The Leadership Quarterly 26 (2015) 402–418

Contents lists available at ScienceDirect

The Leadership Quarterly

journal homepage: www.elsevier.com/locate/leaqua

Leadership emergence in face-to-face and virtual teams: A multi-level model with agent-based simulations, quasi-experimental and experimental tests

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ARTICLE INFO

Article history:
Accepted 19 February 2015
Available online 22 April 2015

Editor: M. Mumford

Keywords:
Leadership emergence
Leader cognitive ability and personality
Comfort with technology
Team virtuality and density of network ties
Agent-based modeling and experimental tests

ABSTRACT

With leadership as a major predictor of team performance in both face-to-face and virtual teams, research on differences in leadership emergence in these contexts seems warranted. We offer a multi-level model analyzing the roles of degree of team virtuality and density of social network ties as boundary conditions on leadership emergence, viewed as a fundamentally social–cognitive process. Using agent-based modeling and simulations, our results suggest that virtuality moderates the relationships between cognitive ability, extraversion, and self-efficacy (as independent variables) and leadership emergence (as dependent variable); and density of network ties serves as a moderator for the associations of cognitive ability and self-efficacy with leadership emergence. Subsequent quasi-experimental and experimental tests support the role of density of network ties as a moderator for the association of extraversion with leadership emergence. Implications of these findings and future paths for research bridging the fields of leadership, team virtuality and social networks are discussed.

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Introduction

Organizations of today are characterized by increased dynamism and complexity. The competitive challenges that have appeared as a result of these conditions have made organizations consider alternatives to traditional work environments and face-to-face teams. As a result, research interest in virtual (or non-co-located) teams has grown exponentially (Avolio, Kahai, Dumdum, & London, 2001; Avolio, Sosik, Kahai, & Baker, 2014). Although the tasks, goals, or mission they are designed to accomplish can be similar to those of conventional teams, the way virtual teams go about accomplishing their tasks and the constraints they face along the way are essentially different. In this context, leadership characteristics, behavior, and tactics will need to be reconsidered, as some can become more relevant than in the traditional context and would need to be scaled up, while others would need to be toned down (Kahai, 2012).

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http://dx.doi.org/10.1016/j.leaqua.2015.02.006
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Leadership can be viewed as a combination of skills and knowledge structures (including cognitive abilities, cognitions, and meta-cognitions) that contribute to performance (e.g., Fleishman et al., 1991; Mumford, Antes, Caughron, & Friedrich, 2008; Mumford, Friedrich, Caughron, & Byrne, 2007; Zaccaro, Gilbert, Thor, & Mumford, 1991). However, the development of these depends on a set of abilities, motives and personality characteristics (Mumford, Zaccaro, Connelly, & Marks, 2000; Mumford et al., 2007; Zaccaro et al., 1991). A significant base of studies has indicated a relationship between leader attributes, such as general cognitive ability, or personality and performance. For the purpose of this study, however, we focus on the relationship between a combination of skills and knowledge structures of individual team members and their relationship with leadership emergence.

Joshi, Lazarova, and Liao (2009) suggest that technology-enabled and geographically dispersed settings provide exciting opportunities for extending theory and research on leadership in teams. Avolio et al. (2001) have also suggested that when analyzing an organization's shift towards the use of virtual teams, their impact on organizational processes and outcomes must be understood. Researchers must identify how leadership and technology interact to influence performance antecedents and determine whether the emergence of leadership parallels what has been found in face-to-face settings (Avolio et al., 2014).

Virtual teams can often be created without a formally designated leader, and since there are many different roles to fill, more than one leader can emerge (Wickham & Walther, 2009). Research suggests that different personal characteristics may make a leader emerge in face-to-face versus virtual teams. Based on a review of the literature on teams in general and virtual teams in particular, four major variables have been selected that can render a potentially significant contribution to leadership emergence in both team types—cognitive ability, personality, self-efficacy, and comfort with technology—and have been integrated into a multi-level model of leadership emergence.

Research has also suggested that synergy between leadership studies and social network approaches is essential and would be extremely beneficial for both literatures (Balkundi & Kilduff, 2006). Through networks, entities gain information, exercise influence, and look for social support (Kilduff & Tsai, 2003). Studies suggest that informal leaders can be just as powerful as formal ones and can alter organizational functioning through their emergent social network structures and the exercise of social influence (Balkundi & Kilduff, 2006). Because reviews of social network research reveal little empirical work on leadership and social networks (Brass, Galaskiewicz, Greve, & Tsai, 2004), we address this issue by analyzing leadership emergence in teams, in relation to the density of network ties that develop as team members engage in project-oriented teamwork (see Fig. 1).

As such, the current research contributes to the literature in three key ways: (1) bridging the fields of leadership, social networks and virtual teams to build a multi-level model of leadership emergence, (2) providing a rigorous test of the model by means of multiple methods and research designs (an agent-based computational model simulation, a quasi-experimental study and a laboratory experiment), and (3) assessing the convergence among the tests to enhance our understanding of leadership emergence.

Conceptualization and hypotheses development

Leadership emergence

Leadership emergence can be defined as a fundamentally social–cognitive process (Lord & Maher, 1990; Mumford et al., 2008), as well as the result of followers' perceptions of how well the leader fits their idealized image of the prototypical leader (Gershenoff, 2003; Hogan, Curphy, & Hogan, 1994). The information-processing theories of leadership categorization (Lord, Foti, & Phillips, 1982) suggest that leadership is an outcome of traits associated with, behaviors displayed, and outcomes produced by the leader,

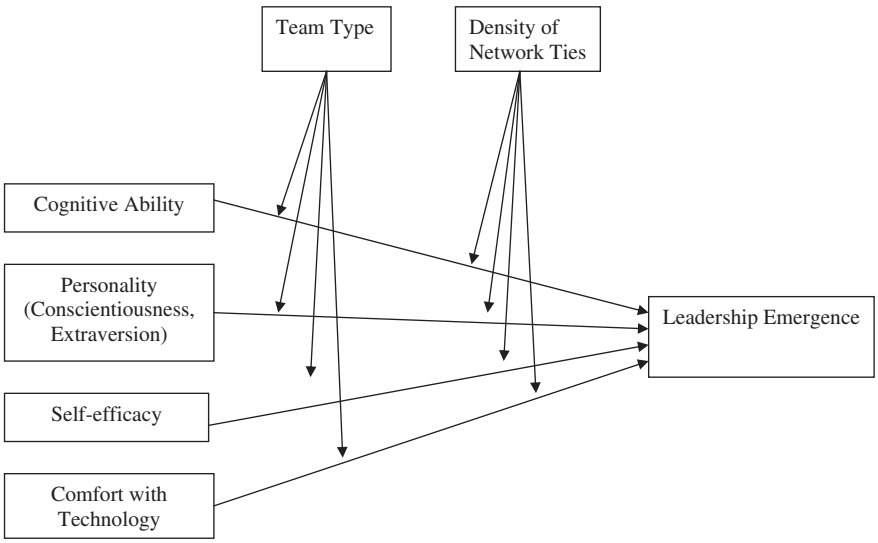

Fig. 1. A multi-level model of leadership emergence in face-to-face and virtual teams.

and perceived by followers. As such, leadership emergence occurs when an individual in a leaderless group exhibits high leadership behavior and is perceived by his/her group members as the leader (Berdahl, 1996).

Leadership emergence has been mostly studied in autonomous work teams, due to the lack of a designated leader. Emergent leaders exert significant influence over other group members, despite having no formal authority (Schneider & Goktepe, 1983). Moreover, autonomous/leaderless teams differ from traditional work situations in that they display low role differentiation and the roles members assume are flexible and dynamic, which may lead to multiple members exhibiting leadership (Seers, 1989).

The individual differences perspective suggests that all individuals have attributes associated with leadership and may exhibit leadership behavior at one time or another (Neubert & Taggar, 2004). However, some people exhibit behavior attributed to leadership more often than others, which is why studies focusing on leadership emergence typically operationalize the emergent leader as the member with the highest leadership ratings among all team members (Neubert & Taggar, 2004).

A significant amount of research indicates a relationship between individual differences and leadership emergence (Gershenoff, 2003). Lord, De Vader, and Alliger (1986) found significant and consistent associations between leadership emergence and traits such as intelligence, dominance, and masculinity. A strong relationship between cognitive ability and leadership emergence has been demonstrated consistently by many researchers (Lord et al., 1986; Taggar, Hackew, & Saha, 1999). Taggar et al. (1999) indicate that individuals with high levels of general mental ability, extraversion, conscientiousness, emotional stability, and openness to experience are more likely to emerge as leaders. Other research has also supported the idea that personality and leadership emergence are significantly related (e.g., Anderson & Kilduff, 2009).

