	-1.07	[-1.13, -1.01]	
	Heterogeneity X Schema	0.09*	[0.07, 0.10]	0.37	[0.31, 0.43]	$\Delta R^2 = .015^*$
Reciprocity	(Intercept)	0.35*	[0.34, 0.37]			
	Heterogeneity	0.05*	[0.02, 0.07]	0.07	[0.03, 0.10]	$R^2 = .423^*$
	Schema	-0.27*	[-0.29, -0.24]	-0.72	[-0.78, -0.65]	
	Heterogeneity X Schema	0.04*	[0.01, 0.07]	0.08	[0.01, 0.16]	$\Delta R^2 = .001^*$

Note. Leadership schema is dummy coded with 0 indicating shared leadership schema and 1 indicating hierarchical schema. ΔR^2 indicates the change in the coefficient of determination above the main effects model achieved by including the interaction term. R^2 indicates the coefficient of determination for the full interaction model presented.

* indicates $p < .05$.

Hypothesis 3a predicts a positive relationship between heterogeneity and influence skew for a team with a shared leadership schema. Both influence strength skew and degree centrality skew have positive intercepts with similar values but while the slope for heterogeneity is positive in teams with hierarchical schemas, the slope is negative in teams with shared schemas. This is the opposite of the relationship predicted in Hypothesis 3a. The original justification for

Hypothesis 3a is built on the idea that in highly homogeneous teams there is little preference for one leader over another. This was built on an implicit assumption that the prototypes used to evaluate leadership qualities are correlated with individual characteristics. However, the CGTL theory does not provide any justification for correlated leadership prototypes and group characteristics, and the model did not include any such relationship. In the absence of a correlation between group characteristics and individual leadership prototypes, the reverse of Hypothesis 3a is supported.

Under highly homogeneous situations, there are a few individuals with leadership prototypes that correspond to the group characteristics; these few will be more likely to make leadership claims and thus be more likely to receive grants. The rest of the individuals will remain low in their influence, creating a situation where few individuals have more influence than the rest (i.e. a right skew leadership distribution). As heterogeneity increases, these central figures will tend to receive less influence from each other, and the rest of the group will tend to receive more influence from each other, shifting the influence to be less right-skewed. This is the pattern found in the data.

Density and average influence strength followed the predicted pattern that heterogeneity was positively related to each of these variables in teams with hierarchical schemas but not teams with shared schemas. This supports Hypothesis 4a. Hypothesis 3b predicted a negative relationship between density and heterogeneity in teams with a shared leadership schema. The simple slopes from the regression reveal a non-significant relationship. However, the significant interaction indicates the predicted relationship between teams with shared and teams with hierarchical schemas. See Figure 6.

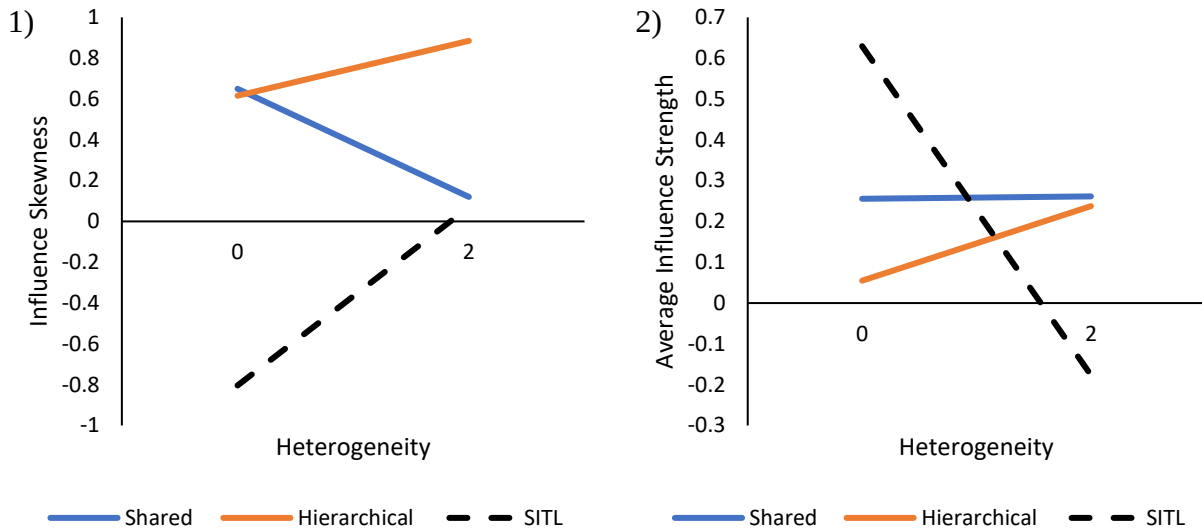


Figure 6. Graph of interaction between average leadership strength and heterogeneity for team simulated with the CGTL model. (1) Interaction between weighted skewness in influence and team compositional heterogeneity. (2) Interaction between weighted average influence strength in a team and team compositional heterogeneity. SITL is included for comparison.

Reciprocity followed a pattern similar to the analysis for the skew of the influence distribution. Where hypothesis 3c predicted heterogeneity to be negatively related to reciprocity, the relationship is positive. The same explanation used there appears to hold for this result.

Study 4: Heterogeneity in TPTL

In Study 4, I assessed the impact of team heterogeneity on the network structure as moderated by leadership schema. Analyses were run using 6003 simulated TPTL teams. These teams are split with 2001 having a shared leadership schema and 2001 having a hierarchical leadership schema, and 2001 teams with randomly varying schemas. As part of Study 4, I ran two distinct sets of analyses. First, I used all simulated teams to test the general average relationships predicted by Hypothesis 9. Next, I ran moderation tests to evaluate the interaction between heterogeneity and leadership schema.

Table 6

Regression results for test of Hypothesis 9 in Study 4 assessing the general relationship between leadership network characteristics and heterogeneity in TPTL teams.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Influence Strength	(Intercept)	0.82*	[0.77, 0.86]			
	Heterogeneity	-0.08*	[-0.12, -0.03]	-0.04	[-0.06, -0.02]	R ² = .002*
Skew Degree Centrality	(Intercept)	0.52*	[0.48, 0.56]			
	Heterogeneity	0.04	[-0.00, 0.08]	0.02	[-0.00, 0.04]	R ² = .000
Average Strength	(Intercept)	0.07*	[0.07, 0.07]			
	Heterogeneity	0.04*	[0.03, 0.04]	0.29	[0.27, 0.31]	R ² = .084*
Density	(Intercept)	0.12*	[0.12, 0.13]			
	Heterogeneity	0.02*	[0.02, 0.03]	0.18	[0.16, 0.20]	R ² = .031*
Reciprocity	(Intercept)	0.11*	[0.10, 0.12]			
	Heterogeneity	0.04*	[0.03, 0.05]	0.10	[0.07, 0.12]	R ² = .009*
Hierarchy	(Intercept)	0.27*	[0.27, 0.28]			
	Heterogeneity	-0.00	[-0.01, 0.00]	-0.02	[-0.04, 0.01]	R ² = .000
Transitivity	(Intercept)	0.93*	[0.93, 0.94]			
	Heterogeneity	-0.02*	[-0.03, -0.02]	-0.15	[-0.17, -0.12]	R ² = .021*

* indicates $p < .05$.

General pattern TPTL. In this analysis, I tested general relationships between group heterogeneity and leadership network structures that arise as part of TPTL's combined mechanisms. Notably, one of the fitting parameters of the model adjusted the relative strength of SITL and CGTL mechanisms in the combined model. The results of this analysis are descriptive. Without a more in-depth analysis of the relative impact of this ratio on these outcomes, we cannot substantively consider these differences. Therefore, these results provide a general idea of how these two mechanisms are balanced in the present model more than a strong test of hypotheses. Results were mixed regarding how well they aligned with the predictions made by Hypothesis 9. Furthermore, despite being "statistically significant" most of these results have very small effect sizes. This was intentionally the fitting parameter; to balance CGTL and SITL processes. Statistics for results are provided in Table 6.

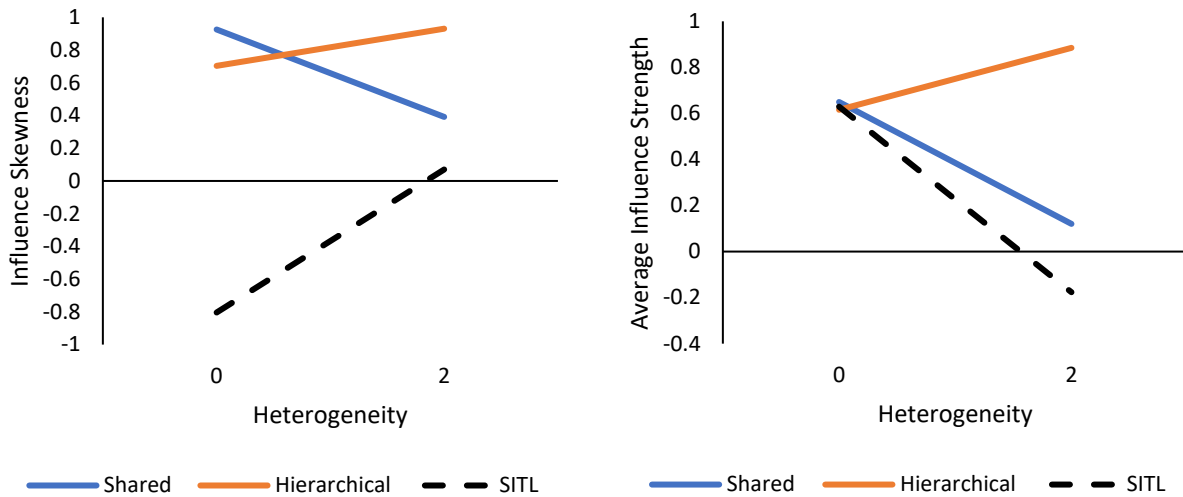


Figure 7. Graph of interaction between average leadership strength and heterogeneity for team simulated with the TPTL model. Left: Interaction between weighted skewness in influence and team compositional heterogeneity. **Right:** Interaction between weighted average influence strength in a team and team compositional heterogeneity. SITL is included for comparison.

Moderation analysis in TPTL. After testing the general pattern of relationships between team heterogeneity and emergent leadership network characteristics, I tested the moderating impact of leadership schema on these. This analysis is aimed at evaluating Hypotheses 6 and 7. Results (found in Tables 7 and 8) indicated a different pattern than predicted for Hypothesis 6 and 7, but results were consistent with the reasoning discussed for Hypothesis 3 (see Figure 7). Skew in influence (both influence strength and degree centrality) indicated a result opposite in direction to Hypothesis 6 and Hypothesis 7. Interestingly, the intercepts are set such that highly homogeneous teams with shared schemas and highly heterogeneous teams with hierarchical schemas have the most centralized leadership structure. Thus, leadership becomes more centralized when the schema matches the group composition.

The interaction term for average influence and density is positive, which aligns with Hypothesis 6a, but the simple slopes indicate that there is not a negative relationship between

heterogeneity and density for teams with a shared schema as predicted. In teams with a hierarchical schema, heterogeneity is positively associated with hierarchy which is again inconsistent with Hypothesis 7a. By contrast, for reciprocity, there is a significant interaction term supporting the relationship proposed in Hypothesis 6b and Hypothesis 7b.

Table 7

Regression results for Hypothesis 6a and 7a in Study 4 assessing the relationship between leadership network characteristics and heterogeneity in TPTL teams with either a shared schema or hierarchical schema.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Individual Strength	(Intercept)	0.82*	[0.77, 0.86]			
	Heterogeneity	-0.08*	[-0.12, -0.03]	-0.04	[-0.06, -0.02]	$R^2 = .002^*$
Skew Degree Centrality	(Intercept)	0.52*	[0.48, 0.56]			
	Heterogeneity	0.04	[-0.00, 0.08]	0.02	[-0.00, 0.04]	$R^2 = .000$
Reciprocity [†]	(Intercept)	0.12*	[0.12, 0.13]			
	Heterogeneity	0.02*	[0.02, 0.03]	0.18	[0.16, 0.20]	$R^2 = .031^*$

Note. † The reciprocity analysis used teams with a hierarchical schema as described in Hypothesis 7a. The remaining models used simulated teams with a shared leadership schema as described in Hypothesis 6a.

* indicates $p < .05$.

After running separate regression models for Studies 1 through 4, I ran a single set of multiple-predictor regression models (Appendix H). Results are consistent with the results presented in Tables 2 through 8 supporting these findings. Additionally, this analysis indicates that team heterogeneity has a unique contribution to the structure of emergent leadership networks above and beyond which mechanism (i.e. SITL, CGTL, or TPTL) is at play.

Table 8

Regression results for Hypothesis 6 and 7 in Study 4 assessing the moderated relationship between leadership network characteristics and heterogeneity in TPTL teams.

