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Shared Cognitive–Emotional–Interactional Platforms: Markers and Conditions for Successful Interdisciplinary Collaborations

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Abstract

Given the growing centrality of interdisciplinarity to scientific research, gaining a better understanding of successful interdisciplinary collaborations has become imperative. Drawing on extensive case studies of nine research networks in the social, natural, and computational sciences, we propose a construct that captures the multidimensional character of such collaborations, that of a *shared cognitive–emotional–interactional* (SCEI) *platform*. We demonstrate its value as an integrative lens to examine markers of

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and conditions for successful interdisciplinary collaborations as defined by researchers involved in these groups. We show that (1) markers and conditions embody three different dimensions: cognitive, emotional, and interactional; (2) these dimensions are present in all networks, albeit to different degrees; (3) the dimensions are intertwined and mutually constitutive; and (4) they operate in conjunction with institutional conditions created by funders. We compare the SCEI platforms to available frameworks for successful interdisciplinary work.

Keywords
interdisciplinarity, interdisciplinary research, collaboration, disciplines, disciplinary culture, interdisciplinary cognition, knowledge production, emotion and cognition, boundary work, research evaluation

Shared Cognitive–Emotional–Interactional (SCEI) Platforms

Interdisciplinarity is increasingly viewed by North American scientific funding agencies and policy makers as the philosopher's stone, capable of turning vulgar metals into gold. Interdisciplinary research is often described as conducive to creativity, progress, and innovation (Bruce et al. 2004; European Union Research Advisory Board [EURAB] 2004; Huutoniemi et al. 2008; Jacobs and Frickel 2009). While academic strategic plans and funding agencies have committed more resources to interdisciplinary research and graduate training (Bruun et al. 2005; Feller 2002, 2006; Leahey and Moody 2014; Hackett and Rhoten 2009; National Science Foundation [NSF] 2006), the number of interdisciplinary collaborations, centers, interinstitutional teams, and university–industry partnerships has steadily increased (Leahey and Moody 2014; Wuchty, Jones, and Uzzi 2007). Unsurprisingly, interdisciplinarity itself has also attracted considerable attention among scholars (Bergmann et al. 2012; Brint et al. 2009; EURAB 2004; Klein 2013; National Academies 2005; Paletz and Schunn 2010; Weingart 2010), some of whom are studying the challenges of supporting and assessing the quality of interdisciplinary work (Boix Mansilla 2006; Boix Mansilla, Feller, and Gardner 2006; Feller 2002; Lamont, Mallard, and Guetzkow 2006; Lamont, 2009; Laudel 2006; Leahey and Moody 2014; Pachucki, Pendergrass, and Lamont 2007; Wagner et al. 2011). In this context, understanding what defines successful interdisciplinary collaborations and how participants achieve it has become imperative.

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Recognizing the difficulty of reaching consensus over a definition of interdisciplinary research (Frodeman 2010; Klein 1996, 2012; Kockelmans 1979; Lattuca 2001; Organization for Economic Cooperation and Development/Center for Educational Research and Innovation [OECD/CERI] 1972; Jacobs and Frickel 2009; O'Rourke et al. 2014), we here adopt the one proposed by the US National Academies (2005, 2):

> [Interdisciplinary research] is a mode of research by teams or individuals that integrates information, data, techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance a fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline.[1]

In this article, we respond to the call by Powell, Owen-Smith, and Smith-Doerr (2011), Jacobs (2014), Leahey (2008), and others for a more integrated sociological approach to interdisciplinarity. Drawing on extensive case studies of nine research networks in the social, natural, and computational sciences supported by three institutions (the Canadian Institute for Advanced Research [CIFAR], the MacArthur Foundation, and the Santa Fe Institute [SFI]), we propose the analytical construct of an SCEI platform to capture multidimensional processes of interdisciplinary collaboration. The concept refers to a collaboratively constructed and shared "platform" that serves both as a *space* in which researchers practically engage one another to work on a common problem and as a *basis* that organizes their behaviors and activities. In this shared space, researchers define problems to study, exchange expertise, build personal relations, project and maintain academic self-concepts, and yoke for status; what they create together constitutes a basis that shapes how they collaborate with each other—such as shared language, key concepts, tacit rules of interaction, group culture and identity, and collective mission. The concept of an SCEI platform highlights the lived reality of interdisciplinary collaboration as it unfolds by encompassing (1) a *cognitive dimension* captured, for instance, by the notion of a "trading zone" (Galison 1997); (2) an *emotional dimension* captured by Parker and Hackett's (2012) study of emotions in interdisciplinary research teams; and (3) an *interactional dimension* captured by the notion of "interactional expertise" (Collins and Evans 2007; Collins, Evans, and Gorman 2010). We advance these contributions by demonstrating how central aspects of interdisciplinary collaboration—such as how participants define success and set objectives, pursue them, and understand they have achieved them—are simultaneously cognitive, emotional, and/or interactional in