Self-efficacy has been accepted as a predictor of leadership emergence as well (Gershenoff, 2003). Also, Kayworth and Leidner's (2002) study suggests that comfort with technology might also be related to leadership emergence especially in virtual teams, where membership may be biased towards individuals skilled at learning new technologies, and biased against those who experience technophobia.

Team type

The focus here is on two types of teams: face-to-face (co-located) and virtual (non-co-located) teams. Researchers suggest several dimensions by which types of virtual teams can be distinguished, such as temporal distribution, boundary spanning, lifecycle, and member roles (Balkundi & Harrison, 2006). Yoo and Alavi (2004) suggest that the roles of emergent virtual leaders may differ from the roles of face-to-face leaders. In their study, participants were instructed to communicate via e-mail through a single group address, as the primary communication channel, but were allowed to occasionally use telephone and fax. Individuals perceived as emergent leaders sent more and longer email messages than the other team members (especially task-oriented messages related to logistics coordination) and enacted the roles of initiator, scheduler, and integrator.

Cognitive ability

General cognitive ability refers to individuals' tendency to consistently perform information-processing tasks successfully (Barry & Friedman, 1998). Research supports the idea that cognitive ability is a stable and reliable construct, which predicts multiple outcomes including job performance across a wide variety of jobs (Pearlman, Schmidt, & Hunter, 1980), as employees with higher levels of cognitive ability are better at acquiring knowledge that is relevant for facilitating problem solving (Schmidt, Hunter, Outerbridge, & Goff, 1988). A strong relationship between cognitive ability and leadership emergence has been demonstrated (Lord et al., 1986), with general mental ability suggested as the strongest predictor of emergence (Taggar et al., 1999). We also view cognitive abilities as thinking skills that represent key predictors of who will emerge as a leader.

Authors have argued that certain individual differences variables (e.g., personality, gender, and race) may become less salient in teams with a high degree of virtuality (Kahai, Sosik, & Avolio, 2003; Mehra, Smith, Dixon, & Robertson, 2006; Yoo & Alavi, 2004), while others can become more salient. Cognitive ability is among the latter, as working virtually involves more information processing. In a recent study comparing leadership in face-to-face and virtual teams, where virtual teams used email and instant messaging to communicate, Purvanova and Bono (2009) indicate that communication in virtual teams is more confusing, laborious and cognitively taxing than face-to-face communication. Moreover, some of the interactions between cognitive ability and other individual differences variables might become insignificant in virtual teams and thus it would be easier to identify the main effects of cognitive ability on outcomes of interest (for example, whereas in face-to-face teams a combination of cognitive ability and extraversion may be key to leadership emergence, in virtual settings the role of extraversion may be neutralized). As such, the impact of cognitive ability on leadership emergence might be higher in virtual rather than face-to-face-settings. Thus, it is proposed that:

Hypothesis 1. *At the individual level, team type moderates the effect of cognitive ability on leadership emergence, such that the influence of cognitive ability is stronger when the team is virtual (non-co-located) than when the team is co-located (face-to-face).*

Self-efficacy

The concept of self-efficacy has been defined as a comprehensive judgment about one's capability to mobilize the motivation, cognitive resources, and courses of action necessary to perform a certain task (Bandura, 1986, 1997). Research findings have indicated that self-efficacy is a strong predictor of self-set goals, task-related effort, as well as individual task performance across various domains (Stajkovic & Luthans, 1997). Self-efficacy has also long been accepted as a predictor of leadership emergence (Gershenoff,

2003). In an experimental study of newly formed groups, Smith and Foti (1998), found that a pattern of high dominance, high general self-efficacy, and high intelligence was strongly associated with leadership emergence.

Several studies have analyzed self-efficacy in virtual settings as well (e.g., Hardin, Fuller, & Davison, 2007; Hardin, Fuller, & Valacich, 2006), and the results suggest that individual-level efficacy beliefs are stronger in traditional face-to-face environments than in virtual environments. Subjects in these experiments were instructed to use WebCT, a Web-based learning environment to communicate through a private discussion area, but were not prevented from using other types of technology to communicate. In search for the potential reasons for the difference between the two conditions, research has identified major challenges for electronic (virtual) teams in converting the individual efforts and skills of strangers into interdependent work products in a relatively short amount of time (Iacono & Weisband, 1997). Moreover, authors argue that because geographically dispersed teams lack social and nonverbal cues, the formation of deeper interpersonal relations among the members can be rather slow (Weisband & Atwater, 1999). Thus, efficacy in virtual settings can be affected by the lack of social and nonverbal cues as well. Overall, the preceding discussion suggests the following:

Hypothesis 2. *At the individual level, team type moderates the effect of self-efficacy on leadership emergence, such that the influence of self-efficacy is stronger when the team is co-located (face-to-face) than when the team is virtual (non-co-located).*

Personality

The study of personality has a long history in organizational research in which Goldberg's Five Factor (or "Big Five") approach has emerged as a conceptually sound framework for organizing a myriad of individual differences (Barry & Stewart, 1997). The five dimensions of personality revealed are extraversion, agreeableness, conscientiousness, emotional stability, and openness to experience. Although there is still debate regarding its value and validity, studies suggest fairly consistent relationships between some dimensions of the five factor model and job performance at all levels of analysis (Barry & Stewart, 1997; Neuman & Wright, 1999). Research also suggests that leadership emergence in leaderless groups is related to personality in both face-to-face and virtual teams (e.g., Anderson & Kilduff, 2009; Balthazard, Waldman, & Warren, 2009), and extraversion and conscientiousness appear to be the personality dimensions most widely analyzed in both settings.

Extraversion

Extraversion refers to the tendency to be outgoing, enthusiastic, warm, and friendly (Costa & McCrae, 1992). Extraverts are more likely to be active participants in group discussion, exhibit leader behaviors, and have a high level of intragroup popularity (Barry & Stewart, 1997). Due to high levels of group participation (Stein & Heller, 1979) and the ability to be dominant and assertive (Costa & McCrae, 1992), extraverts can emerge as group leaders and thus influence performance at all levels of analysis. This result is consistent with other research findings that have indicated that extraversion is especially important in work settings where social interaction is particularly salient (Barrick & Mount, 1991). Moreover, the type of communication media (face-to-face versus virtual) has been found to interact with extraversion in predicting transformational leadership emergence. Balthazard et al. (2009) found, in a study where participants communicated through a password-protected "chat room", that in virtual teams, large differences in extraversion levels predicted little or no differentiation in terms of perceived transformational leadership, whereas, in face-to-face teams, the same differences predicted a high level of differentiation.

Conscientiousness

Conscientiousness refers to feelings of competency, the tendency to adhere to ethical principles and obligations, high aspirations and hardworking behavior, the ability to successfully accomplish goals and tasks, and the tendency to carefully plan one's actions (Neuman & Wright, 1999). Conscientiousness has been found to correlate with increased job performance across a variety of roles and task requirements (Barrick & Mount, 1991), and authors argue that, at the individual level, conscientiousness should indicate the team members who are concerned with completing task assignments on time (Barry & Stewart, 1997). Prior research has analyzed the relationship between conscientiousness and leadership emergence as well and has revealed conscientiousness as a strong predictor of leadership emergence, sometimes even stronger than extraversion (e.g., Neubert & Taggar, 2004; Taggar et al., 1999).

Several studies that have analyzed personality in virtual settings have established its relationship with participation in computer-mediated communication (CMC). For example, Martins, Gilson, and Maynard (2004) reported that extraversion was positively related to participation in CMC groups. However, researchers suggest that certain individual differences variables may be less salient in teams with a high degree of virtuality (Yoo & Alavi, 2004), as computer-mediated communication has been viewed as fostering equal participation in discussions (Martins et al., 2004). As such, extraversion may be less salient in virtual environments. Conscientiousness, however, can operate in the other direction, as conscientious individuals can become even more focused in this context. Therefore it is proposed that:

Hypothesis 3a. *At the individual level, team type moderates the effect of extraversion on leadership emergence, such that the influence of extraversion is stronger when the team is co-located (face-to-face) than when the team is virtual (non-co-located).*

Hypothesis 3b. *At the individual level, team type moderates the effect of conscientiousness on leadership emergence, such that the influence of conscientiousness is stronger when the team is virtual (non-co-located) than when the team is co-located (face-to-face).*

Comfort with technology

The rapid spreading of modern technologies (e.g., electronic mail, voice mail, teleconferencing, and videoconferencing) has enhanced the use and demand for CMC in organizations (Olaniran, 1996). Both face-to-face and virtual teams use technology in their daily interactions. In this context, "comfort with technology is key to whether collaboration takes place" (Boettcher & Conrad, 1999, p. 90). Comfort with technology has been defined as the degree of comfort felt when using specific advanced technologies at work (DeSanctis, Poole, & Dickson, 2000). Kayworth and Leidner's (2002) study suggests that comfort with technology can have an impact on leadership emergence especially in virtual teams, where membership can be biased towards individuals skilled at learning and using new technologies.