Criterion	Predictor	<i>B</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Individual Strength	(Intercept)	0.90*	[0.83, 0.98]			
	Heterogeneity	-0.22*	[-0.32, -0.13]	-0.10	[-0.14, -0.06]	$R^2 = .008^*$
	Schema	-0.21*	[-0.31, -0.10]	-0.17	[-0.26, -0.09]	
	Heterogeneity X Schema	0.35*	[0.21, 0.49]	0.23	[0.14, 0.33]	$\Delta R^2 = .006^*$
Skew Degree Centrality	(Intercept)	0.53*	[0.46, 0.60]			
	Heterogeneity	-0.01	[-0.11, 0.08]	-0.01	[-0.05, 0.04]	$R^2 = .013^*$
	Schema	-0.11*	[-0.21, -0.01]	-0.10	[-0.19, -0.01]	
	Heterogeneity X Schema	0.28*	[0.15, 0.42]	0.20	[0.10, 0.29]	$\Delta R^2 = .004^*$
Average Strength	(Intercept)	0.08*	[0.08, 0.08]			
	Heterogeneity	0.02*	[0.01, 0.02]	0.11	[0.07, 0.15]	$R^2 = .195^*$
	Schema	-0.03*	[-0.04, -0.02]	-0.40	[-0.48, -0.32]	
	Heterogeneity X Schema	0.06*	[0.05, 0.07]	0.67	[0.58, 0.75]	$\Delta R^2 = .049^*$
Density	(Intercept)	0.15*	[0.14, 0.15]			
	Heterogeneity	-0.00	[-0.01, 0.00]	-0.03	[-0.07, 0.01]	$R^2 = .112^*$
	Schema	-0.05*	[-0.06, -0.05]	-0.68	[-0.76, -0.60]	
	Heterogeneity X Schema	0.08*	[0.07, 0.09]	0.76	[0.67, 0.85]	$\Delta R^2 = .064^*$
Reciprocity	(Intercept)	0.10*	[0.08, 0.12]			
	Heterogeneity	0.05*	[0.03, 0.07]	0.10	[0.05, 0.14]	$R^2 = .023^*$
	Schema	-0.02	[-0.04, 0.01]	-0.06	[-0.14, 0.03]	
	Heterogeneity X Schema	0.04*	[0.01, 0.07]	0.12	[0.03, 0.21]	$\Delta R^2 = .002^*$

Note. Leadership schema is dummy coded with 0 indicating shared leadership schema and 1 indicating hierarchical schema. ΔR^2 indicates the change in the coefficient of determination above the main effects model achieved by including the interaction term. R^2 indicates the coefficient of determination for the full interaction model presented.

* indicates $p < .05$.

Study 5: Exploratory Hypotheses

Lastly, I conducted three sets of analyses to test Hypotheses 10 through 15. First, I tested the impact of group contextual pressures on leadership network characteristics as related to Hypothesis 10 and Hypothesis 12. Concurrently, I tested the impact of leadership contextual pressures, which is related to Hypothesis 11 and Hypothesis 13; however, all results were non-

significant. Lastly, I tested the impact of heterogeneity on leadership prototypes held by team members. This is related to Hypotheses 14 and 15. Each of these analyses used all 6003 simulated teams from Study 4.

Table 9

Regression results for Study 5 assessing the impact of average contextual pressure to join the group in TPTL teams on leadership network emergence.

Criterion	Predictor	B	b 95% CI	beta	beta 95% CI	Fit
Skew Influence Strength	(Intercept)	0.85*	[0.78, 0.92]			R2 = .001*
	Group Context	-0.21*	[-0.36, -0.07]	-0.03	[-0.05, -0.01]	
Skew Degree Centrality	(Intercept)	0.61*	[0.54, 0.69]			R2 = .000
	Group Context	-0.11	[-0.25, 0.03]	-0.02	[-0.04, 0.00]	
Average Strength	(Intercept)	0.09*	[0.08, 0.09]			R2 = .005*
	Group Context	0.03*	[0.02, 0.04]	0.07	[0.05, 0.09]	
Density	(Intercept)	0.13*	[0.13, 0.14]			R2 = .003*
	Group Context	0.02*	[0.01, 0.03]	0.05	[0.03, 0.08]	
Reciprocity	(Intercept)	0.14*	[0.12, 0.15]			R2 = .000
	Group Context	0.03	[-0.00, 0.06]	0.02	[-0.00, 0.04]	
Hierarchy	(Intercept)	0.93*	[0.92, 0.93]			R2 = .003*
	Group Context	-0.03*	[-0.04, -0.02]	-0.05	[-0.08, -0.03]	
		0.85*	[0.78, 0.92]			R2 = .001*

* indicates $p < .05$.

Context. Results for analysis of the impact of mean group contextual pressures on leadership network characteristics are shown in Tables 9 and 10. Results fully support Hypothesis 10. The mean group contextual pressure is negatively related to skew in influence (Hypothesis 10a). Team group contextual pressures are positively related to the density and average influence strength (Hypothesis 10b) as well as to reciprocity (Hypothesis 10c). The relationships predicted in Hypothesis 12 are between the skew of group contextual pressures and leadership network characteristics. These relationships had the predicted direction but were extremely small in effect size and non-significant. After running tests for group contextual

pressures, I ran a regression analysis testing the relationship between leadership contextual influences and network characteristics. None of the results were significant.

Table 10

Regression results for Study 5 assessing the impact of the skew in contextual pressure to join the group in TPTL teams on leadership network emergence.

Criterion	Predictor	B	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Skew Influence Strength	(Intercept)	0.74*	[0.73, 0.76]			R2 = .000*
	Skew Group Context	0.03*	[0.00, 0.06]	0.02	[0.00, 0.04]	
Skew Degree Centrality	(Intercept)	0.56*	[0.55, 0.57]			R2 = .000
	Skew Group Context	0.01	[-0.02, 0.04]	0.01	[-0.01, 0.03]	
Density	(Intercept)	0.27*	[0.27, 0.27]			R2 = .000
	Skew Group Context	0.00	[-0.00, 0.01]	0.02	[-0.00, 0.04]	

* indicates $p < .05$.

Leadership prototype heterogeneity. I ran a regression-based analysis to test the relationship between heterogeneity in leadership prototype and test the relationship between heterogeneity in leadership prototype and leadership network density, reciprocity, and modularity. The results are found in Table 11. Results were generally supportive or non-significant. Density (and average influence strength) were negatively associated to heterogeneity in leadership prototype; this supports Hypothesis 14a. However, this relationship was notably small. There was not a significant relationship between leadership prototype heterogeneity and reciprocity of influence networks, which fails to support Hypothesis 14b.

Table 11

Regression results for Study 5 assessing the impact of the variability in leadership prototype TPTL teams on leadership network emergence.

Criterion	Predictor	<i>b</i>	<i>b</i> 95% CI	<i>beta</i>	<i>beta</i> 95% CI	Fit
Average Strength	(Intercept)	0.12*	[0.12, 0.13]			$R^2 = .016^*$
	ILT Heterogeneity	-0.02*	[-0.02, -0.02]	-0.13	[-0.15, -0.10]	
Density	(Intercept)	0.16*	[0.16, 0.16]			$R^2 = .007^*$
	ILT Heterogeneity	-0.01*	[-0.02, -0.01]	-0.08	[-0.10, -0.06]	
Reciprocity	(Intercept)	0.15*	[0.14, 0.16]			$R^2 = .000$
	ILT Heterogeneity	0.00	[-0.01, 0.01]	0.00	[-0.02, 0.03]	
Hierarchy	(Intercept)	0.26*	[0.25, 0.26]			$R^2 = .003^*$
	ILT Heterogeneity	0.01*	[0.00, 0.02]	0.05	[0.02, 0.08]	
Transitivity	(Intercept)	0.91*	[0.91, 0.92]			$R^2 = .000$
	ILT Heterogeneity	-0.00	[-0.01, 0.00]	-0.01	[-0.03, 0.01]	
Modularity	(Intercept)	0.29*	[0.28, 0.30]			$R^2 = .001^*$
	ILT Heterogeneity	0.01*	[0.00, 0.02]	0.03	[0.01, 0.05]	
Modularity	(Intercept)	0.34*	[0.31, 0.36]			$R^2 = .007^*$
	ILT Heterogeneity	-0.02	[-0.05, 0.00]	-0.06	[-0.13, 0.01]	
	Leadership Schema	-0.09*	[-0.14, -0.04]	-0.39	[-0.61, -0.17]	
	ILT Heterogeneity X Schema	0.07*	[0.02, 0.11]	0.33	[0.10, 0.56]	

Note. Leadership schema is dummy coded with 0 indicating shared leadership schema and 1 indicating hierarchical schema. ΔR^2 indicates the change in the coefficient of determination above the main effects model achieved by including the interaction term. R^2 indicates the coefficient of determination for the full interaction model presented.

* indicates $p < .05$.

The divergence of leadership prototype was positively associated with modularity, supporting Hypothesis 15a. Furthermore, this relationship is moderated by leadership schema such that teams with a shared schema are less fragmented by divergent leadership prototypes than teams with hierarchical schemas. This supports Hypothesis 15b. Relationships between reciprocity and transitivity and leadership prototype divergence as by Hypothesis 15c are not significant. There is a very small positive relationship between leadership prototype divergence hierarchy. This is counter to the relationship proposed in Hypothesis 15c.

Discussion

This work paves the way to augment leadership emergence research. By building on this work, I provide a path to assess the process of leadership network structural emergence implied by theories of leadership emergence. While researchers have both theorized about the importance of leadership network structures on team outcomes and used theory to describe the processes of leadership emergence, this is the first work, to my knowledge, that lays out how team compositional diversity or homogeneity can drive the leadership networks that emerge. This work is particularly valuable and relevant as diversity and inclusion issues come to the forefront of the field of organizational psychology. I do not delve into the potential impact of leadership network structures currently instead focusing primarily on the structures themselves as outcomes. Researchers have noted the importance of such leadership networks, and I leave it to future work to further develop our understanding of the antecedent relationship between leadership network structures and team outcome criterion.

The contributions of this work can broadly be divided into three groups. First, this thesis has provided a new theory of leadership emergence which builds on two very distinct leadership emergence theories. Not only does this provide a novel insight into the nature of how theoretical mechanisms may interact, but I also provide formal representations for these three theories and test their generative sufficiency. This work provides a single powerful test for the theoretical explanations that link proposed process mechanisms with border phenomenon level propositions. With two exceptions, tests for generative sufficiency passed for every applicable model. The first exception was the test for the impact of context on leadership.

Table 12

Relationships Described by Hypotheses.

	Degree Skew	Density	Reciprocity	Hierarchy	Transitivity	Modularity
SITL						
General Pattern*	$H1a(-)^{\dagger}$	$H1b(+)^{\dagger}$	$H1c(+)^{\dagger}$	$H1d(-)^{\dagger}$	$H1e(+)$	
Homogeneity	$H2a(-)^{\dagger}$	$H2a(+)^{\dagger}$	$H2b(+)$			
CGTL						
General Pattern*	$H1a(+)^{\dagger}$	$H1b(-)^{\dagger}$	$H1c(-)^{\dagger}$	$H1d(+)^{\dagger}$	$H1e(-)$	
Homogeneity						
- Shared Schema	$H3a(-)$	$H3a(+)^{\dagger}$	$H3b(+)^{\dagger}$			
- Hierarchical Schema		$H4(-)^{\dagger}$				
- Divergent Schema						$H5(\sim)$
TPTL						
Homogeneity	$H9(-)$	$H9(+)$	$H9(+)$	$H9(-)$	$H9(+)^{\dagger}$	
- Shared Schema	$H6a(-)$	$H6a(+)$	$H6b(+)^{\dagger}$			
- Hierarchical Schema	$H7a(+)$		$H7b(-)^{\dagger}$	$H7a(+)$		
- Divergent Schema						$H8(\sim)$
Contextual Group**	$H10a(-)^{\dagger},$ $H12(+)$	$H10b(+)^{\dagger}$	$H10c(+)^{\dagger}$	$H12(+)^{\dagger}$		
Contextual Leadership**	$H11a(-)$		$H11d(+)$	$H13(+)$		
- Shared Schema		$H11b(+)$				
- Hierarchical Schema		$H11c(-)$				
ILT Convergence		$H14a(+)^{\dagger}$	$H14b(-)^{\dagger},$ $H15c(0)$	$H15c(0)$	$H15c(0)$	$H15a(-)^{\dagger},$ $H15b(+)^{\dagger}$

Note. Each table entry represents a team characteristic to network structure relationships. Rows correspond to antecedent team characteristics; columns correspond to network structure outcome variables. (+) represents that as the given team characteristic increases, the given network structure's strength also increases. (0) represents that there is no significant relationship. (-) represents that as the given team characteristic increases the given network structure's strength decreases. ($\sim$) represents complex relationships that were not tested. $\dagger$ indicates relationships that were supported. * H1 describes general patterns between SITL and CGTL, not between low and high values for a variable. ** H12 and H13 are relationships between skew of distribution contextual factors, not the value of the given contextual factors.

Both SITL and CGTL mention the impact of contextual pressures on the proposed mechanisms. The context was included as a variable in the three models, but the relationship between leadership contextual pressures as described in CGTL was not apparent. This likely indicates that the formalization does not adequately represent the influence of contextual pressures to lead as described in CGTL. This does not, however, impact the rest of the mechanisms. The proposed computational model is best understood as a closed system model. As such, I significantly reduced the impact of ‘context’ in the final simulations of the models to ensure that this was not a confound in other relationships. Future work will be needed to adapt the model to adequately incorporate context.

The second exception was based on the claim of SITL that under conditions of high homogeneity teams will form a highly hierarchical leadership structure. I predicted that this test would fail because the process mechanisms described in SITL do not sufficiently describe how this relationship would exist. Failure to reproduce this proposed phenomenon could indicate that my model does not adequately represent SITL, or that SITL’s proposed mechanisms do not sufficiently provide a means whereby this relationship could exist. Notably, the proposed relationship does exist in the combined model for teams with a shared schema (See Figure 7).

Passing all other tests for generative sufficiency strongly indicates that these formal models are accurate representations of their corresponding theories. This is a powerful result and contribution that should not be overlooked. This work thus provided a new theory combining existing theories, formalizing these theories in a manner that allows for object exploration of the theory, and testing the ability of the theories to produce proposed outcomes. These formalizations are valuable contributions of their own, but also allow us to demonstrate that

certain proposed phenomena only appear to be adequately explained when combining the mechanism from both theories.

Secondly, I have augmented existing theory by providing a computationally validated theory of the emergence of leadership networks. Specifically, this theory proposes how SITL based mechanisms will lead to a strong, flat, and reciprocal leadership structure relative to CGTL mechanism which tends to produce more hierarchical structures with a few clear leaders. Furthermore, this theory explicitly describes the potential impact of homogeneity on these leadership network structures. A central finding here is that CGTL based teams increase in overall leadership as the heterogeneity of the team composition increase. SITL based teams increased in overall leadership as homogeneity increases. This duality in the impact of diversity suggests that under certain circumstances, where group identity is strong for example, diversity in group composition will likely reduce the overall influence team members have on each other. In other contexts, where a leadership prototype is very salient, for example, we would likely see the reverse relationship because increased heterogeneity will increase the clarity of roles. Both contexts could lead to very distinct disadvantages to those who are less well represented, as well as potential application to other team composition questions. These are potentially very important theoretical results that could dramatically influence our understanding of the impact of team composition and diversity on teams.

Potentially the most interesting theoretical result from this work is found in the synthesized model. As described previously, SITL proposed that high heterogeneity will lead to a strong hierarchical structure with pattern of clear central leadership. All my work indicates that this is not the case for SITL on its own. To produce this result from simulated data I must include both SITL and CGTL mechanisms. As indicated in Figure 7, the model demonstrates that in

teams with a shared leadership schema, high homogeneity can lead to a strong hierarchical leadership structure. This somewhat counterintuitive result comes from the fact that while in homogeneous groups everyone has a relatively high level of influence due to SITL, individuals are much less likely to feel inclined to claim leadership due to the ambiguity afforded by the homogeneity. In this situation, only those who have a leadership prototype that is highly congruent with the group prototype will feel inclined to claim leadership, and similarly, this same group will be the group most likely to reciprocate (i.e. everyone will be similar to their leadership prototype). Thus, a much smaller subset of the group that has a leadership prototype similar to the group prototype will become willing to make claims of leadership and thus gain influence. As heterogeneity increases the relationships will become more random but maintain their general average level of influence. On the other hand, when the team shifts from shared to hierarchical schema, homogeneity will lead to far fewer reciprocated claims, thus the relationship is flipped.

Notably, this was not the relationship I had predicted *a priori*, but after digging into the simulations it makes logical sense and is implied by the process mechanisms. It is simply a complicated relationship that would be difficult to uncover without the aid of computerized representations of formal models. These results, regarding the theoretically implied emergent leadership structures, provide a powerful theory-building tool, an invaluable method of exploratory research, and solid ground for future empirical research.

Results from tests of the hypothesized relationships indicate that there are clear distinctions between the leadership network structures that emerge as a result of the claiming and granting model and the social identity model. Furthermore, results indicate that when combining these two mechanisms there are unique patterns of leadership emergence that develop. This work

has provided unique insight and a powerful tool for further theory development and exploration of these relationships. Notably, results from the simulated data broadly support the hypothesized relationships (See Table 12). Of the fifteen original hypotheses, two were not tested due to incompatibility with the computational model. Two tests (both related to contextual leadership pressure) yielded effects that were essentially zero. The eleven remaining hypotheses were all either fully supported or partially supported. These eleven hypotheses were originally broken into 25 sub-hypotheses. Of these, five had reverse relationships and four had partial support (i.e. the sub-hypothesis described multiple relationships, at least one was supported, and one was either non-significant or reversed). The remaining sixteen sub-hypotheses were fully supported. Because these were largely exploratory, this lends powerful evidence and support to the viability of the potential of this network-centric approach for understanding leadership emergence and the power of this computational model.

Lastly, this thesis will make a significant contribution to the literature as it is combined with empirical research. The computational model I have produced can be used to further explore and develop theory, and after it is adequately validated with empirical data, it can be used as a predictive model. There is tremendous potential for the computational model and other models like it to augment our ability to identify complex relationships and study concepts that were previously unreachable. For example, all the present simulations use a preset stopping point; one point of data was collected for each team. However, this computational model is ideally suited for testing dynamic relationships. This work points to innumerable future empirical research projects, and if it is validated, it could be used to predict relationships where empirical data is impractical or unethical to collect.

Limitations

Although this work will make significant contributions to the literature, I must acknowledge at least two significant limitations. First, this research, as with all theory-based research, requires further empirical validation before being used to develop substantive claims. Without empirical validation, it remains a strong theory-testing and theory-building tool, but with limited substantive applicability. As a tool for theory exploration, validation, and development, it has tremendous power. But without empirical data to support it, this work is only theoretical and must be treated accordingly.

Secondly, the representations of Social Identity Theory of Leadership and Claiming and Granting Theory of Leadership employed in this thesis are based on personal interpretation of the existing theory. This interpretation was guided by a need for an authentic representation as well as a need for simplicity. These narrative theories could be interpreted differently and thus represented in different formal models. It is possible that another interpretation of the theories would produce different network structural results. As such, this work does not completely test SITL or CGTL; instead, it may be better to think of this research as a test of closely related formalized theories. This fact does not mitigate the contributions made by the work in proposing and evaluating theories of leadership emergence. It does however clarify the distinction between narrative and more formalized theories. Because the original theories were not formalized, it is very difficult to “disprove” its theoretical explanations because any interpretation that you make that fails could arguably not quite have been the right interpretation. However, we should recognize that a formalization that is closely based on the existing narrative theory is more than simply a strawman set up to fail. Just as one empirical interpretation of a theory may be different than another, the fact that research always has an element of the researcher’s subjective

interpretation does not discredit the value of empirical work to validate research. We simply must be careful to correctly scope what the results mean.

Lastly, as mentioned previously, the network structural outcomes are highly correlated. For example, network density and reciprocity have a correlation of .67 (see Appendix G). It is important to be careful about interpreting these results as isolated characteristics. There is significant overlap in these network structures, and future work is required to formally parse the nature of the overlap in these network characteristics. Despite this limitation, regression does not explicitly require independence of outcomes for different regression models. Thus, although the results are not independent of each other, they remain statistically valid.

Future Work

This research identifies patterns of leadership predicted by different theoretical mechanisms of leadership emergence. While this work provides support for the viability of these mechanisms, future work will need to empirically validate the network structural predictions made by the computational model. In addition to testing the empirically hypothesized relationships, more work is required to establish what the theoretical impacts of network structures will be. In this thesis, based on the pioneering work of Hogg (2001) and DeRue & Ashford (2010) I have assumed that the structures of leadership networks will be important. Future theoretical and empirical work is needed to more fully establish how leadership network structures impact team-level outcome criterion.

In addition to directing future empirical validation of the model, future research is needed that further explores the implications of the computational model. Many mechanisms were simplified to some extent in the process of providing a formalized representation of the three

theories. This was done for the sake of parsimony. There are many places where more work could be done to thoroughly test the mechanism proposed by SITL and CGTL. One such area is salience in the model. As it is currently proposed, salience is incorporated as an implicit part of how social attraction leads to shifts in group prototype, and influence leads to social attraction. The idea of salience is also incorporated into contextual pressures to claim leadership or identify as a group member. Explicit treatment of salience may open the CM to investigate implications of leadership emergence processes under sudden shocks to the system, for example.

A second area where the CM could be extended would be to explicitly incorporate follower identities. As it is currently proposed, follower identity is implied as an opposite to leader-identity, but this may not be the best match to CGTL. Future work could extend the model to account for separate leader and follower identities.

A third area where the current model could be extended is the process by which a group prototype is established. For the sake of simplicity, I have assumed that the group prototype is shared across the entire team, implying that all team members are members of the “in-group” in question. Social identity theory suggests that individuals may have many personal social-prototypes and that these often change in specific situations. A more true-to-theory evaluation of prototype establishment would allow for in-group and out-group processes and non-share group prototypes.

Another area where the proposed model is simplified, and future work could investigate more fully is the process of identity work. I represent identity (group or leader) as directly related to how closely characteristics match the given prototype. In both theories, this is not exactly described in this direct way. Though closely related, prototypically is separate from identity in

both theories. This computational model provides a tool whereby we could explore the implications of various identity work process mechanisms.

One area where the computational model has a clear potential for significantly augmenting research is in process dynamics. In the current research, every team is given the same amount of time to develop a leadership structure, and the structure is assessed at that time as if it were the static product of the leadership emergence processes. Even though this is focused on leadership emergence it is almost completely devoid of dynamics. This is a common plight in psychology. We often study things that are continually changing but fail to begin to properly incorporate time. The process of formalizing these theories requires thought as to time, but little more than that. However, the computational model is ideally set up to assess the temporal dynamics of leadership emergence, not just the static stepwise version demonstrated here. I found qualitatively that various time courses followed patterns of punctuated equilibrium, stable states, and oscillations. These are all notions of dynamics that will be the object of future research.

Future work extending the CM in any of these ways could make significant contributions to our understanding of leadership emergence by enabling a focused evaluation of the specific mechanisms in question. Other future work regarding CM, will include testing it as a predictive tool. If the CM can predict leadership network structures to some degree based on team composition, this will represent a tremendous amount of future potential for applications of the CM.

Conclusion

This thesis provides direct analysis of theoretical social mechanisms of leadership emergence. This is a significant contribution to the literature, since most methods employed in leadership research are unable to directly evaluate processes or mechanisms. This research will evaluate the ability of proposed mechanisms to produce predicted outcomes and evaluate the implications of these theoretical mechanisms. Specifically, this work focuses on the impact of these mechanisms on leadership's structures that emerge due to various team characteristics. This work makes clear predictions based on established mechanisms of leadership emergence, of structural characteristics of leadership that will emerge under conditions such as team homogeneity, and team agreement on leadership style (shared vs. hierarchical).

Furthermore, as part of the process of evaluating established mechanisms of leadership emergence, I have proposed a new theory of leadership emergence based on mechanisms described by two prominent leadership emergence theories. Building on this work, I developed a formal representation of the three theories, enabling a more objective future evaluation of the theories and their implications to the field of leadership emergence. In connection with this effort, I have developed an agent-based computational model that can be used as a tool enabling future theory building and testing. Using the computational model and formal theories, I provide evidence of the generative sufficiency of the proposed process mechanisms. Thus, I have provided evidence for the theoretical explanation connecting process mechanisms to their hypothesized results.

Not only does this work provide a meaningful test of the theoretical explanation for the three theories (SITL, CGTL, and the new combined theory), I use this model to both explore the implications of existing theory and further develop new theory. This work leaves specific

predictions regarding the relationships between team characteristics and emergent leadership structures which make a strong foundation for future work that can be empirically tested. Thus, this thesis has not only contributed significantly to the theory of leadership, but it has also provided a tool for building new theory, and a process for identifying testable theoretical relationships, therefore substantially enhancing the accumulation of knowledge in the field of leadership emergence.

APPENDICES

Appendix A: Formal Hypotheses

Table 13

List of Formal Hypotheses of the Models.

Hypothesis	
General Patterns	
1a	Under CGTL mechanisms alone, When Compared with SITL mechanisms alone, influence will more strongly follow a pattern where few individuals have most the power and most individuals have little power (i.e. the distribution of influence will be right skewed).
1b	Under SITL mechanisms alone, When Compared with CGTL mechanisms alone, the overall strength of leadership across the entire team will be greater.
1c	Under SITL mechanisms alone, When Compared with CGTL mechanisms alone, influence relationships will more strongly follow a pattern reciprocal influence such that if some individual (A) has influence over another individual (B), B will be more likely also have influence over.
1d	Under CGTL mechanisms alone, When Compared with SITL mechanisms alone, influence will more strongly follow a hierarchical pattern such that individuals are most likely to follow those who have the most followers.
1e	Under SITL mechanisms alone, When Compared with CGTL mechanisms alone, influence relationships will more strongly follow a pattern transitive influence such that if some individual (A) follows another individual (B), and B follows a third (C), under SITL mechanisms A is more likely to follow C than under CGTL mechanisms.
Homogeneity / Heterogeneity	
2a	Under SITL mechanisms alone, increased homogeneity in characteristics of group members will lead to a pattern of strong influence with most individuals having a relatively large amount of influence and few individuals having very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.
2b	Under SITL mechanisms alone, increased homogeneity of characteristics of group members will lead to a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.
3a	Under CGTL mechanisms alone, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of strong influence where most individuals have a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.
3b	Under CGTL mechanisms alone, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.

Table 13 (cont'd)

4	Under CGTL mechanisms alone, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with very weak relationships of influence.
5	Under CGTL mechanisms alone, in groups with divergent leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of leadership, such that individuals with shared schemas will form a clique with strong and bidirectional influence-relationships, but individuals who have a hierarchical schema will have weak influence-relationships with all other group members.
6a	Under TPTL mechanisms, in groups with convergent, shared leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of strong influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.
6b	Under TPTL mechanisms, in groups with convergent, shared leadership schemas, homogeneity in characteristics of group members will be associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.
7a	Under TPTL mechanisms, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with a hierarchical pattern of influence such that one (or a few) individual has significantly more influence than the rest of the group (this will be a heavily right-skewed distribution of influence).
7b	Under TPTL mechanisms, in groups with convergent, hierarchical leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of influence that is unidirectional, such that if some individual (A) has influence over another individual (B), B will not have influence over A.
8	Under TPTL mechanisms, in groups with divergent leadership schemas, homogeneity of characteristics of group members will be associated with a pattern of influence such that individuals with a shared schema will form a clique that has a strong and bidirectional influence-relationship and a group of individuals with a hierarchical schema that has a hierarchical pattern of influence. There will be very weak leadership relationships between the two groups.
9a	The more homogeneous a group is, the more the network that is established will be similar to the pattern of leadership that emerges based on SITL. Including high reciprocity, density, and transitivity, low hierarchy, and a negative skew to leadership distribution (see hypothesis 1).
9b	The more heterogeneous a group is, the more the network that is established will be similar to the pattern of leadership that emerges based on CGTL. Including low reciprocity, density, and transitivity, high hierarchy, and a positive skew to leadership distribution (see hypothesis 1).

Table 13 (cont'd)

Contextual influence	
10a	Increased contextual influences encouraging group membership are associated with patterns of influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.
10b	Increased contextual influences encouraging group membership are associated with increased overall network influence.
10c	Increased contextual influences encouraging group membership are associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.
11a	Increased contextual influences encouraging leadership identity are associated with a pattern of influence with most individuals having a relatively large amount of influence and few individuals have very little influence (the distribution of influence will be left-skewed), such that there is no clear single individual bearing the majority of the influence in the group.
11b	Increased contextual influences encouraging leadership identity are associated with increased overall influence in the leadership network for teams with a convergent, shared leadership schema.
11c	Increased contextual influences encouraging leadership identity are associated with decreased overall influence in the leadership network for teams with a convergent hierarchical leadership schema.
11d	Increased contextual influences encouraging leader identity are associated with a pattern of influence that is bidirectional, such that if some individual (A) has influence over another individual (B), B will typically also have influence over A.
12	The more strongly the contextual influences encouraging group identity are distributed with a positive skew (such that group membership is very strongly reinforced for a few members and more moderately reinforced for most members), the more strongly the leadership is distributed in a hierarchical pattern, and the more strongly the distribution of leadership in the team will form a positively (or less negatively) skewed distribution with few individuals holding significantly more influence than the most the group members.
13	The more strongly the contextual influences encouraging leader identity are distributed with a positive skew (such that group membership is very strongly reinforced for a few members and more moderately reinforced for most members) the more strongly the leadership is distributed in a hierarchical pattern.