Prior literature indicates several reasons why comfort with the medium of communication can differ in traditional face-to-face teams and virtual teams. Olaniran (1996) indicates that CMC (specific to virtual teams) may fall short on ease of use in comparison to face-to-face teams, as CMC requires a relatively higher and more formal degree of training than face-to-face communication for users to be able to use the medium, since virtual teams usually use more advanced technologies than face-to-face teams. Moreover, the accessibility to a computer terminal is a requirement in CMC and while engaged in synchronous group interaction, the tendency to wait for a response to an unanswered question/request can result in member frustration and perceived inadequacy of the medium for accomplishing the group task (Olaniran, 1996). For these reasons, the impact comfort with technology can have on organizational outcomes in general, and leadership emergence in particular, is likely to be higher in virtual than in face-to-face teams. As such, it is asserted that:

Hypothesis 4. *At the individual level, team type moderates the effect of comfort with technology on leadership emergence, such that the influence of comfort with technology is stronger when the team is virtual (non-co-located) than when the team is co-located (face-to-face).*

Density

According to Sparrowe, Liden, Wayne, and Kraimer (2001), density is analogous to the mean number of ties per group member, and the more ties individuals have with their team members, the greater the density of the network. However, Kilduff and Brass (2010) highlight the precise meaning density has in social network research: the actual number of ties in the network divided by the maximum number of possible ties. Balkundi and Harrison (2006) suggest that density of network ties is a critical variable for organizational outcomes, as it represents the flow of information and resources between and within teams. The social ties within the work teams are the informal links between team members (Balkundi & Harrison, 2006). High-density teams (where team members have many ties to one another) should have higher levels of information sharing and thus a higher level of collaboration in successfully completing tasks, while low-density teams (where individuals do not interact with many other members) may be unwilling or unable to exchange essential job-related information and knowledge (Balkundi & Harrison, 2006). Counterarguments to this idea come from early network studies, which suggest that high-density networks are also associated with process losses (e.g., Shaw, 1964).

To date, the relationship between leadership emergence and density of ties has yet to be established. However, density of ties has previously been related to leadership constructions (followers' constructions regarding the image of a leader) (Meindl, 1995) and can affect leadership emergence as well, since the higher the density of network ties is, the more frequent the communication/information sharing between team members. Based on this argument and on Kilduff and Balkundi (2011) who suggest that network variables function as moderators for team performance, under a high density of ties condition, individual differences are likely to become more salient and their impact on leadership emergence will be higher. As such, it is posited that:

Hypothesis 5. *In both co-located (face-to-face) and virtual (non-co-located) teams, density of network ties moderates the effect of cognitive ability on leadership emergence, such that the influence of cognitive ability is stronger when density is high.*

Hypothesis 6. *In both co-located (face-to-face) and virtual (non-co-located) teams, density of network ties moderates the effect of self-efficacy on leadership emergence, such that the influence of self-efficacy is higher when density is high.*

Hypothesis 7a. *In both co-located (face-to-face) and virtual (non-co-located) teams, density of network ties moderates the effect of extraversion on leadership emergence, such that the influence of member extraversion is higher when density is high.*

Hypothesis 7b. *In both co-located (face-to-face) and virtual (non-co-located) teams, density of network ties moderates the effect of conscientiousness on leadership emergence, such that the influence of member conscientiousness is higher when density is high.*

Hypothesis 8. *In both co-located (face-to-face) and virtual (non-co-located) teams, density of network ties moderates the effect of comfort with technology on leadership emergence, such that the influence of comfort with technology is higher when density is high.*

Methods

The substantive model and associated hypotheses have been tested using three different research design methods: agent-based modeling and simulation, a quasi-experimental test on student teams engaged in a class project, and a laboratory experiment also involving students.

Method 1: agent-based modeling and simulations

Combining elements of game theory, complex systems, computational sociology, emergence, evolutionary programming as well as Monte Carlo techniques (Niazi & Hussain, 2011), agent-based modeling and simulation (ABMS) has its main roots in modeling human social and organizational behavior and individual decision-making (Bonabeau, 2001). ABMS is a relatively new tool, which has recently allowed researchers in many fields to model and explore complex systems composed of interacting "agents", with the aim of evaluating their effects on the system as a whole. Agent-based models (ABMs) are increasingly being used across a variety of domains and disciplines such as finance, marketing, medical sciences, and the social sciences as well. Several social phenomena that have been already explored using this technique are the collective behavior of people in crowds, social emergence, generation of social instability, and decision-making processes (Macal & North, 2010).

In ABMs, the essential idea is that simple behavioral rules can generate complex behavior, and the process employed in ABMs is one of emergence, from a lower level of systems to a higher level. One of the main advantages of ABMs is that they allow for exploring dynamic models with a great number of variables operating under several different conditions, which are challenging to analyze using traditional approaches (e.g., field studies and lab experiments). And even when traditional techniques of collecting and analyzing data are appropriate and feasible, the use of ABMs as a preliminary test allows researchers to find out how their predictors can influence their outcomes of interest before going into the field or lab and performing tests on human subjects.

Unlike agency theory, which attempts to describe an agency relationship between a principal who delegates work and an agent who performs that work (Jensen & Meckling, 1976), in agent-based modeling (ABM), also known as individual-based modeling (IBM), the "agent" is autonomous and can be any type of individual component (software, model, individuals, groups or larger collectives, organizations, etc.) whose behavior can vary from base-level behavior rules on how to respond to the environment to complex adaptive artificial intelligence or high-level "rules to change the rules", where agents/components change their behavior as a result of prior interactions. During these interactions, agents pass informational messages and adapt their behavior according to what they learn from these messages (e.g., detection of the effects of another agent's actions). The environment can sometimes represent a geographical space (where agents have coordinates that indicate their location), a knowledge space, or have no spatial representation, in which case agents are linked together into a network in which an agent's relationship with other agents is given by the list of agents to which it is connected by network ties (Gilbert, 2008).

When developing computational models via computer simulations, researchers start with setting a target phenomenon to explore—the dependent variable or outcome of interest—and building a model of it through theoretically motivated abstraction. The model can be based on a set of mathematical equations, a statistical equation such as a regression equation, or a computer program (Gilbert & Terna, 2000). When the model is based on a mathematical equation, behavior can be inferred through a process of mathematical reasoning. When the model is a statistical equation, it can be run through a statistical analysis program (e.g., SPSS). In the case of regression equations, a vector of expected values of the dependent variable is derived, based on measured values of the independent variables. When the model is based on a computer program, behavior can be evaluated by "running" the program many times to assess the effect of different input parameters on the program's outputs. The input parameters can be based on prior empirical studies or meta-analyses.

In this study, ABM was implemented using the Python programming language (http://www.python.org/) and literature reviews were conducted to help determine parameter values to be entered into the simulations, as well as the rules for the agents' interactions. After running the program, a dataset for simulated individuals was generated in a .csv format, with all the variables employed in the model. Data analysis was subsequently performed using SPSS. Table 1 displays means and ranges for the variables employed.

Individual characteristics

Cognitive ability (CA). Individual cognitive ability follows a normal distribution with a mean of 21.75 and a standard deviation of 7.6. These values were obtained from Wonderlic reports and have been used in prior empirical studies (e.g., Taggar et al., 1999). The Wonderlic Personnel Test is a timed, 50-item cognitive ability measure widely used for pre-employment selection purposes.

Table 1
Model components based on a leadership emergence simulation heuristic.