Table 13 (cont'd)

ILT	
14a	Convergence of ILT (so that individuals have similar ITLs) leads to increased influence across the network.
14b	Convergence of ILT (so that individuals have similar ITLs) leads to an increased pattern of unidirectional influence relationships such that if some individual (A) has influence over another individual (B), B is unlikely to have influence over A.
15a	Divergence of ILT (so that there is no strong agreement on what makes a leader) leads to segmentation of group into highly connected cliques (based on similarity in ILT) that influence each other, but do not influence individuals in the other groups as strongly.
15b	Segmentation of influence network due to a divergence of ILT will be moderated by leadership schema such that groups that have a convergent, shared schema will have more influence-relationships and be less segmented by clique than groups with less convergent schemas or groups with a convergent, hierarchical schema.
15c	Divergence of ILT leads to a more random pattern of leadership, so that the structure of leadership is not significantly reciprocal, transitive, or hierarchical.

Appendix B: Representations of SITL, CGTL and Synthesis Model Processes.

Figure 8, 9, 10: Representation of the social identity theory of leadership. Dark brown represents static values. Light tan represents dynamic values. Boxes (except for prototypes) are values from other agents, circles are values from the agent of interest. Blue arrows represent a positive or facilitative relationship, red arrows represent a negative or inhibitive relationship. The Group Prototype is shared, but dynamic while the implicit leadership theories prototype is individual and static. The context values are represented in a triangle. Green is used to mark events (an individual makes a claim or grant during a given interaction).

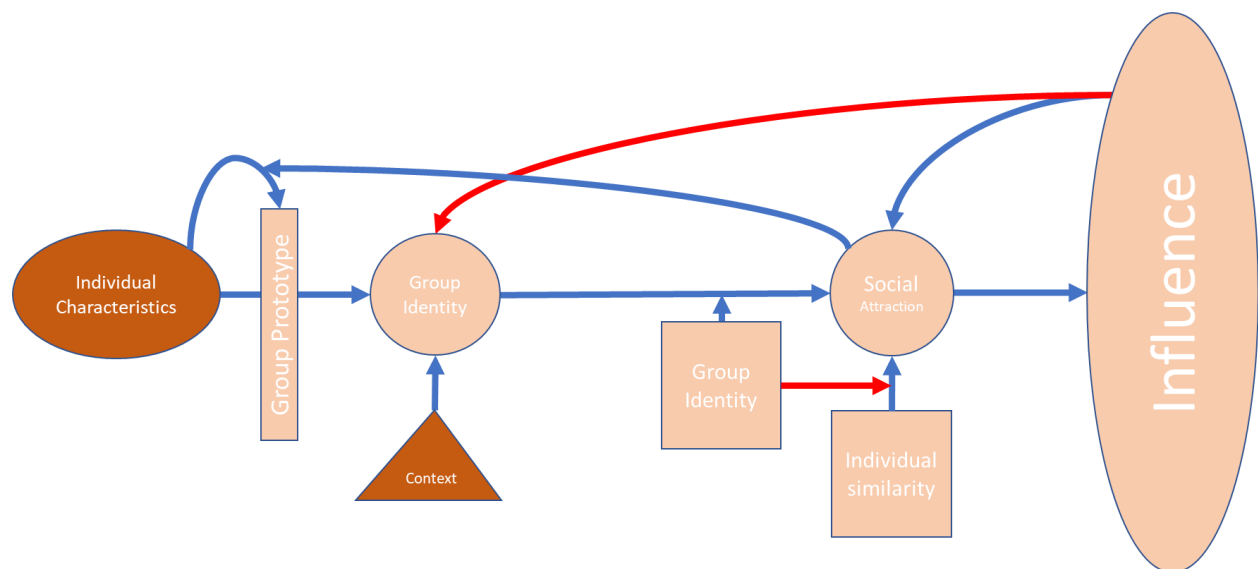


Figure 8. Representation of mechanisms described by social identity theory of leadership.

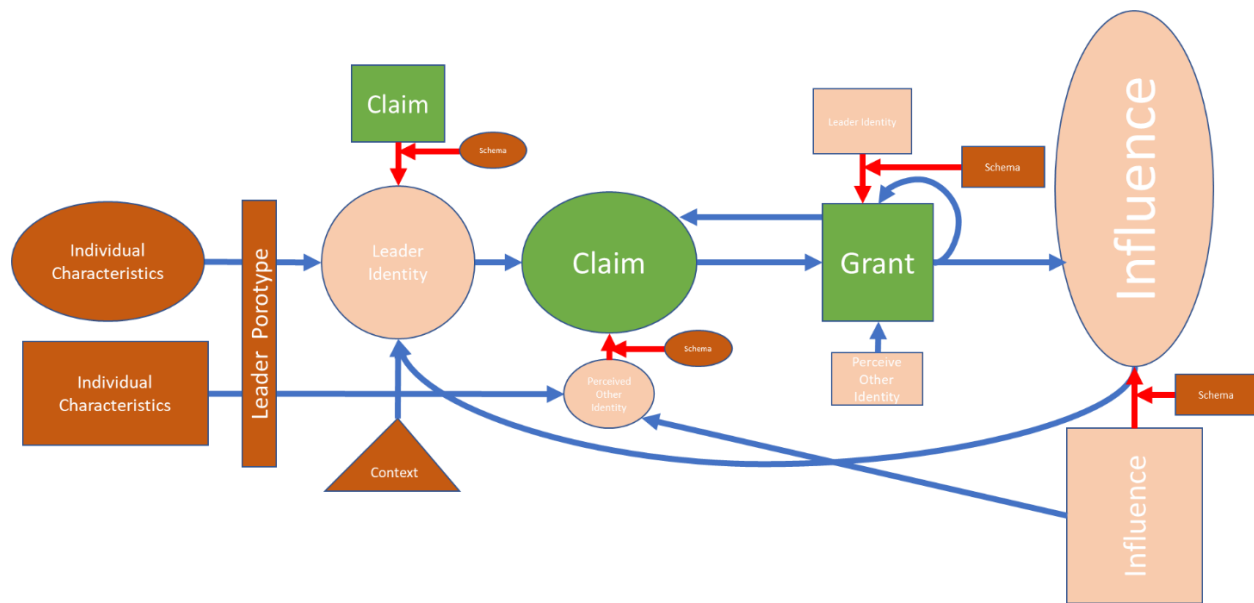


Figure 9. Representation of mechanisms described by Claiming and Granting theory of leadership.

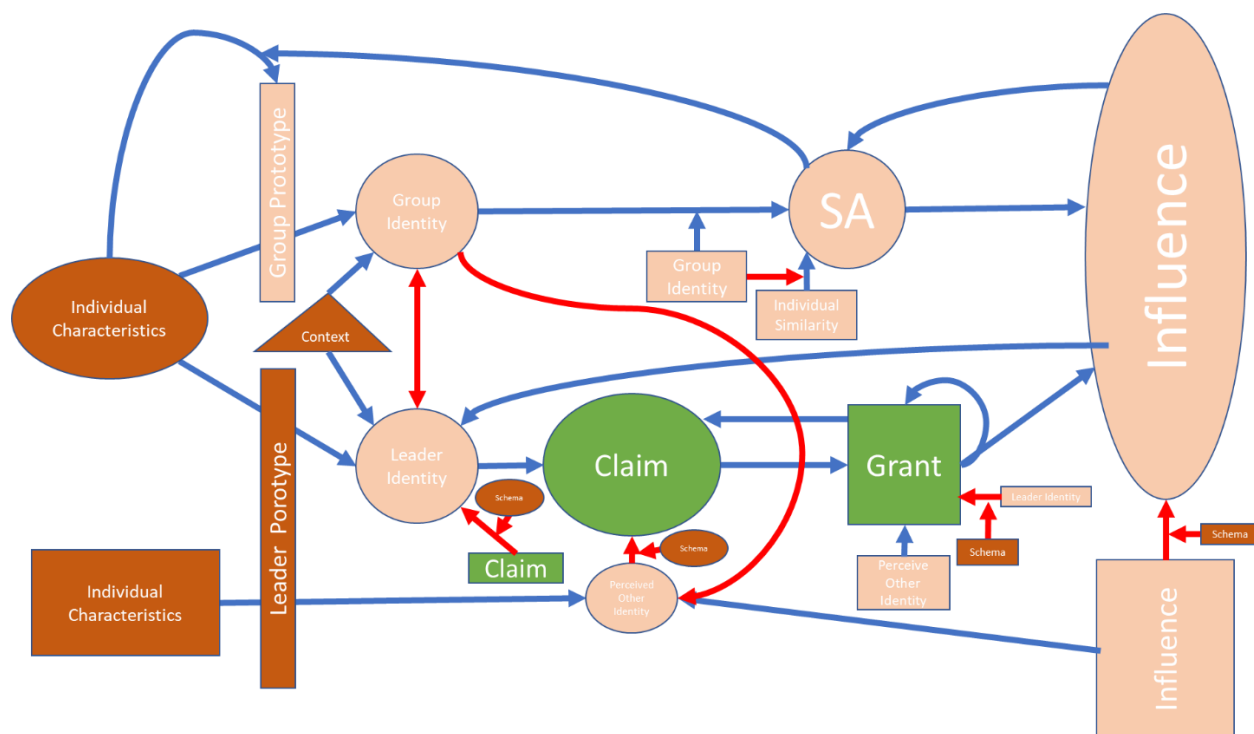


Figure 10. Representation of the synthesis theory of leadership emergence.

Appendix C: Formalization Process

General Notes on Formalization

The process of forming formal models from the original narrative theories is systematic but remains somewhat subjective. Followed a four-step iterative process. First, I identify mechanisms, propositions, and variables of interest. Secondly, I reduce and simplify. Thirdly I formulate equations. Lastly, I iterate, identifying problematic formulations as I continue in the computational modeling process described previously in this paper.

Identification. In the first step, I identified all statements of the process mechanisms general phenomena-level propositions, and key variables described in the paper. As part of this step, I read both the SITL and CGTL papers line by line to identify every mechanism proposition and variable. As part of this process, I recorded how each variable was related through the process mechanisms and how these relate to the phenomena-level proposition. As part of this process, I made system dynamics figures that were similar to those found in Appendix B.

Consolidation and simplification. After generating the original master list of all propositions, mechanisms, and variables, I assessed each individually. I identified mechanisms and propositions that were very similar, worked in a parallel manner, or were overly complicated. I evaluated each based on the complexity and uniqueness it had. Very similar mechanisms were combined into one, and overly complicated mechanisms were simplified to provide a representation of the general process. This process was repeated until the formalized models appeared to adequately represent the process mechanisms described in the theory while remaining optimally simple. I used system dynamics figures such as those found in Appendix B to visualize this process and identify inconsistencies.

Formulization. One I had a list of mechanisms variables and propositions that I felt were core to and adequately covered the theories I generated equations for each remaining variable. If a value was described as fairly constant or there was reason to believe that on the time scale of a team leadership emergent process it would not very much, I left it is constant. For example, both theories describe a process by which individual characteristics help determine leadership emergence. Individual characteristics do change, but I assumed that in the time scale of a team this change would be irrelevant. Thus, in all models, individuals do not change, only their relationships.

Further formulization required more insight into the differences in the time scale of variables. Simon and Ando (1961) demonstrate that it is possible to work on a given time scale or level of analysis if lower-level processes happen isolated from each other, and faster than higher-level processes such that for any time step, they find equilibrium relatively fast. Psychology notoriously avoids theory that provides specific direction for how fast psychological variables happen, thus there is no theoretical framework I have found from which to understand how the timescales of the remaining variables relate. The memory for history of claiming and granting needed to be slower than the influence actualization process or it would decrease the stability of the system or make it meaninglessly constant.

Incremental changes in one identity could influence incremental changes in the other identity however in the absence of such a theory I opted for the simplest representation which assumed that incremental changes in the identity work processes were independent of other processes described and stable on the timescale of the claiming process. Based on this notion I assumed all processes were on a faster timescale than the claiming process and happened independently. Future work may want to explore the implications of alternatives.

After identifying variables that would be treated as a constant, and variables that would be treated as fast timescale vs. slow timescale, I reviewed all equations for logical consistency and consistency with the original theory. Each equation is centered on a single variable and includes the described relationship to other variables. These relationships were generally explicitly positive, negative, or interaction. As such, I modeled these relationships in the simplest form that I could and included a fitting parameter for each relationship to allow for the possibility that these relationships needed to have specific relative weights for key phenomena to develop.

Slow equations, scale, and similarity. As discussed previously, in a computational model often an equation will be treated as a “slow” timescale equation. What this means is that in the discrete-time step interval the process will not necessarily have been fully completed. In the following sections, I will present all the finalized formulas for the formal models. These are all presented in the fast timescale manor. In the actual code, all equations are standardized to ensure that the maximum value for any variable is 1. Thus, each equation is divided by the theoretical maximum to ensure the correct scale, though this is not represented in the equations below.

In addition to rescaling all equations, the claiming history equation is set as a slow timescale equation. This is necessitated by the fact at any time point there may be a claim forgotten nor do we want the first reciprocated claim to mandate that the history say to represent that the claim history is maximally positive. Each time step has a claim or grant and of necessity, the history or memory of this must be auto-regressive and on a slower timescale. For simplicity, this equation is represented in the fast time scale manner bellow when we review all equations. The equation used by the computer is as follows.

$$V_t = (1 - d)V_{t-1} + df$$

Where V_t is the values of the slow variable at time t . f represents the fast time scale function, and d is the learning parameter or rate of decay. In this model, d is set to 0.05. This can notionally describe as meaning that the learning rate for this parameter is 1/20 the rate of the time scale. Notice that the smaller d is the slower the variable changes to the extreme case where d is 0 in which case no learning takes place. On the other extreme, d is 1 which is identical to the fast equation. This would be an appropriate way to represent variables that have different learning rates if desired.