Simulation component recommendations	Leadership emergence model	Component mean values		Component ranges	
		Face-to-face	Virtual	Face-to-face	Virtual
Individual characteristics					
Cognitive ability	Wonderlic	21.75	21.75	(0; 50)	(0; 50)
Personality	Extraversion	.5	.5	(0;1)	(0;1)
	Conscientiousness	.5	.5	(0;1)	(0;1)
Self-efficacy	High vs. low	3.89	3.89	(1; 5)	(1; 5)
Comfort with technology	High vs. low	.5	.5	(0; 1)	(0; 1)
Team characteristics					
Team type	Ftf vs. virtual	.5	.5	(0;1)	(0;1)
Network characteristics					
Density of ties	High vs. low	.5	.5	(0;1)	(0;1)

Personality (P). Individual *extraversion* and *conscientiousness* are both randomly generated by the program and their values range from 0 to 1, with 0 representing low extraversion/conscientiousness and 1 representing high extraversion/conscientiousness. Although these dimensions of personality have the same mean and ranges, in the simulations they have been assigned different weights in terms of their contribution to leadership emergence, depending on team type.

Self-efficacy (SE). Self-efficacy (SE) has been defined as an individual-level variable following a normal distribution with a mean of 3.89 and a standard deviation of .54. These values were based on the study of Chen, Gully, and Eden (2001), in which self-efficacy was measured at two different time points. We have used an average of their Time 1 and Time 2 values. Prior literature indicates that an individual's self-efficacy increases over time as they become more competent performing the team task (e.g., Pethe, Chaudhari, & Dhar, 1999). Accordingly, we increased self-efficacy value by an increment of .01 for each iteration in the simulation.

Comfort with technology (CT). Due to a lack of prior empirical studies reporting measures for this variable, it is randomly generated by the program and its values range from 0 to 1, with 0 representing low comfort and 1 representing high comfort. The value of CT was also incremented by .01 for each iteration, which reflected the findings in prior literature (Rose, Allen, & Fulton, 1999) that comfort tends to increase over time.

Team characteristics

Team type. Two codes were produced for the face-to-face and virtual teams, having different weight assignments of the contributions of the five independent variables to leadership emergence. The prior empirical studies which served as sources for weight assignment in the face-to-face environment were Taggar et al. (1999), Ritter and Yoder (2004), Smith and Foti (1998), Gershenoff (2003), and Hardin et al. (2007). Empirical research using these same variables in the virtual environment is rather scarce. The weight assignment in virtual teams was therefore guided by prior empirical studies (e.g., Balthazard et al., 2009), as well as by theory when empirical evidence was not available. The following weights were used for face-to-face/virtual teams respectively: CAW = .34/.30 (Cognitive Ability Weight), EW = .17/.09 (Extraversion Weight), CONW = .17/.22 (Conscientiousness Weight), SEW = .25/.15 (Self-Efficacy Weight), and CTW = .08/.25 (Comfort with Technology Weight).

Network characteristics

Density of network ties. Density of network ties has been computed using a built-in Python function. Its values range from 0 to 1, with higher values reflecting higher density. To allow for interaction with the five individual-level antecedents of leadership emergence, density is a contributor to the leadership emergence formula, with a .10 weight in both types of teams.

Simulation algorithm

Generally, we followed a rule-based modeling approach where we developed a set of rules that could both explain the observation of the phenomena and extrapolate its possible (i.e., future) states. The benefit of this approach is that dynamical equations (e.g., difference equations and differential equations) can quantitatively formulate complex dynamic theories. Sayama (2015) outlined a procedure for modeling that was followed in the current research: 1) define the key questions the research addresses, 2) select the right scale of microscopic components, 3) identify the structure of the system, including component identification and how components are interacting with each other, 4) define the state space of the system (i.e., what kind of dynamic states each component can take), and 5) describe how the state of the system changes over time. In the final step, models should define the dynamical rules by which the components' states will change over time via their mutual interaction, as well as define how the interactions among the components will change over time (Sayama, 2015).

In the first stage of code writing, the nodes (team members) were created. The nodes' properties in terms of the five leadership emergence antecedents were then randomly selected from either the random or the normal distribution of the variables already defined. We used unidirectional graphs for the information exchange between the nodes since any of the four team members could initiate a conversation with any of the others. Based on the four individual characteristics (cognitive ability, personality, self-efficacy, and comfort with technology) and their specific weight assignments for their contributions to leadership emergence in face-to-face/virtual teams, one or more leaders emerge in each team after a number of iterations, which in our case refer to the number of discussion rounds the teams go through before indentifying the leader(s).

A "state" variable which ranges from 0 to 1 has been created to indicate how close to becoming a leader a team member is, based on a weighted sum of its individual characteristics, and another simulation parameter, levels of "mutual influence". The first team member(s) whose "state" reaches 1, a preset value of leadership threshold, is/are recognized as leaders. This is used to represent leadership emergence. "Mutual influence", M, whose value ranges from 0 to 6, is a function of team type, number of iterations (which represents number of discussion rounds in this case) and network density. M = 0 means team members have no influence over others in the same team, and their individual personality traits and abilities are not known or recognized by the team, while M = 6 means their characteristics are well known and recognized by their team members and therefore the probability of being perceived as a leader is high.

After running the code, a Python Shell provides numeric information for each team member in terms of the antecedents of leadership emergence hypothesized and whether or not they are a leader. Visual representations of leadership emergence can also be obtained at this point. Fig. 2 below presents leadership emergence in four teams.

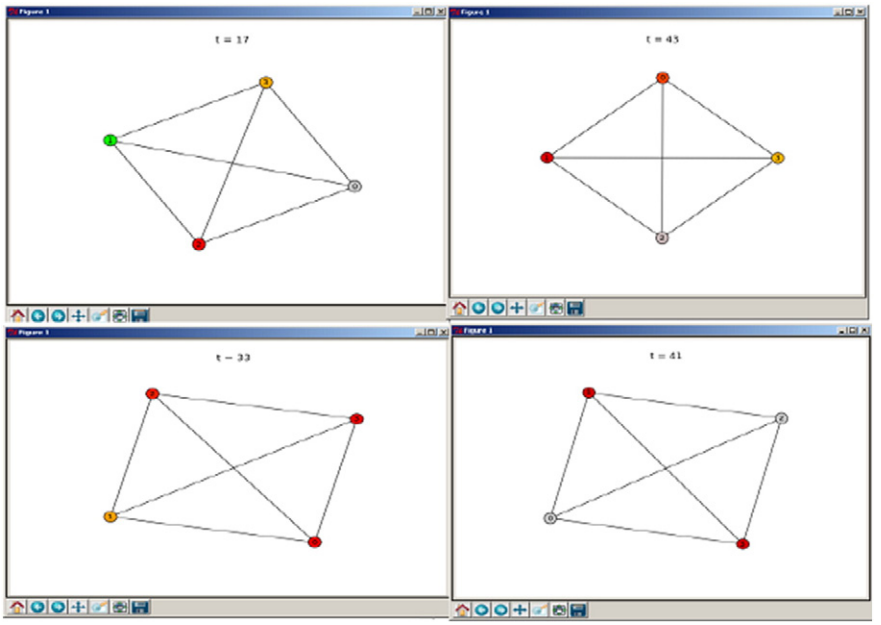

Fig. 2. Visual diagrams for the leadership emergence dynamic. Note: the figure presents leadership emergence in four teams. The top two figures indicate a full cycle and the identified leaders; the bottom left figure reflects a team which is still in process of identifying a leader, and in the bottom right figure is a team there two leaders have emerged. Color indicates leadership emergence, where cool colors (e.g., green, blue, purple) are far from emergence, warm colors (e.g., red, orange, yellow) are close to emergence, and gray indicates a leader.

Method 2: quasi-experiment and empirical tests

The data collection took place at a public research university in the Northeast United States. The sample was comprised of 201 senior undergraduate students, who received extra-credit for their participation. The average age was 20 years and most students were Finance/Accounting majors. Subjects formed 49 project-oriented teams of four or five members each. Students engaged in teamwork activities throughout a period of one semester, for the purpose of delivering a team-based project that represented 10% of their grade. At the beginning of the semester, students provided their consent for participating in the experiment and completed the 60-item NEO Five-Factor Inventory (NEO-FFI; Costa & McCrae, 1992) and a short survey assessing their self-efficacy and individual comfort with technology. They also reported individual-level variables (e.g., age, gender, race, functional background, and ethnicity). Three weeks after the beginning of the semester, the Wonderlic test was administered, as a measure of individual cognitive ability. Their team project consisted of a five-page organizational analysis of J. C. Penney Company, Inc., in which students had to provide a summary of changes in the last five years, an assessment of the current leader, as well as the outlook for the next five years in terms of four dimensions: leadership, strategy, organizational culture and organizational effectiveness.

The face-to-face teams were awarded class time to work on the projects and their progress was monitored by the class instructor. Virtual teams used Google accounts to communicate. Each team had a Google group in which all messages from each of the team members appeared in a chronological and easy to follow manner. Two facilitators (Ph.D. students) were part of each Google group and monitored the information exchange without interfering with the team conversations. Two and a half weeks after the teams were formed, team members were asked to complete a survey assessing density of network ties. At the end of the project, members were asked to report who had emerged as the informal leader of the team.

Measures

Cognitive ability. Cognitive ability was assessed with the Wonderlic Personnel Test (WPT, Wonderlic, Inc, 2003). Wonderlic scores are highly consistent with other well-recognized measures of cognitive ability, such as the Wechsler Adult Intelligence Scale and the Stanford Achievement Test (Hawkins, Faraone, Pepple, & Seidman, 1990; McKelvie, 1989).

Personality. Personality was assessed through the 60-item NEO Five-Factor Inventory (NEO-FFI, Costa & McCrae, 1992). This instrument has sound psychometric properties (Costa & McCrae, 1992; Leong & Dollinger, 1990) and is valid and reliable when administered to college students (Costa & McCrae, 1992). Scale reliabilities were .78 (Cronbach's alpha) for extraversion and .85 (Cronbach's alpha) for conscientiousness.

Self-efficacy. We used an eight-item measure of general self-efficacy developed and validated by Chen et al. (2001) ($\alpha = .87$). Sample items include, "I will be able to achieve most of the goals that I have set for myself," and "Compared to other people, I can do most tasks very well."

Comfort with technology. Comfort with technology was assessed using a scale adapted from Rodriguez, Ooms, and Montañez (2008), by asking participants to respond, on a scale of 1 to 4, how comfortable they feel with various technology tasks and tools ($\alpha = .92$). Examples of such tasks include using chat, uploading documents/files, and using a discussion forum (e.g., Google groups).

Team type. Team type was a dichotomous variable indicating weather the team had been assigned to the face-to-face (co-located) or the virtual (non-co-located) condition.

Density of ties. Density of ties was measured following the study of Neubert and Taggar (2004), by asking respondents to provide answers to two questions: "Please indicate the team members who are important resources for advice, whom you frequently interact with and on whom you can count on for work related guidance" and "Please write the names of team members who you view as allies and can count on in times of crisis." Respondents can list as many team members as they wish. The measure was standardized and computed as the proportion of actual nominations among the total possible number of nominations.

Leadership emergence. Following the study of Yoo and Alavi (2004), emergent leaders were identified by asking individual members, at the end of each project, the following question: "If you were told today to pick who has emerged as the informal leader of your team for the project, based on your experience with your team, who would you pick (including yourself)?" The variable was coded as 1 for one or more members who received the largest number of votes in each team and 0 for other members.

Method 3: lab experiment and empirical tests

The data collection was conducted at a public research university in the West Midlands region of England. The sample was comprised of 178 undergraduate and master students, who received £15 each for participation. Ninety percent of the students were between 18 and 25 years of age. The students came from a very wide range of academic programs (e.g., Economics, Accounting and Finance, History and Politics, Law, Psychology, and Mechanical Engineering). Subjects formed 47 (23 face-to-face and 24 virtual) project-oriented teams of three or four members each. The researchers aimed for four member teams. However, there are nine three-member teams in the sample due to last minute student participation cancellations. We ran all analyses with and without these teams, and the pattern of results did not change. As such, we decided to include them in the sample and results reported here.

The lab experiment lasted for 2.5 h and started by having the students complete an online individual differences survey which lasted up to 10 min, through which we collected demographic data (e.g., age, gender, academic background, race, etc.) and which assessed participants' personality, self-efficacy and comfort with technology. Next, the paper-based Wonderlic test was administered for another 12 min, as a measure of individual cognitive ability.

After collecting these, team members were given 5 min to read the task scripts and started working on the team task, which involved generating a business project proposal for a prototype of an Automatic Post Office. This task has previously been used in experiments by Olson, Olson, and Meader (1997) and Purvanova and Bono (2009).

After 5 min of individual reading and thinking time, team members started working together on the task. In the case of face-to-face teams, members' interactions were audio recorded, and they had letter tags on their shirts and addressed each other as team members A–D. In the virtual condition, the team members interacted via Xchat, an IRC (Internet Relay Chat) program for Linux and Windows. Team members' IDs were suggestive of their teams and who they were within their team (e.g., Team25MemberA). Aside from the chat, virtual team members also had a shared file for the business proposal. Even though the participants were allowed to work individually on parts of the project, they were instructed to have everything in the one shared file at the end of the experiment. To avoid issues related to members writing in the file at the same time (e.g., overwriting), we password protected the documents and students could only work in their team's document one at a time. They had to inform the team via chat when each of them opened the file. After editing the file, saving it and closing it, they also had to inform the other team members that the file was available for editing by someone else.

About 50 min into the task, for up to 5 min, participants were interrupted to complete a second online survey, assessing their team efficacy, cohesion and trust, after which they resumed their work on the task. Participants were alerted when they had 25 min left for the task, and then again at 10 min and 5 min. After the task, for about 10 min, they had to complete the third and last online survey, assessing leadership emergence, leader centrality and density of network ties.

All measures used in the lab experiment study were the same as those used in the quasi-experimental study with the exception of personality, for which, in the interest of time, we used the Big Five Inventory (Benet-Martínez & John, 1998; John, Donahue, & Kentle, 1991; John, Naumann, & Soto, 2008) instead of the NEO-Five Factor. Sample items are: "I am someone who is talkative", "I am someone who perseveres until the task is finished". The following internal consistency coefficients (α's) were obtained: .83 for extraversion, .79 for conscientiousness, .86 for self-efficacy and .90 for comfort with technology.

Results

Tables 2a, 2b, and 2c and Tables 3a, 3b and 3c present the descriptive statistics and correlations for the simulations and experimental studies, as well as reliability coefficients of the measures used in the quasi-experiment and laboratory experiment, overall and split by team type, respectively. For the simulations, we have used a cap of 50 discussion rounds to identify the emergence of a leader or shared leadership emergence. All of the relationships were in the expected direction. When analyzing the correlations by team type,

Table 2a
Descriptive statistics and correlations for the overall model—simulations[a].

	Variable	Mean	S.D.	1	2	3	4	5	6	7
1	Cognitive ability	21.68	7.57							
2	Extraversion	.50	.29	.01						
3	Conscientiousness	.50	.29	.00	.01					
4	Self-efficacy	4.36	.47	−.02*	.01	.01				
5	Individual comfort with technology	.88	.16	.01	.00	−.01	.01			
6	Team type	.50	.50	.01	.01	.01	.00	−.02		
7	Density of ties	.59	.18	.00	.38**	−.02	.00	.01	.02*	
8	Leadership emergence	.51	.50	.44**	.14**	.02	.01	.00	.60**	.36**

[a] N = 8000.
* $p < .05$.
** $p < .01$.

we found that cognitive ability, extraversion, and density of ties were significantly correlated with leadership emergence in both face-to-face and virtual teams. The relationship between comfort with technology and leadership emergence was significant in face-to-face but not virtual teams. In the quasi-experimental study, we found significant correlations between leadership emergence and extraversion, conscientiousness and self-efficacy, respectively, in face-to-face but not virtual teams. As for the experimental study, we found significant correlations between cognitive ability and leadership emergence and extraversion and leadership emergence, in face-to-face but not in virtual teams.

For all three methods, we used Fisher's Z test to determine whether the difference between a simple correlation coefficient in face-to-face teams versus its analogue in virtual teams was significant. We also used Student's *t* tests to determine whether the slopes for within-cell (team type) regressions are statistically different. Both Fisher's Z test and Student's *t* test results converge and indicate that, in the simulated data, there is a significant difference between face-to-face and virtual teams in terms of the relationship between cognitive ability and leadership emergence ($Z = 7.02$, $p < .01$; $t = 2.83 > 2.58$), extraversion and leadership emergence ($Z = -1.84$, $p < .05$; $t = -2.4 < -1.96$) and comfort with technology and leadership emergence, respectively ($Z = -2.24$, $p < .05$; $t = -2.05 < -1.96$). We obtained no such differences in the quasi-experimental study. However, a significant difference between face-to-face and virtual teams in terms of the relationship between cognitive ability and leadership emergence was obtained again in the laboratory experiment study ($Z = 1.75$, $p < .05$; $t = 1.91 < 1.65$).