Throughout the equations listed below, I use norm notation to indicate a Euclidean distance-based measure. When comparing similarity between two vectors (e.g. when comparing characteristics of an individual to a prototype) I use a normalized Euclidean distance. It returns a value between -1 and 1, with 1 provided if the two vectors of characteristics exactly match, and -1 representing the extreme case where they are as opposite as possible (e.g. the two vectors $(1,1,1\dots)$ and $(-1,-1,-1,\dots)$).

Iteration and changes. There is not a single correct formal model for any given narrative theory. As such it is faulty to assume that the process is fixed. As you move from formalization to computerization, certain aspects of a formal representation may be incompatible with the computerization. This is an iterative process, by which each successive attempt is a little cleaner and a little bit better representation of the theory.

During the process of this research, I incorporated various slight changes into the representations of model equations to be more consistent with the original theory or to be more appropriate for the computational modeling environment. Three main changes should be noted.

First, in the original SITL and TPTL model the social attraction equation included compared the source team member's group identity to the target member's group identity. This was not as consistent with SITL theory as it is to use the similarity between group prototype and targets characteristics. Additionally, this mathematically resolves an issue without significantly changing the meaning of the equation or interpretation.

Secondly, after computerizing the formal model, I restructured the time scale process to be more consistent with theory and more compatible with the modeling environment. The core nature of the equations presented below did not change but the under-the-surface manner in which they were updated changed through the process. In connection with the, there were various changes to the claiming and granting equations. Specifically, the output of the given equation was theoretically supposed to represent a probability. Worked through various versions of this transformation to ensure that the resulting probability was appropriate. Again the core equation did not change, but the transformation of this equation to a probability was adjusted to make it appropriate and consistent with theory.

Lastly, through the iteration process, I remove most of the fitting parameters from the equations. There were originally 13 parameters. Originally the formalizations for the three models included 13 different fitting parameters. These each adjusted the relative weights of the theoretical process mechanism. I tested the model with various values for these and qualitatively assessed the impact on the patterns of influence networks. After testing various combinations of variables, I identified fitting parameters from the original equations that did not have a significant impact on the overall behavior of the system and removed them from the equations.

Formalization of Social Identity Theory of Leadership

Overview of the model. As pictured in Figure 8 (Appendix B), SITL describes a process by which social identities are a driving force for the establishment of leadership structures. Individual characteristics and group prototypicality cause social attraction which in turn causes increased influence. Table 14 provides a list of variables, and parameters important to each mechanism. Table 15 provides a list of each equation used in the formal model of SITL and the mechanisms that are associated with each given equation. Following the tables and figures, I provide a discussion of each variable and mechanism and their formalization.

Table 14

Variables and Parameters Associated with the Social Identity Theory of Leadership Formal Model.

Name	Symbol	Notes
Static Variables		
Individual Characteristics	IC	Static vector with entries representing various characteristics. Each entry is 1 or -1. This is unique to each agent
Contextual Influences	C_{Group}	Contextual influences encouraging or discouraging (or inhibiting) group membership identification.
Dynamic Variables		
Shared Group Prototype	P_{Group}	Dynamic vector with entries representing various characteristics representative of the group. Each entry is 1 (for prototypical), -1 (for anti-prototypical), or 0 (for agnostic). Equal to the average of group characteristics weighted by social attraction
Individual Group Identity	I_{Group}	A value indicating the amount to which an agent identifies with the group.
Dyadic Social Attraction	SA_{ij}	The level of social attraction agent j feels toward agent i .
Dyadic Influence	L_{ij}	The level of influence agent i has over agent j .
Parameters		Values Used
Context Weight	e	Parameter controlling the relative importance of external influences .05

Table 15

Processes Mechanisms and Equations Associated With the Social Identity Theory of Leadership Formal Model.

Name	Equations
Identity	$I_{G,i} = IC_i - P_G _2 - Avg(L_{ij}) + eC_G$
Internalization	
Depersonalization	$SA_{i,j} = I_{G,i} * IC_j - P_G _2 + L_{ij} + IC_i - IC_j _2$
Leadership	$L_{ij} = SA_{i,j}$
Actualization	
Prototype Update	$P_G = \frac{\sum[IC_i(Avg(SA_i)^3 + 1)]}{\sum[Avg(SA_i)^3 + 1]}$

SITL variables. This section lists the variables described by SITL, with descriptions of how they will be represented in the formal model of SITL. Note that various methods could be employed to represent these values; this section clarifies these possible points of confusion and clearly defines how these values are to be represented formally.

Individual characteristics. Individual characteristics will be represented by an n-dimensional vector of unlabeled values. Each value will represent some characteristic which could be important to the group prototype or ILT's. For the sake of simplicity, each characteristic is binary with a value of 1 reprinting the presence of the given characteristic and a -1 representing the absence of a given characteristic.

A variety of characteristics that could be important to group prototypes and ILT's. It is impossible to identify a comprehensive list of characteristics that the prototype may be based, for this reason, I propose a generic method that uses an unlabeled list of orthogonal characteristics.

Each characteristic hypothetically represents a dimension on which group membership (and fit with ILT's) could be evaluated. For example, these dimensions could represent traits that are physical, personality, mental, cultural, etc. I do not specifically label these for the sake of generalizability and consistency. Likewise, I do not specify the number of characteristics in question, at this time. I will determine the number of characteristics that allow reasonable variability in group membership without becoming overly computationally expensive.

Group prototypes. The Group prototype is represented as a list of characteristics that corresponds directly to the characteristics used in the individual characteristics vector. Values are continuous and can range from 1 to -1. Note that according to this representation, the group prototype is shared across the group and represents membership in the team's general group.

Similar to individual characteristics, this representation of a group prototype is a simplification. SITL describes Prototypes as a method for distinguishing between members of different groups, and contextual pressures make certain characteristics more salient under different situations. A team may break apart into separate cliques that have their group prototypes. This formalization of SITL is not equipped to evaluate this type of situation. The present simplification is sufficient to investigate general patterns of social identities influence on leadership emergence in small teams, but a more detailed representation would be required for deeper analysis of the impact of differing prototypes on leadership emergence.

Contextual group influence. Influences encouraging group membership are represented as a single coefficient. Greater values for this variable indicate groups where membership is particularly salient for some reason. This variable is an individual-level variable, enabling different team members to have different levels of contextual pressure to identify with the group. Various contextual factors may encourage group membership. This representation of contextual

influence assumes that these factors essentially act additively together. Again, for the sake of simplicity, it is assumed that these contextual influences are relatively static for a given team.

Note that this interpretation of this variable should be investigated more thoroughly because the model failed to generate the expected context relationship. This is largely since the theory presented contextual influences without thoroughly describing process mechanisms for it.

Individual group identity. Group Identity is represented as a single continuous value and is an individual-level variable. Identity-based theories, discuss the concept of differential activation of identities (Abrams & Hogg, 1999; Stets & Burke, 2000) and this seems to fit well with using a single value to encode how much a given identity is activated.

Social attraction. Social attraction is represented as a single value for each dyadic pair of team members. SITL describes social attraction as the degree of liking one team member will have toward another. SITL separately discusses perceived influence as an important factor. In this formal representation of SITL, I incorporate both of these constructs into the same value because the functionally act in the same way.

Influence. Influence as a single value indicating the strength of an influence relationship. Notably, between two members of a team, there are two possible influence relationships (one going each way), the strength of each of these is represented separately. The influence of leadership in a team may be better represented by a more complicated representation, however, this representation is sufficient to illustrate the strength and direction of leadership, and should be more than adequate.

SITL Mechanisms. In this section, I provide a discussion for how each mechanism is represented formally in the model. Narrative versions of mechanisms provided in the theory are

subject to personal interpretation. The formalized versions are much more objective in their meaning. However, it is very reasonable that a separate individual developing a formalized set of mechanisms from the same theories would use very different equations to represent the narrative mechanisms. For these reasons, I must provide a transparent discussion of where the current interpretation originated.

Prototype establishment. The group prototype is a list of characteristics that are representative of the group. This is established as an average of the characteristics of all individuals in the group weighted by how salient they are. As salience is not explicitly incorporated into this formalization, I use average social attraction as a proxy for salience. Thus, the most socially attractive individuals will thus become the most influential on the group prototype.

Identity internalization. Three main factors impact group identity. The first factor is group prototypicality. The more an individual matches the group prototype (evaluated using Euclidian distance) the more strongly they will identify with the group. Secondly, social influence is encouraged by contextual factors. If group memberships have some sort of instrumental value or social utility, individuals will be more likely to identify with the group. Lastly, individuals that gain influence will become more distal from the group, thus an individual's average influence is negatively related to their group identity.

Social attraction. Individuals will identify with others who are more similar to themselves and to those that are more similar and identify more strongly with the group. Social attraction incorporates these processes. Individuals with influence can increase their salience and social attraction through their actions. Notably, the process by which individuals use their

influence to increase social attraction is dependent on their ability to use influence generally and not dependent on a dyadic relationship.

Depersonalization. As described by SITL, the more one identifies with a given group the more they view others in terms of group membership instead of individual characteristics. This mechanism impacts the process of social attraction. The more one identifies with a given group the more others who identify with the group will be socially attractive, thus one's group identity moderates the relationships between other individuals' group identity and one's social attraction to them. On the other hand, the impact of similarity in individual characteristics (as measured by Euclidean distance) on social attraction will be moderated negatively by group identity because of depersonalization.

Influence actualization. As theorized, an increased social attraction between two individuals leads to influence.

Formalization of Claiming and Granting Theory of Leadership

Overview of the model. As pictured in Figure 9 (Appendix B), CGTL describes a process by which individuals interact, making claims, and grants of leadership. When these claims and grants are reciprocated, individuals establish leadership relationships. Table 16 provides a list of variables and parameters important to each mechanism equation described in the formal model. Table 17 provides a list of each equation used in the formal model of CGTL and the mechanisms that are associated with each given equation. Following the tables and figures, I provide a discussion of each variable and mechanism and their formalization.

Table 16

Variables and Parameters Associated with the Claiming and Granting Theory of Leadership Formal Model.

Name	Symbol	Description	Value
Static Variables			
Individual Characteristics	IC	Static vector with entries representing various characteristics. Each entry is 1 or -1. This is unique to each agent	
Leadership Prototype	P_{Leader}	Static vector with entries representing various characteristics representing an individual's implicit theories of leadership. Each entry is 1 (for prototypical), -1 (for anti-prototypical), or 0 (for agnostic).	
Contextual Influences	C_{Leader}	Contextual influences encouraging or discouraging (or inhibiting) taking leadership.	
Leadership Schema	S	Value representing individual schema of leadership. Scores represent the individual view of leadership from heretical ($S = 0$) to shared leadership ($S = 1$).	
Dynamic Variables			
Individual Leadership Identity	I_{Leader}	Value indicating the amount to which an agent identifies with the group.	
Dyadic Perceived Leader Quality	PLI_{ij}	Agent i 's perception of agent j 's leadership quality	
Dyadic Influence	L_{ij}	The level of influence agent i has over agent j .	
Parameters			Values Used
Context Weight	e	Parameter controlling the relative importance of external influences	.05
Model Balancing Parameter	k_1	Parameter controlling how strongly CGTL impacts influence relative to SITL mechanisms	40
Claim Reinforcement Parameter	k_2	Parameter influencing how reinforcing it is for a claim to be reciprocated	.5
Baseline Claiming Rate	k_3	Parameter influencing how strongly reinforced interactions increase dyadic influence	.25

Note. Pparameters used in similar functions within the equations are assumed to be equal, and parameters similar to those used in the social identity theory model use the same names.

Table 17

Processes and Equations Associated with the Claiming and Granting Theory of Leadership Formal Model.

Name	Equations
Identity	$I_{L,i} = IC_i - P_L - \sum_j (s_i * cl_{ij}) + Avg(L_{ij}) + eC_L$
Internalization	
Depersonalization	$PLI_{ij} = IC_j \cdot p_l + \frac{1}{k_1} L_{ji}$
Claiming	$cl_{ij} = I_{L,i} + s_i * PLI_{i,j} + k_2 g_{ji}$
Granting	$g_{ij} = cl_{ij} * (k_2 g_{ij} + PLI_{j,i} - s_j * I_{L,j})$
Leadership	$L_{ij} = k_1 * g_{ij} - s_j * L_{ji}$
Actualization	

Note. that in the model claiming and granting are probabilistic events that either has a value of 1 or 0 at any given time. The equations provided below are a simplistic representation of the processes influencing the probability of making a claim or granting leadership.

CGTL variables. It is assumed that the same individual characteristics important to the group prototype can be incorporated into an implicit theory of leadership. It is likewise assumed that individual characteristics influence is represented in the same way they are in SITL.

Following is a list of additional variables important to CGTL (Table 16).

Leadership prototype. The Leadership prototype is specific to each agent but static. It is represented, similarly to group prototypes as a list of values between -1 and 1 corresponding to individual characteristics defined in the individual characteristics.

Contextual leader influence. Influences encouraging individuals to claim leadership are represented as a single coefficient. Greater values for this variable indicate contexts where the given individual leadership is highly rewarding. AS with group contextual influences in SITL,

This variable is an individual-level variable, enabling different team members to have different levels of contextual pressure to identify with the group. Various contextual factors may encourage group membership. This representation of contextual influence assumes that these factors essentially act additively together. Again, for the sake of simplicity, it is assumed that these contextual influences are relatively static for a given team. This value encodes influences such as gaining notoriety, pay increases, prestige, etc. as well as influences such as being assigned a formal role and thus feeling obligated to take charge of a group.

Leadership schema. Individuals vary on their leadership schema which represents the extent to which a person prefers to work under a hierarchical leadership structure or a shared leadership structure. An individual's schema may be context-dependent, but we assume for the sake of simplicity that it is constant within the same context. This is an individual-level value that ranges from 0 (Totally shared schema) to 1 (total hierarchical schema).