To test Hypotheses 1–8, because emergence is a dichotomous 1–0 variable, hierarchical logistic regression analysis was employed. Table 4 presents these results. We found direct effects for cognitive ability and extraversion in the simulations, for extraversion, conscientiousness and self-efficacy in the quasi-experimental study, and for cognitive ability and extraversion in the experimental study. In terms of the moderation effects of team type on these relationships, in the simulations we found significant interactions between cognitive ability, extraversion and, self-efficacy (as independent variables) and team type. As such, Hypotheses 2 and 3a were supported for the simulations. The moderation effects put forth by Hypothesis 1 were not supported in the data; however, the direction was different, with the relationship being stronger in face-to-face than in virtual teams. Contrary to our hypotheses and what correlations split by team type suggested, team type was not found to significantly moderate these hypothesized relationships in the quasi-experimental and experimental studies.

Significant interactions were found between density of network ties and cognitive ability and self-efficacy in the simulated data. As such, Hypotheses 5 and 6 were supported in this context. The quasi-experimental study supported the moderating role of density of network ties between extraversion and leadership emergence as the dependent variable. Therefore, the quasi-experimental study supported Hypothesis 6.

We also used computational modeling for an additional analysis of the evolution of leadership emergence over time. In this case, we used leadership "state" as a dependent variable, and considered leadership emergence to be continuous, indicating how far a team member is from reaching the leader level. We use three different times for the purpose of comparison: at 25, 50 and 75 discussion

Table 2b
Descriptive statistics and correlations for the overall model—quasi-experimental[a].

	Variable	Mean	S.D.	1	2	3	4	5	6	7
1	Cognitive ability	24.19	6.11							
2	Extraversion	30.80	6.20	.03	(.78)					
3	Conscientiousness	31.95	6.94	.24**	.21**	(.85)				
4	Self-efficacy	4.00	.51	.25**	.37**	.56**	(.87)			
5	Individual comfort with technology	3.61	.55	.23**	.22**	.31**	.17*	(.92)		
6	Team type	.51	.50	.10	.00	−.13	.11	.06		
7	Density of ties	.50	.17	.30**	−.02	.22**	.00	.16*	−.12	(.79)
8	Leadership emergence	.24	.43	.05	.16*	.21**	.20**	.09	.00	.00

[a] N = 201. Reliabilities (α's) are in parentheses.
* $p < .05$.
** $p < .01$.

Table 2c
Descriptive statistics and correlations for the overall model—experimental[a].

	Variable	Mean	S.D.	1	2	3	4	5	6	7
1	Cognitive ability	29.00	5.66							
2	Extraversion	3.33	.70	−.17*						
3	Conscientiousness	3.60	.64	.10	.18*					
4	Self-efficacy	3.91	.53	.05	.34**	.18*				
5	Individual comfort with technology	3.59	.48	.13	.16*	.07	.15			
6	Team type	.51	.50	.12	.02	−.06	.02	−.06		
7	Density of ties	.54	.14	.08	.10	.02	.07	.03	.29**	
8	Leadership emergence	.30	.46	.12	.24**	.09	.07	.14	−.02	.02

[a] N = 178. Reliabilities (α's) are in parentheses.
* $p < .05$.
** $p < .01$.

rounds/iterations. While we found several constantly significant main effects (e.g., cognitive ability: β = .02**, .02**, .02**, $p < .01$ at time 25, 50, 75, respectively) and interactions across time, we also found interactions that changed over time. As such, the interactions between team type and cognitive ability and extraversion, respectively, as well as the interactions between density of ties and cognitive ability and extraversion, were significant at all three time points (team type * cognitive ability: β = −.01**, −.01**, −.01**, $p < .01$ at time 25, 50, 75, respectively; team type * extraversion: β = −.18**, −.17**, −.18**, $p < .01$ at time 25, 50, 75, respectively; density * cognitive ability: β = −.01**, −.01**, −.02**, $p < .01$ at time 25, 50, 75, respectively; and density * extraversion: β = −.25*, −.25*, −.32*, $p < .05$ at time 25, 50, 75). However, the relationship between density of ties and self-efficacy was significant at 25 (β = −.03*, $p < .05$), but not 50 and 75 iterations (β = −.02, −.01, $p > .05$ at time 50 and 75 respectively). Moreover, the interaction between comfort with technology and density is not significant at 25 and 50 iterations, but significant at 75 iterations (β = −.03, $p > .05$; β = −.06, $p > .05$, β = −.09*, $p < .05$ at time 25, 50 and 75 respectively). Fig. 3 presents the simulated evolution of leadership emergence in face-to-face and virtual teams over time.

A summary of results from all three methods/studies is presented in Table 5. This table and the key findings (or lack thereof) form the basis of the discussion that follows.

Discussion

Studies focusing on the relationship between cognitive traits and leadership emergence and performance have a long history and consistently indicate that cognition is a very strong antecedent of both emergence and performance (Mumford, Campion, & Morgeson, 2007). Intelligence, as a cognitive individual differences variable, has probably received the most research attention of all the facets of cognition and is considered a critical determinant of leader emergence (Mumford et al., 2007). Our study serves to reinforce these findings by means of both agent-based modeling and experimental data, where cognitive ability was found to have direct effects on leadership emergence.

A major contribution of the current research to the literature on leadership emergence, however, is exploring the role of team type (face-to-face vs. virtual) as a contextual moderator for the cognitive ability/intelligence–leadership relationship. Based on the idea that the uncertainty and ambiguity associated with working in a fully virtual environment (where communication is done via email and chat) will enhance the need for leader cognition and strengthen the relationship between intelligence and leadership emergence, we had hypothesized that the influence of cognitive ability on leadership emergence would be stronger in virtual (non-co-located) than in face-to-face (co-located) teams. However, we found the opposite effect: the relationship seems to be stronger in face-to-face teams, revealing that cognitive ability is more salient in this context and contributes to an individual's dominance or acknowledgement/recognition as a leader. There are two possible, and not mutually exclusive, explanations that draw from two major leader cognition theories—implicit leadership theory and cognitive resources theory.

Table 3a
Descriptive statistics and correlations by team type—simulations[a].

Face-to-face/Virtual									
	Variable	Mean	S. D.	1	2	3	4	5	6
1	Cognitive ability	21.77/21.59	7.60/7.53						
2	Extraversion	.50/.50	.29/.29	.02/00					
3	Conscientiousness	.50/.49	.29/.28	−.02/.02	−.02/.04**				
4	Self-efficacy	4.36/4.36	.48/.47	−.03/−.02	.01/.02	.02/.01			
5	Individual comfort with technology	.87/.88	.16/.16	.02/.00	.02/−.01	−.02/−.01	.00/.01		
6	Density of ties	.60/.59	.19/.18	.00/.00	.37**/.38**	−.03/−.01	−.02/.02	.01/.00	
7	Leadership emergence	.81/.21	.39/.41	.60**/.49**	.15**/.19**	.00/.02	.00/.02	−.04**/−.01	.36**/.51**

[a] N = 8000.
* $p < .05$.
** $p < .01$.

Table 3b
Descriptive statistics and correlations by team type—quasi–experimental[a].

Face-to-face/Virtual									
	Variable	Mean	S. D.	1	2	3	4	5	6
1	Cognitive ability	23.56/24.81	6.12/6.08						
2	Extraversion	30.83/30.78	6.18/6.25	−.01/.08					
3	Conscientiousness	32.88/31.06	6.49/7.27	.33**/.18	.18/.24*				
4	Self-efficacy	3.95/4.06	.51/.51	.30**/.20	.28**/.45**	.68**/.49**			
5	Individual comfort with technology	3.58/3.64	.59/.50	.19/.26*	.20*/.24*	.38**/.27*	.17/.17		
6	Density of ties	.52/.48	.19/.16	.34**/.29**	−.15/.12	.25*/.18	.01/.01	.16/.19	
7	Leadership emergence	.24/.25	.43/.43	.04/.06	.26**/.06	.22**/.20	.27**/.13	.06/.12	.00/.00

[a] N = 102/99. Reliabilities (α's) are in parentheses.
* $p < .05$.
** $p < .01$.

First, it may well be that the lack of social cues associated with working in a fully virtual condition makes team members pay more attention to accomplishing the task and to the frequency with which team members contribute to the discussion rather than to whether their teammates are making intelligent contributions or they perceive them to be intelligent at all. According to findings from the implicit leadership theory literature, people attach leadership ability to those they perceive as intelligent, and vice versa (Judge, Colbert, & Ilies, 2004). Thus, if social cues regarding intelligence are not as readily available, as they may be in the virtual environment, perceptions of these individuals as emergent leaders may not be as strong.