Individual leader identity. Lear Identity is represented as a single continuous value and is an individual-level variable. This value represents the extent to which an individual's identity as a leader is activated.

Dyadic perceived leadership quality. Each individual assesses the quality of the others in their team as leaders to determine if they should be followed or should follow. This is an individual value where the greater the value the more strongly the other individual in the dyad is seen as a leader.

CGTL mechanism. At the heart of CGTL, Individuals interact, and as they interact, they will often make discreet or overt claims of leadership (followership). The mechanisms below

describe how during a random interaction the probability of making a claim or grant changes depending on various factors, and how reciprocated claims lead to influence strength.

Identity internalization. Four factors impact the process of leader identity internalization. First individuals identify as a leader based partly on their match to their ILT's. The more they feel like they match a leader, the more they will identify as a leader. Secondly, influence leads to leader identity internalization. The more influence an individual gains the more they will identify as a leader. A third factor is contextual influences including formal leadership assignments and rewards for being a leader. An individual that has strong contextual pressure to become a leader is more likely to identify as a leader. Lastly, individuals will internalize claims of leadership they receive from other people as indicating their status as a follower, not a leader. Thus claims of leadership received from other team members will decrease an individual's strength of leadership identity. This attenuating process is hypothesized to be reduced or even eliminated for individuals that have a shared leadership schema instead of a hierarchical leadership schema.

Depersonalization. According to CGTL individuals determine how to interact with others based on how well they fit ILT's. Thus, an understanding of others is distanced from individual characteristics (i.e. depersonalized) and instead based simply on leadership prototype match. Part of this process includes the fact that others who have influence are automatically seen as greater leaders, so regardless of how well they match one's ILT's, someone who has significant influence will be interpreted as a leader.

Claiming. As individuals interact during a random interaction the probability of making a claim is given by the equation given above. To be clear, this value represents a probability of claiming leadership when an interaction happens, it does not represent a value of itself that is

meaningful. In its present form, the equation illustrates factors important to this value, but will likely need to be modified to properly model the probability it represents.

The probability of making a claim is affected by three things. The more one's own leadership is activated the more likely the individual will claim leadership in concordance with their identity. Similarly, the more strongly they perceive the other individual's claim on leadership is the less likely they are to claim leadership. Lastly, as CGTL explicitly describes, an established relationship strongly dictates future action. Thus, if claims and grants have been reciprocated between two individuals in the past this past behavior will largely determine who will make a claim or grant.

Notably, this representation of claims could be interpreted in various other ways. We suggest that this is a simple representation that is useable for the sake of modeling, and adequately covers the main concepts.

The value of this equation is not a probability score. Therefore, we transform this “raw” score to a probability score as follows. We define a theoretical maximum raw score as follows:

$$Raw_{Max} = (2 - S_i)/3$$

Additionally, we define k_3 as the baseline probability of making a claim for team members. If the raw score is 0 then it is transformed to the value k_3 . As the raw score increase from 0, the final probability score increases linearly from k_3 to 1. If the raw score is above the max the probability is set to 1. Similarly, as the raw score decreases from 0 to $-Raw_{Max}$ the output probability decreases linearly from k_3 to 0. Not that the equation for Raw_{Ma} is derived was derived based on simulated raw scores and the raw score equation. It was designed to make the distribution of raw scores to be independent of the given individual's schema. This is a somewhat arbitrary value

and it would be valuable to investigate these values more fully. Note that changes in the Raw_{Max} do not significantly change the pattern or analysis variables, they do adjust the extent of randomness in the data. If Raw_{Max} were set to a very small number, for example, the behavior would become much more deterministic. The fact that this may impact shared and hierarchical schema teams somewhat differently is not problematic given the fact that this influences the amount of randomness, not the actual relationships underlying the noise.

Granting. As with claiming, the equation provided for the granting process describes a probability of reciprocating a claim of leadership when it is received with a grant. The process of deciding to reciprocate a grant or not similarly has various factors. First, as with making claims, when grants were made in the past this behavior sets a pattern that tends to be followed, so grants are most likely where claims of leadership have been previously reciprocated. The more the other individual looks like a leader, the more likely they are to reciprocate a claim, and likewise the more their own leadership identity is activated the less likely they are to grant leadership. This last relationship is attenuated by shared leadership schemas, which is to say individuals that have a shared leadership schema are expected to care less about how much of a leader they are and more about how much of a leader the other person is when determining whether to reciprocate a claim.

Leadership actualization. Influence increases when claims of leadership are reciprocated. Influence is, however, negatively affected by the influence others have. As in other places, this negative relationship is attenuated by a shared leadership schema.

Formalization of Two-Process Theory of Leadership

Overview of the model. As pictured in Figure 10 (Appendix B), TPTL describes a process by which both theories are combined into a two-process model of leadership emergence. Table 18 provides a list of variables and parameters important each mechanism equation described in the formal model.

Table 18

Processes and Equations Associated with the Formal Synthesis Model.

Name	Equations
Group Identity	$I_{G,i} = IC_i - P_G - I_{L,i} + eC_G$
Internalization	
Leader Identity	$I_{L,i} = IC_i - P_L - \sum_j (s_i * cl_{ij}) - I_{G,i} + k_1 Avg(L_{ij}) + eC_L$
Internalization	
Leader	$PLI_{ij} = IC_j - p_l + \frac{1}{k_1} L_{ji} - I_{G,i}$
Depersonalization	
Leadership	$L_{ij} = k_1 * g_{ij} + SA_{i,j} - s_j * L_{ji}$
Actualization	

Note. All equations provided above in both models are assumed to be used in the combined model as described above except the equations listed here. Additions or changes are marked in red. As described in the paper

TPTL mechanisms. The formalization of the synthesis model builds off of the formalizations for SITL and CGTL with a few adjustments to the mechanisms from the two formal models. All other mechanisms and variables are the same as previously described.

Group identity internalization. The group identity internalization mechanism described as part of the formalization of SITL is no longer directly, negatively impacted by influence. This relationship is now represented as being mediated by leadership identity.

Leader identity internalization. The negative relationship between group identity and leader identity is represented as a two-directional relationship. With that leader, identity internalization is adapted from the CGTL formal model with the addition of a negative relationship with group identity.

Leader depersonalization. The process of depersonalization described by SITL is assumed to affect how individuals view others when assessing their status as a leader. Thus the more an individual identifies with the group the less they will see others in terms of a leader identity.

Leadership actualization. The processes of leadership actualization described by both theories will be combined to include both leadership gains due to social attraction and claiming and granting processes.

Appendix D: Generative Sufficiency Test

Tests are split into those designed to test the function of mechanisms explicitly incorporated into the computational model (Table 19), and those that are based on broader predictions of a phenomenon that emerge as a result of this phenomenon (Table 20). Note I hypothesized one SITL prediction will fail without the mechanisms from both theories. Also, note that in addition to these predictions I will test all mechanism-level predictions.

Table 19

Tests for Explicitly Encoded Process Mechanisms.

Theoretical Mechanism	Expected Behavior
Prototype Establishment	- Group prototypes represent an average of group characteristics weighted by social attraction. - These prototypes update appropriately as social attraction changes.
Group Identity Internalization	- Group identity increases invers-proportionally to the Euclidian distance between the group prototype and their own individual characteristics - Group identity increases with contextual group influence - Group identity decreases with increased leader identity
Social Attraction	*Social attraction increases with increased group identity - Social attraction increases with increased individual similarities
Depersonalization	- One's own Group identity positively moderates how strongly an other's group identity impacts social attraction - One's own Group identity negatively impacts how strongly others are seen as having a leader identity
Influence Actualization	- Increased social attraction leads to increased influence - Increased influence leads to increased social attraction - Reciprocation of claims of leadership increases influence - Influence given to others negatively impacts one's own influence
Claiming	Individuals with greater leader identity are more likely to make claims
Granting	- Individuals are more likely to grant leadership to those the more closely match their ILT's - Previous granting behavior predicts future behavior

* Social Attraction increases with targets prototypicality and source's group identity.

Table 20

Tests of Theoretical Predictions.

Predicted relationships	Formal predicted outcomes
	SITL
Context strength leads to leadership strength	• **High density • Highly reciprocity • **Highly transitive • **Highly hieratical
Group Homogeneity leads to leadership strength	• High density • Highly transitive • Highly hieratical
Strong context strong and group homogeneity leads to a single very centralized leader that has a relatively low group identity	• Centrality distribution is right-tailed
Minorities rarely emerge as leaders	• *Distance from the prototype is correlated negatively with the likelihood of emerging as a leader
Minorities are unlikely to maintain leadership they have	• *Distance from the prototype is correlated negatively with the likelihood of maintaining leadership
	CGTL
Schema convergence leads to strong relationships	• High density
Schema divergence leads to weak relationships	• Low density
Shared Schema leads to bidirectional relationships	• High reciprocity
Hierarchical Schema leads to unidirectional relationships	• Low reciprocity

Note. *Indicate relationships that could not be tested due to the nature of the computational model. **Indicate tests that did not pass.

Appendix G: Correlation Tables

Table 21

Means, standard deviations, and correlations with confidence intervals for SITL simulations.

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Skew Individual Strength	-0.50	0.60				
2. Skew Degree Centrality	-0.31	0.60	.69* [.67, .71]			
3. Average Strength	0.35	0.11	-.21* [-.24, -.18]	-.18* [-.21, -.15]		
4. Density	0.51	0.05	-.37* [-.39, -.34]	-.31* [-.34, -.29]	.09* [.06, .12]	
5. Reciprocity	0.90	0.11	.01 [-.02, .04]	-.01 [-.04, .02]	-.74* [-.76, -.73]	.20* [.17, .23]
6. Hierarchy	0.16	0.02	.36* [.34, .39]	.59* [.57, .61]	-.27* [-.30, -.24]	-.35* [-.38, -.32]
7. Transitivity	0.68	0.08	-.17* [-.20, -.14]	-.29* [-.32, -.26]	-.10* [-.13, -.07]	-.22* [-.25, -.19]
8. Modularity	0.12	0.07	.40* [.37, .42]	.48* [.46, .50]	-.42* [-.44, -.39]	-.29* [-.32, -.26]
9. Heterogeneity	0.70	0.27	.19* [.16, .22]	.16* [.13, .19]	-1.00* [-1.00, -1.00]	-.08* [-.11, -.05]
10. Group Context	0.50	0.09	-.01 [-.05, .02]	.00 [-.03, .03]	-.06* [-.09, -.03]	-.02 [-.05, .02]
11. Skew Group Context	-0.00	0.47	-.01 [-.04, .02]	-.02 [-.05, .01]	.05* [.02, .08]	.04* [.01, .08]

Table 21 (cont'd)

Variable	5	6	7	8	9	10
5. Reciprocity						
6. Hierarchy	.20* [.17, .23]					
7. Transitivity	.09* [.05, .12]	-.20* [-.23, -.17]				
8. Modularity	.30* [.27, .33]	.15* [.11, .18]	-.02 [-.05, .01]			
9. Heterogeneity	.75* [.73, .76]	.26* [.23, .29]	.12* [.09, .15]	.41* [.38, .43]		
10. Group Context	.08* [.05, .11]	.03 [-.00, .06]	.01 [-.02, .04]	.04* [.01, .07]	.02 [-.01, .06]	
11. Skew Group Context	-.04* [-.07, -.01]	-.03 [-.06, .00]	.00 [-.03, .03]	-.05* [-.09, -.02]	-.03 [-.06, .00]	-.70* [-.72, -.69]

* indicates $p < .05$.

Table 22

Means, standard deviations, and correlations with confidence intervals for CGTL simulations.

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Skew Individual Strength	0.52	0.58				
2. Skew Degree Centrality	0.45	0.57	.90* [.89, .90]			
3. Average Strength	0.19	0.08	-.33* [-.35, -.31]	-.28* [-.30, -.26]		
4. Density	0.20	0.08	-.33* [-.35, -.30]	-.29* [-.31, -.26]	.99* [.99, .99]	
5. Reciprocity	0.26	0.17	-.26* [-.28, -.24]	-.23* [-.25, -.21]	.66* [.65, .68]	.67* [.65, .68]
6. Hierarchy	0.25	0.07	.76* [.75, .77]	.81* [.81, .82]	-.49* [-.51, -.47]	-.51* [-.53, -.49]
7. Transitivity	0.83	0.10	.35* [.33, .37]	.32* [.29, .34]	-.94* [-.94, -.94]	-.95* [-.95, -.95]
8. Modularity	0.25	0.09	.15* [.12, .17]	.11* [.08, .13]	-.71* [-.72, -.70]	-.72* [-.73, -.71]
9. Heterogeneity	0.85	0.31	-.08* [-.10, -.05]	-.06* [-.09, -.04]	.05* [.03, .08]	.05* [.03, .08]
10. Leadership Schema	0.50	0.42	.24* [.22, .27]	.21* [.18, .23]	-.70* [-.71, -.68]	-.69* [-.70, -.68]
11. Variance in Leadership Schema	0.02	0.04	-.06* [-.08, -.03]	-.05* [-.07, -.02]	-.03* [-.06, -.01]	-.03* [-.06, -.01]
14. Leadership Context	0.50	0.09	.02 [-.00, .05]	.03* [.00, .05]	.01 [-.01, .04]	.01 [-.02, .03]
15. Skew Leadership Context	0.01	0.48	-.02 [-.05, .01]	-.02 [-.05, .00]	-.01 [-.03, .02]	-.00 [-.03, .02]
16. ILT Heterogeneity	1.15	0.09	.05* [.02, .07]	.05* [.03, .08]	-.09* [-.12, -.07]	-.09* [-.12, -.07]

Table 22 (cont'd)

Variable	5	6	7	8	9
5. Reciprocity					
6. Hierarchy	-.38* [-.40, -.36]				
7. Transitivity	-.67* [-.68, -.65]	.53* [.52, .55]			
8. Modularity	-.37* [-.39, -.35]	.24* [.21, .26]	.71* [.70, .72]		
9. Heterogeneity	.04* [.02, .07]	-.14* [-.16, -.11]	-.05* [-.08, -.03]	-.10* [-.13, -.08]	
10. Leadership Schema	-.57* [-.59, -.55]	.37* [.35, .39]	.65* [.64, .67]	.48* [.46, .50]	-.01 [-.03, .02]
11. Variance in Leadership Schema	-.02 [-.04, .01]	-.10* [-.12, -.07]	.03* [.00, .05]	-.02 [-.04, .01]	.59* [.58, .61]
12. Leadership Context	-.00 [-.03, .02]	.01 [-.01, .04]	-.00 [-.03, .02]	-.01 [-.03, .02]	.01 [-.01, .04]
13. Skew Leadership Context	.01 [-.02, .03]	-.02 [-.04, .01]	.00 [-.02, .03]	.01 [-.02, .03]	-.00 [-.03, .02]
14. ILT Heterogeneity	-.04* [-.07, -.02]	.06* [.03, .08]	.09* [.07, .12]	.06* [.03, .08]	.00 [-.02, .03]

Table 22 (cont'd)

Variable	10	11	12	13
10. Leadership Schema				
11. Variance in Leadership Schema	-.00 [-.03, .02]			
12. Leadership Context	.00 [-.02, .03]	.00 [-.02, .03]		
13. Skew Leadership Context	-.01 [-.04, .01]	.00 [-.02, .03]	-.70* [-.72, -.69]	
14. ILT Heterogeneity	-.00 [-.03, .02]	.01 [-.02, .03]	-.01 [-.04, .01]	-.00 [-.03, .02]

* indicates $p < .05$.