While the first explanation focuses on team members' *perceptions* of the emergent leader's intelligence, the second focuses on the possible explanation that intelligence is actually related to leader emergence more strongly in face to face teams than virtual teams. While it may seem that the relationship between intelligence and emergent leadership would be stronger in virtual teams because the environment may be more ambiguous and intelligence would facilitate problem solving, evidence from research on cognitive resources theory (Fielder, 1995) might help explain why it was actually face-to-face teams that saw the stronger effect. According to the cognitive resources theory research (Fielder, 1995) the influence of intelligence on leadership performance is stronger under conditions of low stress—when individuals have time to engage in deliberate problem solving. In conditions of high stress, which the complex environment of virtual teams may elicit, leaders rely more on experience than cognitive ability. Another possible caveat is that the virtual conditions applied in the present studies were low fidelity relative to real virtual teams. Organizational virtual teams often times use a wide range of technology, varying from email, which is low on both media richness (Daft & Lengel, 1986) and media synchronicity (Dennis & Valacich, 1999) to videoconferencing, which is high on both. It is entirely possible that increasing media richness and media synchronicity for communication will make intelligence become more salient in the virtual environment and will increase its likelihood to become a strong predictor of leadership emergence in this context as well.

Aside from cognitive ability, we have explored several other antecedents of leadership emergence: personality, through two of its facets (extraversion and conscientiousness), self-efficacy and comfort with technology. We acknowledge the fact that these do not represent an exhaustive list of antecedents of leadership emergence, as nomination criteria. There can be other factors that can significantly contribute to a team member being recognized as a leader under different tasks (e.g., age, gender, race, functional background or expertise). The choice to focus on five determinants only (cognitive ability, extraversion, conscientiousness, self-efficacy and comfort with technology) has been based on prior literature which has incorporated various degrees of virtuality. This way we were able to establish parameter values and rules of interaction for computational modeling and compare face-to-face and virtual teams through this method, as well as subsequent quasi-empirical and empirical tests.

Personality and self-efficacy have been extensively associated with leadership emergence in both face-to-face and virtual teams, and although the role of comfort with technology as an antecedent for leadership emergence had not yet been explored, prior literature had suggested that comfort with technology may be key to whether collaboration takes place (Boettcher & Conrad, 1999). As such, we decided to incorporate it in our model. While self-efficacy did emerge as an antecedent of leadership emergence in the

Table 3c
Descriptive statistics and correlations by team type—experimental[a].

Face-to-face/Virtual									
	Variable	Mean	S. D.	1	2	3	4	5	6
1	Cognitive ability	28.33/29.66	5.23/6.00						
2	Extraversion	3.32/3.35	.71/.70	−.09/−.24*					
3	Conscientiousness	3.57/3.62	.60/.68	.11/.08	.09/.26*				
4	Self-efficacy	3.90/3.92	.46/.60	.07/.03	.24*/.43**	.40**/.40**			
5	Individual comfort with technology	3.62/3.56	.36/.57	.13/.15	.36**/.04	.29**/.16	.32**/.07		
6	Density of ties	.50/.60	.11/.16	.18/−.03	.04/.14	.14/.07	−.05/.12	.02/.07	
7	Leadership emergence	.31/.29	.46/.46	.26*/.00	.28**/.20	.08/−.08	.13/.04	.09/.18	−.03/.06

[a] N = 88/90. Reliabilities (α's) are in parentheses.
* $p < .05$.
** $p < .01$.

Table 4
Hierarchical logistic regression analyses predicting leadership emergence with team type as moderator.

Variable	Simulations (Time 50)			Quasi-experimental/Experimental data		
	Block 1	Block 2	Block 3	Block 1	Block 2	Block 3
Independent variable						
Cognitive ability	.15**	1.01**	.49	−.01/.07*	−.01/.07*	−.03/.13*
Extraversion	1.21**	.14	1.41	.03/.93**	.03/.93**	.09/1.19*
Conscientiousness	.13	.46*	4.13	.07*/−.29	.08*/−.29	.08/.30
Self-efficacy	.10	1.02**	−5.15	.33/−.05	.26/−.04	.88/.04
Comfort with technology	−.04	.41	−29.20	.02/.49	.01/.48	−.39/−.61
Moderation						
Team type		16.08**	364.67**		.17/−.16	.16/−.13
Density of network ties		32.11**	728.13**		−.37/.04	−1.34/.22
Cognitive ability × team type			11.17**			.03/−.11
Extraversion × team type			10.43**			−.09/−.22
Conscientiousness × team type			−3.06			−.00/−1.1
Self-efficacy × team type			13.04**			−.81/−.05
Comfort × team type			12.85			.68/1.65
Cognitive ability × density of ties			27.49**			.04/.04
Extraversion × density of ties			6.43			.46*/−.31
Conscientiousness × density of ties			17.74			.13/2.72
Self-efficacy × density of ties			22.97**			2.07/−2.36
Comfort × density of ties			43.97			−1.32/−2.96
Df	5	7	17	5	7	17
Chi^2	1935.44**	9627.23**	11035.28**	13.89*/17.73**	14.25*/17.91*	29.36*/27.91*
−2Loglikelihood	9152.54	1460.75	52.69	196.44/199.06	196.08/198.87	180.96/188.87
Cox & Snell R square	.22	.70	.75	.07/.10	.07/.10	.14/.15
Nagelkerke R square	.29	.93	1.00	.11/.14	.11/.14	.21/.21

Entries represent unstandardized regression weights.
N = 5000 for simulations; N = 49 for quasi experimental data; N = 47 for laboratory experiment data.
* $p < .05$.
** $p < .01$.

quasi-experimental data, comfort with technology was not related to leadership emergence in either the simulations or the quasi-experimental and experimental data. This may be due to the sample being comprised of students of similar ages, which are likely to have similar levels of comfort with technology as well. Perhaps a more diverse sample in terms of academic level or age would yield different results.

As for the role of personality, conscientiousness was related to leadership emergence only in the quasi-experimental data, but we have found extraversion to be a consistent predictor of leadership emergence across studies. It seems that more than making intelligent contributions to the discussion or being focused on the task and providing task-relevant inputs, exhibiting high levels of group

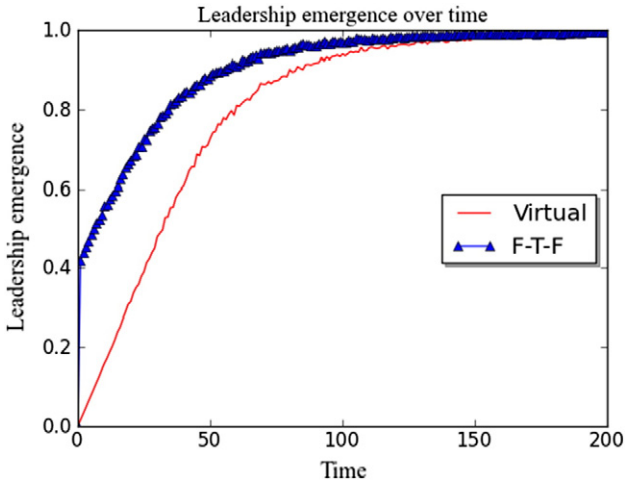

Fig. 3. Evolution of leadership emergence in face-to-face and virtual teams. Note: the figure displays leadership emergence in face-to-face and virtual conditions. Values of leadership "state", ranging from 0 to 1, were used as scores of leadership emergence. Each data point on each curve represents an averaged score of leadership emergence of 4000 individuals within each condition.

Table 5
Summary of results.

Hypotheses	Moderator	Direct effect support			Hypothesis support		
		Simulations	Quasi-experimental	Experimental	Simulations	Quasi-experimental	Experimental
H1: CA → LE	Team type	Yes	No	Yes	Yes	No	No
H2: SE → LE		No	No	No	Yes	No	No
H3a: E → LE		Yes	No	Yes	Yes	No	No
H3b: C → LE		No	Yes	No	No	No	No
H4: CT → LE		No	No	No	No	No	No
H5: CA → LE	Density of ties	Yes	No	Yes	Yes	No	No
H6: SE → LE		No	No	No	Yes	No	No
H7a: E → LE		Yes	No	Yes	No	Yes	No
H7b: C → LE		No	Yes	Yes	No	No	No
H8: CT → LE		No	No	No	No	No	No

CA—cognitive ability; SE—self-efficacy; E—extraversion; C—conscientiousness; CT—comfort with technology; LE—leadership emergence.

participation is a key to being regarded as a leader by others. As prior literature suggests, this personality characteristic is less salient in the virtual environment, but still important. Our agent-based simulation results indicate that team type moderates the relationship between extraversion and leadership emergence, the relationship being stronger in face-to-face teams.