Table 23

Means, standard deviations, and correlations with confidence intervals for TPTL simulations

Variable	<i>M</i>	<i>SD</i>	1	2	3	4
1. Skew Individual Strength	0.74	0.60				
2. Skew Degree Centrality	0.56	0.57	.72* [.70, .73]			
3. Average Strength	0.10	0.04	-.18* [-.20, -.15]	-.07* [-.09, -.05]		
4. Density	0.15	0.04	-.17* [-.19, -.15]	-.12* [-.14, -.10]	.90* [.89, .90]	
5. Reciprocity	0.15	0.14	-.11* [-.13, -.09]	-.08* [-.10, -.06]	.29* [.27, .31]	.31* [.29, .33]
6. Hierarchy	0.27	0.08	.67* [.66, .69]	.86* [.86, .87]	-.24* [-.26, -.22]	-.33* [-.35, -.31]
7. Transitivity	0.91	0.05	.23* [.21, .25]	.20* [.18, .23]	-.75* [-.76, -.74]	-.84* [-.85, -.83]
8. Modularity	0.30	0.09	-.01 [-.04, .01]	-.07* [-.09, -.05]	-.53* [-.55, -.51]	-.57* [-.59, -.56]
9. Heterogeneity	0.92	0.30	-.04* [-.06, -.02]	.02 [-.00, .04]	.29* [.27, .31]	.18* [.16, .20]
10. Leadership Schema	0.50	0.36	.03* [.01, .05]	.06* [.04, .08]	.15* [.13, .17]	.01 [-.01, .03]
11. Variance in Leadership Schema	0.04	0.04	-.02 [-.04, .00]	.01 [-.01, .03]	.16* [.14, .18]	.08* [.06, .11]
12. Group Context	0.50	0.09	-.03* [-.05, -.01]	-.02 [-.04, .00]	.07* [.05, .09]	.05* [.03, .08]
13. Skew Group Context	0.00	0.47	.02* [.00, .04]	.01 [-.01, .03]	-.04* [-.06, -.02]	-.03* [-.05, -.00]
14. Leadership Context	0.50	0.09	.02 [-.00, .04]	.02 [-.00, .04]	-.03* [-.05, -.00]	-.02 [-.04, .00]
15. Skew Leadership Context	-0.00	0.47	-.01 [-.03, .01]	-.01 [-.03, .01]	.02 [-.00, .04]	.01 [-.01, .03]
16. ILT Heterogeneity	1.04	0.25	.04* [.02, .07]	.02 [-.00, .04]	-.13* [-.15, -.10]	-.08* [-.10, -.06]

Table 23 (cont'd)

Variable	5	6	7	8	9	10
5. Reciprocity						
6. Hierarchy	-.15* [-.18, -.13]					
7. Transitivity	-.34* [-.36, -.32]	.39* [.37, .41]				
8. Modularity	-.02 [-.04, .00]	-.01 [-.03, .01]	.57* [.56, .59]			
9. Heterogeneity	.10* [.07, .12]	-.02 [-.04, .01]	-.15* [-.17, -.12]	-.13* [-.15, -.11]		
10. Leadership Schema	.03* [.01, .05]	.08* [.06, .10]	-.07* [-.09, -.05]	-.07* [-.09, -.05]	.00 [-.02, .02]	
11. Variance in Leadership Schema	.03* [.01, .05]	-.02 [-.04, .00]	-.05* [-.07, -.03]	-.06* [-.08, -.04]	.66* [.64, .67]	.00 [-.02, .02]
12. Group Context	.02 [-.00, .04]	-.03* [-.06, -.01]	-.05* [-.08, -.03]	-.03* [-.05, -.01]	.00 [-.02, .03]	-.01 [-.03, .01]
13. Skew Group Context	-.02 [-.04, .01]	.02 [-.00, .04]	.03* [.01, .05]	.01 [-.01, .03]	-.02 [-.04, .01]	.01 [-.02, .03]
14. Leadership Context	-.01 [-.03, .01]	.02 [-.00, .04]	.01 [-.01, .04]	-.01 [-.03, .02]	-.01 [-.04, .01]	.01 [-.01, .03]
15. Skew Leadership Context	-.00 [-.02, .02]	-.01 [-.03, .01]	-.00 [-.02, .02]	.01 [-.01, .03]	.00 [-.02, .03]	.01 [-.02, .03]
16. ILT Heterogeneity	.00 [-.02, .03]	.05* [.03, .07]	-.01 [-.03, .01]	.03* [.01, .05]	-.35* [-.37, -.33]	-.00 [-.02, .02]

Table 23 (cont'd)

Variable	11	12	13	14	15
11. Variance in Leadership Schema					
12. Group Context	.00 [-.02, .02]				
13. Skew Group Context	-.01 [-.03, .01]	-.70* [-.71, -.68]			
14. Leadership Context	.01 [-.02, .03]	-.02* [-.04, -.00]	.03* [.00, .05]		
15. Skew Leadership Context	-.02 [-.04, .00]	.01 [-.01, .03]	-.01 [-.04, .01]	-.69* [-.71, -.68]	
16. ILT Heterogeneity	-.46* [-.48, -.45]	.01 [-.02, .03]	-.01 [-.03, .01]	-.01 [-.03, .01]	.01 [-.01, .03]

* indicates $p < .05$.

Appendix H: Multiple Regression Tables

Table 24

Multiple regression results for each criterion variable predicted by mechanism type, heterogeneity, and leadership schema

Criterion	Hypothesis	Predictor	<i>b</i>	95% CI	Fit
Skew Individual Strength	H1a(+) [†]	(Intercept)	-0.80*	[-0.85, -0.75]	<i>R</i> ² = .490*
		CGTL	1.45*	[1.37, 1.54]	
		TPTL	1.71*	[1.62, 1.80]	
	H2a(+) [†]	Heterogeneity	0.44*	[0.37, 0.50]	
		Heterogeneity X CGTL	-0.82*	[-0.94, -0.70]	
	H9(+)	Heterogeneity X TPTL	-0.66*	[-0.78, -0.54]	
		Schema X CGTL	-0.03	[-0.14, 0.07]	
		Schema X TPTL	-0.21*	[-0.31, -0.10]	
	H3a(-) [‡]	Heterogeneity X Schema X CGTL	0.52*	[0.38, 0.66]	
	H6a, H7a(-)	Heterogeneity X Schema X TPTL	0.35*	[0.21, 0.49]	
Skew Degree Centrality	H1a(+) [†]	(Intercept)	-0.56*	[-0.61, -0.51]	<i>R</i> ² = .340*
		CGTL	1.14*	[1.05, 1.23]	
		TPTL	1.09*	[1.00, 1.18]	
	H2a(+) [†]	Heterogeneity	0.36*	[0.29, 0.42]	
		Heterogeneity X CGTL	-0.70*	[-0.82, -0.59]	
	H9(+)	Heterogeneity X TPTL	-0.37*	[-0.48, -0.25]	
		Schema X CGTL	-0.08	[-0.18, 0.02]	
		Schema X TPTL	-0.11*	[-0.21, -0.01]	
	H3a(-) [‡]	Heterogeneity X Schema X CGTL	0.50*	[0.36, 0.63]	
	H6a, H7a(-)	Heterogeneity X Schema X TPTL	0.28*	[0.15, 0.42]	
Average Strength	H1b(-) [†]	(Intercept)	0.63*	[0.63, 0.63]	<i>R</i> ² = .911*
		CGTL	-0.37*	[-0.38, -0.37]	
		TPTL	-0.55*	[-0.56, -0.54]	
	H2a(-) [†]	Heterogeneity	-0.40*	[-0.41, -0.40]	
		Heterogeneity X CGTL	0.41*	[0.40, 0.41]	
	H9(-)	Heterogeneity X TPTL	0.42*	[0.41, 0.43]	
		Schema X CGTL	-0.20*	[-0.21, -0.19]	
		Schema X TPTL	-0.03*	[-0.04, -0.02]	
	H3a, H4(+) [†]	Heterogeneity X Schema X CGTL	0.09*	[0.08, 0.10]	
	H6a(+) [‡]	Heterogeneity X Schema X TPTL	0.06*	[0.05, 0.07]	
Density	H1b(-) [†]	(Intercept)	0.52*	[0.52, 0.52]	<i>R</i> ² = .922*
		CGTL	-0.25*	[-0.26, -0.24]	
		TPTL	-0.38*	[-0.38, -0.37]	
	H2a(-) [†]	Heterogeneity	-0.01*	[-0.02, -0.01]	
		Heterogeneity X CGTL	0.02*	[0.01, 0.03]	
	H9(-)	Heterogeneity X TPTL	0.01	[-0.00, 0.02]	
		Schema X CGTL	-0.19*	[-0.20, -0.19]	
		Schema X TPTL	-0.05*	[-0.06, -0.05]	
	H3a, H4(+) [†]	Heterogeneity X Schema X CGTL	0.09*	[0.07, 0.10]	
	H6a(+) [‡]	Heterogeneity X Schema X TPTL	0.08*	[0.07, 0.09]	

Table 24 (cont'd)

Criterion	Hypothesis	Predictor	<i>b</i>	95% CI	Fit
Reciprocity		(Intercept)	0.69*	[0.68, 0.70]	$R^2 = .889^*$
	H1c(-) [†]	CGTL	-0.34*	[-0.36, -0.32]	
		TPTL	-0.59*	[-0.61, -0.57]	
	H2b(-)	Heterogeneity	0.30*	[0.29, 0.31]	
		Heterogeneity X CGTL	-0.25*	[-0.28, -0.23]	
	H9(-) [†]	Heterogeneity X TPTL	-0.25*	[-0.27, -0.22]	
		Schema X CGTL	-0.27*	[-0.29, -0.25]	
		Schema X TPTL	-0.02	[-0.04, 0.01]	
	H3b(-) [‡]	Heterogeneity X Schema X CGTL	0.04*	[0.01, 0.07]	
	H6b, H7b(+) [†]	Heterogeneity X Schema X TPTL	0.04*	[0.01, 0.07]	
Hierarchy		(Intercept)	0.15*	[0.14, 0.15]	$R^2 = .444^*$
	H1d(+) [†]	CGTL	0.12*	[0.11, 0.13]	
		TPTL	0.12*	[0.11, 0.13]	
		Heterogeneity	0.02*	[0.01, 0.02]	
		Heterogeneity X CGTL	-0.08*	[-0.09, -0.06]	
	H9(+)	Heterogeneity X TPTL	-0.01*	[-0.03, -0.00]	
		Schema X CGTL	0.02*	[0.01, 0.03]	
		Schema X TPTL	0.00	[-0.01, 0.01]	
		Heterogeneity X Schema X CGTL	0.06*	[0.04, 0.07]	
	H7a(-) [‡]	Heterogeneity X Schema X TPTL	0.02*	[0.00, 0.03]	
Transitivity		(Intercept)	0.66*	[0.65, 0.66]	$R^2 = .705^*$
	H1e(-)	CGTL	0.12*	[0.11, 0.13]	
		TPTL	0.27*	[0.26, 0.28]	
		Heterogeneity	0.04*	[0.03, 0.04]	
		Heterogeneity X CGTL	-0.07*	[-0.09, -0.06]	
	H9(-) [†]	Heterogeneity X TPTL	-0.04*	[-0.06, -0.03]	
		Schema X CGTL	0.20*	[0.19, 0.21]	
		Schema X TPTL	0.03*	[0.02, 0.05]	
		Heterogeneity X Schema X CGTL	-0.05*	[-0.06, -0.03]	
		Heterogeneity X Schema X TPTL	-0.06*	[-0.08, -0.05]	

Note. CGTL and TPTL are dummy coded variables with 1 indicating CGTL and TPTL teams respectively and 0 indicating SITL teams. SITL simulations do not use the leadership schema so no un-moderated main schema effect was included in any of the models. Results are consistent with findings reported in Studies 1-4 with significant regression coefficient for mechanism type (i.e. SITL, CGTL, TPTL), homogeneity, schema, and their interaction terms. In addition to supporting the same conclusions as previously discussed, this indicates that heterogeneity and schema have a significant impact on emergent leadership network structures separate from the impact of the leadership emergence mechanism.

† indicates hypotheses that had significant regression coefficients consistent with the hypothesized relationships.

‡ indicates hypothesized relationships that are described by significant simple slopes not interactions. These were not directly assessed here and therefore it is unclear if these hypotheses are supported or not from this analysis.

* indicates $p < .05$.

REFERENCES

- Abrams, D., & Hogg, M. A. (1999). *Social identity and social cognition*. Blackwell Oxford.
- Acton, B. P., Foti, R. J., Lord, R. G., & Gladfelter, J. A. (2018). Putting emergence back in leadership emergence: A dynamic, multilevel, process-oriented framework. *The Leadership Quarterly*.
- Adner, R., Pólos, L., Ryall, M., & Sorenson, O. (2009). Introduction to Special Topic Forum: The Case for Formal Theory. *The Academy of Management Review*, 34(2), 201–208.
- Anderson, B. S., Butts, C., & Carley, K. (1999). The interaction of size and density with graph-level indices. *Social Networks*, 21(3), 239–267. [https://doi.org/10.1016/S0378-8733\(99\)00011-8](https://doi.org/10.1016/S0378-8733(99)00011-8)
- Antonakis, J., Avolio, B. J., & Sivasubramaniam, N. (2003). Context and leadership: An examination of the nine-factor full-range leadership theory using the Multifactor Leadership Questionnaire. *The Leadership Quarterly*, 14(3), 261–295. [https://doi.org/10.1016/S1048-9843\(03\)00030-4](https://doi.org/10.1016/S1048-9843(03)00030-4)
- Baddeley, A. (1992). Working memory. *Science*, 255(5044), 556–559.
- Barrat, A., Barthélemy, M., Pastor-Satorras, R., & Vespignani, A. (2004). The architecture of complex weighted networks. *Proceedings of the National Academy of Sciences*, 101(11), 3747–3752. <https://doi.org/10.1073/pnas.0400087101>
- Bastardo, N., & Van Vugt, M. (2018). The nature of followership: Evolutionary analysis and review. *The Leadership Quarterly*.
- Baumeister, R. F., & Tice, D. M. (1985). Self-esteem and responses to success and failure: Subsequent performance and intrinsic motivation. *Journal of Personality*, 53(3), 450–467.
- Bienefeld, N., & Grote, G. (2014). Shared leadership in multiteam systems: How cockpit and cabin crews lead each other to safety. *Human Factors*, 56(2), 270–286.
- Bonabeau, E. (2002). Agent-based modeling: Methods and techniques for simulating human systems. *Proceedings of the National Academy of Sciences*, 99(Supplement 3), 7280–7287. <https://doi.org/10.1073/pnas.082080899>
- Brown, A. D. (2015). Identities and identity work in organizations. *International Journal of Management Reviews*, 17(1), 20–40.
- Carson, J. B., Tesluk, P. E., & Marrone, J. A. (2007). Shared leadership in teams: An investigation of antecedent conditions and performance. *Academy of Management Journal*, 50(5), 1217–1234.
- Carter, D. R., DeChurch, L. A., Braun, M. T., & Contractor, N. S. (2015). Social network approaches to leadership: An integrative conceptual review. *Journal of Applied Psychology*, 100(3), 597–622. <https://doi.org/10.1037/a0038922>

- Chen, C., Cheng, L., & Xiu, C. L. (2013). Distribution of centrality of traffic network and its relationship with economic density of tertiary industry in Shenyang. *Progress in Geography*, 32(11), 1612–1621.
- Clauset, A., Newman, M. E., & Moore, C. (2004). Finding community structure in very large networks. *Physical Review E*, 70(6), 066111.
- Csardi, G., & Nepusz, T. (2006). The igraph software package for complex network research. *InterJournal, Complex Systems*, 1695(5), 1–9.
- Denis, J.-L., Langley, A., & Sergi, V. (2012). Leadership in the plural. *The Academy of Management Annals*, 6(1), 211–283.
- DeRue, D. S., & Ashford, S. J. (2009). Assuming the Mantle: Unpacking the Process by Which Individuals Internalize a Leader. In L. M. Roberts & J. E. Dutton (Eds.), *Exploring Positive Identities and Organizations: Building a Theoretical and Research Foundation* (p. 28).
- DeRue, D. S., & Ashford, S. J. (2010). Who will lead and who will follow? A social process of leadership identity construction in organizations. *Academy of Management Review*, 35(4), 627–647.
- Dinh, J. E., Lord, R. G., Gardner, W. L., Meuser, J. D., Liden, R. C., & Hu, J. (2014). Leadership theory and research in the new millennium: Current theoretical trends and changing perspectives. *The Leadership Quarterly*, 25(1), 36–62. <https://doi.org/10.1016/j.leaqua.2013.11.005>
- D’Innocenzo, L., Mathieu, J. E., & Kukenberger, M. R. (2016). A Meta-Analysis of Different Forms of Shared Leadership–Team Performance Relations. *Journal of Management*, 42(7), 1964–1991. <https://doi.org/10.1177/0149206314525205>
- Dunegan, K. J., Uhl-Bien, M., & Duchon, D. (2002). LMX and Subordinate Performance: The Moderating Effects of Task Characteristics. *Journal of Business and Psychology*, 17(2), 275–285. <https://doi.org/10.1023/A:1019641700724>
- Dweck, C. S. (2013). *Self-theories: Their role in motivation, personality, and development*. Psychology press.
- Epitropaki, O., & Martin, R. (2004). Implicit Leadership Theories in Applied Settings: Factor Structure, Generalizability, and Stability Over Time. *Journal of Applied Psychology*, 89(2), 293–310. <https://doi.org/10.1037/0021-9010.89.2.293>
- Epstein, J. M. (1999). Agent-based computational models and generative social science. *Complexity*, 4(5), 41–60. [https://doi.org/10.1002/\(SICI\)1099-0526\(199905/06\)4:5<41::AID-CPLX9>3.0.CO;2-F](https://doi.org/10.1002/(SICI)1099-0526(199905/06)4:5<41::AID-CPLX9>3.0.CO;2-F)
- Fioretti, G. (2013). Agent-Based Simulation Models in Organization Science. *Organizational Research Methods*, 16(2), 227–242. <https://doi.org/10.1177/1094428112470006>

- Fitzsimons, D., James, K. T., & Denyer, D. (2011). Alternative approaches for studying shared and distributed leadership. *International Journal of Management Reviews*, 13(3), 313–328.
- Grand, J. A., Braun, M. T., Kuljanin, G., Kozlowski, S. W. J., & Chao, G. T. (2016). The dynamics of team cognition: A process-oriented theory of knowledge emergence in teams. *Journal of Applied Psychology*, 101(10), 1353–1385. <https://doi.org/10.1037/apl0000136>
- Guastello, S. J. (1998). Self-Organization in Leadership Emergence. *Nonlinear Dynamics, Psychology, and Life Sciences*, 2(4), 14.
- Harrison, J. R., Lin, Z., Carroll, G. R., & Carley, K. M. (2007). Simulation modeling in organizational and management research. *Academy of Management Review*, 32(4), 1229–1245. <https://doi.org/10.5465/amr.2007.26586485>
- Hogg, M. A. (2001). A Social Identity Theory of Leadership. *Personality and Social Psychology Review*, 5(3), 184–200. https://doi.org/10.1207/S15327957PSPR0503_1
- Hogg, M. A., & Abrams, D. (1993). *Towards a single-process uncertainty-reduction model of social motivation in groups*.
- Hollenbeck, J. R., DeRue, D. S., & Nahrgang, J. D. (2015). The opponent process theory of leadership succession. *Organizational Psychology Review*, 5(4), 333–363. <https://doi.org/10.1177/2041386614530606>
- Horn, R. L. V. (1971). Validation of Simulation Results. *Management Science*, 17(5), 247–258.
- Kenney, R. A., Schwartz-Kenney, B. M., & Blascovich, J. (1996). Implicit leadership theories: Defining leaders described as worthy of influence. *Personality and Social Psychology Bulletin*, 22(11), 1128–1143.
- Kozlowski, S. W. J., Chao, G. T., Grand, J. A., Braun, M. T., & Kuljanin, G. (2013). Advancing Multilevel Research Design: Capturing the Dynamics of Emergence. *Organizational Research Methods*, 16(4), 581–615. <https://doi.org/10.1177/1094428113493119>
- Kozlowski, S. W. J., Mak, S., & Chao, G. T. (2016). Team-Centric Leadership: An Integrative Review. *Annual Review of Organizational Psychology and Organizational Behavior*, 3(1), 21–54. <https://doi.org/10.1146/annurev-orgpsych-041015-062429>
- Kramer, M. W. (1999). Motivation to reduce uncertainty: A reconceptualization of uncertainty reduction theory. *Management Communication Quarterly*, 13(2), 305–316.
- Le Blanc, P. M., & González-Romá, V. (2012). A team level investigation of the relationship between Leader–Member Exchange (LMX) differentiation, and commitment and performance. *The Leadership Quarterly*, 23(3), 534–544. <https://doi.org/10.1016/j.leaqua.2011.12.006>

- Lord, R. G., Day, D. V., Zaccaro, S. J., Avolio, B. J., & Eagly, A. H. (2017). Leadership in applied psychology: Three waves of theory and research. *Journal of Applied Psychology*, 102(3), 434.
- Lord, R. G., Epitropaki, O., Foti, R. J., & Hansbrough, T. K. (2020). Implicit Leadership Theories, Implicit Followership Theories, and Dynamic Processing of Leadership Information. *Annual Review of Organizational Psychology and Organizational Behavior*, 7(1), 49–74. <https://doi.org/10.1146/annurev-orgpsych-012119-045434>
- Martin, R., Guillaume, Y., Thomas, G., Lee, A., & Epitropaki, O. (2016). Leader–Member Exchange (LMX) and Performance: A Meta-Analytic Review. *Personnel Psychology*, 69(1), 67–121. <https://doi.org/10.1111/peps.12100>
- Mehra, A., Smith, B. R., Dixon, A. L., & Robertson, B. (2006). Distributed leadership in teams: The network of leadership perceptions and team performance. *The Leadership Quarterly*, 17(3), 232–245. <https://doi.org/10.1016/j.leaqua.2006.02.003>
- Naylor, T. H., Finger, J. M., McKenney, J. L., Schrank, W. E., & Holt, C. C. (1967). Verification of Computer Simulation Models. *Management Science*, 14(2), B92–B106.
- North, M. J., Collier, N. T., Ozik, J., Tatara, E. R., Macal, C. M., Bragen, M., & Sydelko, P. (2013). Complex adaptive systems modeling with Repast Symphony. *Complex Adaptive Systems Modeling*, 1(1), 3. <https://doi.org/10.1186/2194-3206-1-3>
- Oc, B., & Bashshur, M. R. (2013). Followership, leadership and social influence. *The Leadership Quarterly*, 24(6), 919–934. <https://doi.org/10.1016/j.leaqua.2013.10.006>
- Offermann, L. R., Kennedy, J. K., & Wirtz, P. W. (1994). Implicit leadership theories: Content, structure, and generalizability. *The Leadership Quarterly*, 5(1), 43–58. [https://doi.org/10.1016/1048-9843\(94\)90005-1](https://doi.org/10.1016/1048-9843(94)90005-1)
- Otte, E., & Rousseau, R. (2002). Social network analysis: A powerful strategy, also for the information sciences. *Journal of Information Science*, 28(6), 441–453.
- Parry, K. W. (1998). Grounded theory and social process: A new direction for leadership research. *The Leadership Quarterly*, 9(1), 85–105. [https://doi.org/10.1016/S1048-9843\(98\)90043-1](https://doi.org/10.1016/S1048-9843(98)90043-1)
- Sargent, R. G. (2013). Verification and validation of simulation models. *Journal of Simulation*, 7(1), 12–24. <https://doi.org/10.1057/jos.2012.20>
- Shamir, B., & Howell, J. M. (1999). Organizational and contextual influences on the emergence and effectiveness of charismatic leadership. *The Leadership Quarterly*, 10(2), 257–283. [https://doi.org/10.1016/S1048-9843\(99\)00014-4](https://doi.org/10.1016/S1048-9843(99)00014-4)
- Simon, H. A., & Ando, A. (1961). Aggregation of Variables in Dynamic Systems. *Econometrica*, 29(2), 111–138.

- Stets, J. E., & Burke, P. J. (2000). Identity theory and social identity theory. *Social Psychology Quarterly*, 224–237.
- Turner, J. C., Hogg, M. A., Oakes, P. J., Reicher, S. D., & Wetherell, M. S. (1987). *Rediscovering the social group: A self-categorization theory*. Basil Blackwell.
- Uhl-Bien, M., Riggio, R. E., Lowe, K. B., & Carsten, M. K. (2014). Followership theory: A review and research agenda. *The Leadership Quarterly*, 25(1), 83–104.
- Vancouver, J. B., Tamanini, K. B., & Yoder, R. J. (2010). Using Dynamic Computational Models to Reconnect Theory and Research: Socialization by the Proactive Newcomer as Example. *Journal of Management*, 36(3), 764–793.
<https://doi.org/10.1177/0149206308321550>
- Vancouver, J. B., Wang, M., & Li, X. (2020). Translating Informal Theories Into Formal Theories: The Case of the Dynamic Computational Model of the Integrated Model of Work Motivation. *Organizational Research Methods*, 23(2), 238–274.
<https://doi.org/10.1177/1094428118780308>
- Vancouver, J. B., & Weinhardt, J. M. (2012). Modeling the Mind and the Milieu: Computational Modeling for Micro-Level Organizational Researchers. *Organizational Research Methods*, 15(4), 602–623. <https://doi.org/10.1177/1094428112449655>
- Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications* (Vol. 8). Cambridge university press.
- Weick, K. E. (1993). The Collapse of Sensemaking in Organizations: The Mann Gulch Disaster. *Administrative Science Quarterly*, 38(4), 628. <https://doi.org/10.2307/2393339>
- Weinhardt, J. M., & Vancouver, J. B. (2012). Intelligent interventions. *Industrial and Organizational Psychology*, 5(2), 179–182.
- Wellman, N. (2017). Authority or Community? A Relational Models Theory of Group-Level Leadership Emergence. *Academy of Management Review*, 42(4), 596–617.
<https://doi.org/10.5465/amr.2015.0375>
- Wolff, S. B., Pescosolido, A. T., & Druskat, V. U. (2002). Emotional intelligence as the basis of leadership emergence in self-managing teams. *The Leadership Quarterly*, 13(5), 505–522.