In terms of the lack of a moderating effect of team type on the relationship between personality and leader emergence it may be that even though the relationship between extraversion and conscientiousness and leader emergence does not change in different team environments, the *way* personality affects leader emergence does change. Extraverted individuals may be more skilled communicators in either face-to-face or virtual environments (Mumford, Zaccaro, Connelly, et al., 2000; Mumford, Zaccaro, Johnson, et al., 2000; Zaccaro, Mumford, Connelly, Marks, & Gilbert, 2000).

The difference between a lack of moderation in the present study and the significant moderation found by Balthazard et al. (2009) may be explained by the different outcomes used in each study. Balthazard et al. used a measure of perceived transformational leadership, a more complex construct than the dichotomous variable used in the present study. Thus it seems that extraversion is related to leader emergence generally but more strongly related to perceptions of exceptional leadership in environments where face-to-face interactions occur. This makes sense given the complexity and "intangibleness" of transformational leadership behaviors (Hater & Bass, 1988; Rafferty & Griffin, 2004).

Conscientiousness exerted a significant main effect on leader emergence only in the quasi-experimental study. Compared to the other two studies, this was the only study where participants engaged with their teams over an extended period of time. It may be that more time and a greater number of interactions are required for team members to make assessments of someone as being hard working and diligent. For example, because highly conscientious people are careful and thorough, it may take longer for their efforts to translate into performance or, in the present study, into being perceived as a leader (Yeo & Neal, 2004). Moreover, as with extraversion, how conscientiousness is related to emergence may differ in virtual teams versus face-to-face teams, even though the strength of the relationship is the same.

In terms of team type acting as a moderator for leadership emergence, our simulation results have revealed that aside from significant interaction effects between team type and cognitive ability and extraversion, respectively, the relationship between self-efficacy and leadership emergence is stronger in virtual than in face-to-face teams. It seems that, in an environment characterized by ambiguity, being confident in succeeding to accomplish a task may make one engage in more leadership behaviors and thus more likely to be acknowledged as a leader at the end of the task. However, our quasi-experimental and experimental data failed to provide support for the moderating role of team type for all other antecedents except cognitive ability. In this case, when using additional tests (Fisher's Z test and Student's *t* test), we found a significant difference between face-to-face and virtual teams. From the lack of significant differences in terms of the other leadership emergence antecedents, we may infer that face-to-face and virtual teams are similar in terms of a variety of individual differences, which may be transferable between the different media/virtualities.

Because team processes and social networks evolve over time, we used simulations to determine whether certain interaction effects between team type and the antecedents of leadership emergence change over time. However, we found that interactions between team type and cognitive ability and team type and extraversion, respectively, are significant and fairly stable. As such, in order to increase the likelihood of leaders possessing such traits to emerge in virtual teams as well, a recommendation would be to, at strategic points in time at least, use technologies high in media richness and synchronicity (e.g., videoconferencing).

As for the moderating role of density of network ties, in the simulations we found significant interactions between density of network ties and cognitive ability, as well as density of network ties and self-efficacy. The quasi-experimental data indicated a significant interaction between extraversion and density of ties with leadership emergence. Depending on the nature of the task or work employed, if these are the desired characteristics of the team leader, a higher communication between team members should be fostered.

As in the case of team type, we also used simulations to determine whether the interactions between density and the hypothesized leadership emergence predictors change over time. Our results indicated that the interaction between self-efficacy and density is significant initially, but becomes insignificant afterwards, while the interaction between comfort with technology and density of ties becomes significant over time. As such, the hypothesized interaction effects may depend on the different time points at which measures

are collected. To increase rigor, future research can indicate the stage of the project at which they expect the moderating effects to appear and design longitudinal studies to capture these variables' changes over time.

In terms of limitations, there are several associated with this research that are worthy of being acknowledged. First, while results of the three different studies revealed common characteristics of emerging leaders (e.g., extraversion), some predictors of leadership under one method failed to appear as such in others (e.g., conscientiousness, self-efficacy). Also, we had differences in the significant interaction terms across the three types of studies. As such, there is somewhat limited cross-validation of results across study designs that could be explored further in future work.

Second, for both the simulations and the experimental studies, the models are oversimplified and interpretations are limited to the conditions and model properties represented by the models. There might be other factors affecting the relationships between the variables analyzed in these studies that have not been accounted for. As Kerr and Tindale (2004, p. 642) indicated, "A common criticism of much small-group research is that it oversimplifies an obviously complex set of processes." Beyond the variables included in this study, other factors could serve as mediators or moderators. Some examples include culture, gender, race, or trust for leadership emergence, and task interdependence and shared mental models for team performance. As such, future research may want to add other relevant variables, to obtain better theoretical completeness and higher methodological rigor. Although this shortcoming restricts the usefulness of the results, there is consensus among researchers that dynamical models which simulate organizational phenomena are still at an initial, preliminary stage (Dionne, Sayama, & Yammarino, 2009). Simplification is helpful in providing the robust, parsimonious and interpretable models in this preliminary stage; and simulations provide valuable information for future work using other research designs.

Another limitation arises from the value of key parameters employed in the simulation. These values are generated by a program, and reflect a pattern that may be found in teams, but is not tied to specific empirical evidence. Admittedly, varying values—for example, considering a different weight for the influence of personality in the leadership emergence process—have the potential to produce significantly different results. However, that is not to say there is little utility in this approach in modeling reality.

Robustness of a model is how insensitive the model's prediction is to minor variations of model assumptions and/or parameter settings. This is important because there are always errors when creating assumptions about, or measuring parameter values from, the real world (Sayama, 2015). If a prediction made by a model is sensitive to minor variations of assumptions and parameters, then conclusions derived from the model are probably not reliable. However, if a model is robust, conclusions will hold under minor variations of model assumptions and parameters. In this event, because the model likely applies to reality too, we can have more trust in its efficacy. Thus, following a typical cycle for rule-based modeling closely approximates a typical cycle of scientific discovery (Sayama, 2015), which aids in building robust models.

Moreover, to develop the external validity and generalizability of computational model results, Dionne and Dionne (2008) suggest that "field studies must be a next step in the research process." Because of this, we have used the quasi-experimental and experimental studies to further test the model simulated via agent-based modeling, and we obtained some consistent findings but also some divergent results as well.

Fourth, in terms of the role of comfort with technology, this variable did not emerge as a significant predictor in the experimental study in either type of team and may be due to the sample being comprised of students of similar ages, which are likely to have similar levels of comfort with technology as well. Perhaps a more diverse sample in terms of academic level or age would yield different results.

Fifth, with regard to personality, because prior literature indicates extraversion and conscientiousness as strong predictors of leadership, particularly emergent leadership, these have been the traits selected to represent personality in the simulation. However, it is entirely possible that other dimensions of the Big Five would be highly related to leadership emergence in both face-to-face and virtual teams. Openness to experience is likely to be another trait that could be salient in both types of teams. As such, future ABM-based studies can either replace one or both personality characteristics that we have used or add other characteristics contributing to leadership emergence.

Sixth, our quasi-experimental study sample consisted of only 49 groups for both the face-to-face and the virtual conditions, and our laboratory experiment study sample consisted of 47 teams for both conditions. Future research may want to increase the sample size to obtain higher statistical power.

Another limitation is associated with the difference in terms of density of network ties' meaning across studies and the way in which it was operationalized: whereas in the simulations density was computed using a built-in Python function, for the experimental and quasi-experimental data collected, density was based on participants' answers regarding whom within the team they saw as allies, resources for advice, whom they frequently interacted with and on whom they could count on for work related guidance. While in computational modeling density reflects only frequency of interaction, the emphasis in the quasi-experimental and experimental data is also on the quality of the relationship. This may explain why we have obtained different results in terms of the role of density of ties in the simulations vs. the real data.

Lastly, pure face-to-face and virtual teams are rarely used, and a combination of face-to-face and virtual interaction is more likely to occur in teams operating in an organizational setting. Moreover, virtual teams continue to evolve in terms of the technologies used (e.g., some use, beyond phone calls and videoconferencing, virtual environments such as Second Life, which imitates the real world and is full of animations and allows for any type of virtual social interaction). As such, our research on and understanding of virtual teams will need to continue to keep up and a good place to start would be analyzing leadership and team processes in teams of various degrees of virtuality. Agent based models can help researchers easily manipulate different degrees of virtuality and provide a good base for predictions of how different variables can interact to predict performance before pursuing field and lab studies in this

direction. We hope the ideas and three studies reported here will encourage future researchers to explore the intricacies associated with leadership emergence in various types of teams.

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