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character. Moreover, with the concept of platform, we hope to describe what is both a site of and springboard for collaborative activities—a dynamically coconstructed space with a set of rules and objectives that members develop—and both resultant of and contributing to collaboration.[2]

Data suggest that members of interdisciplinary projects bring their respective disciplinary cognitive tools, exchange ideas, revise, and recast. In interacting around questions and findings, they feel joy and tensions and develop shared identities. Moreover, as voluntary participants in collaboration, they engage in give and take, develop a flexible and practical orientation toward shared goals, and deploy knowledge in a way that helps the group. They are expected to contribute and adjust to evolving intellectual objectives and styles of interaction and deliberation. Interactions unfold at the intersection of what is being studied, who is studying, and what kinds of emotional dynamics are at play. These interactions are enabled by particular institutional contexts set up by funders. Thus, researchers interact on an SCEI platform shaped by funding institutions.

We examine how interdisciplinary collaboration works and makes a case for the notion of SCEI platforms, focusing on two key aspects researchers emphasize: what signals interdisciplinary success (''markers'') and what facilitates such success (''factors''). The networks studied are regarded as successful by funders and by standard academic measures (publications and policy impact). By analyzing participant accounts, we identify how each network sought such success. We also show that:

1. Markers of and factors for successful interdisciplinarity encompass three dimensions: cognitive, emotional, and interactional.
2. The cognitive, emotional, and interactional are present for all networks to different degrees: respondents across networks associate successful interdisciplinary collaboration with features such as their substantive impact on subsequent research, participants' excitement, and interaction styles that enable mutual learning.
3. The cognitive, emotional, and interactional dimensions operate in conjunction with institutional conditions established by funders. These include rules and organizational context for collaboration, material and organizational resources, and institutionalized expectations about collaborations communicated to researchers.
4. The cognitive, emotional, and interactional dimensions are intertwined and mutually constitutive (Sewell 1992). While analytically distinct, in practice these dimensions are deeply entangled, structuring each other and informing the recruitment of members, as

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intellectual caliber, likeability, and sociability are considered. These dimensions are also intertwined in participants' descriptions of the cooperation necessary for intellectual integration.

The first section locates our research in the literature. The second section describes our methodological approach and data. The third section presents our empirical findings, starting with the role of institutional settings for successful interdisciplinary collaborations. It then introduces the three dimensions of SCEI platforms that were identified inductively, demonstrates their presence across networks, and shows that they are intertwined and mutually constitutive. The fourth section draws conclusions and proposes a future research agenda.

Toward a Multidimensional Approach

A growing literature on collaboration has been informed by perspectives distinctively illuminating functional, structural, psychodynamic, and symbolic dimensions of collaborations (Poole and Hollingshead 2005). Functional approaches have focused on inputs, outputs, and group procedures, bringing a normative emphasis to such phenomena as collective information processing (Stasser and Titus 1985) and groupthink (Janis 1982; van Knippenberg, De Dreu, and Homan 2004). Classic psychodynamic studies have favored the analysis of emotional, unconscious processes underlying the more rational and conscious interactions between group members (Bales and Cohen 1979). Social identity and power-centered approaches have explored how individuals construe their participation, belonging, and status (Poole and Hollingshead 2005). Beyond studies of collaboration *writ large*, investigators of *interdisciplinary* collaborations have focused on demands of integrative knowledge production such as understanding methods and assumptions of disciplines or arrangements that facilitate cross-disciplinary dialogue (Holland 2014).

Cognition

Cognitive approaches to interdisciplinary research have emphasized the nature of knowledge and its representation, exchange, integration, and validation (Boix Mansilla 2010; Frodeman 2010; Klein 1996). Drawing on interviews and observation data from leading interdisciplinary research centers, Boix Mansilla (2002), Nikitina (2005), and Miller (2006) have shown that experts employ multiple *disciplinary integration styles*—conceptual bridging, aesthetic synthesis, comprehensive, and practical. Each stresses distinct *cognitive processes* for integration and concomitant validation criteria. The

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cognitive criteria for validating interdisciplinary work—for example, disciplinary coherence, pragmatic balance, and cognitive advancement—differ from the commonly used quality proxies such as publication number, funding success, and institutional prestige (Boix Mansilla 2006).

In recent years, scholars have focused on cognitive *integration* as key to interdisciplinary work (Bammer 2013; Bergmann et al. 2012; O'Rourke, Crowley, and Gonnerman 2016; Klein 2012; Repko 2012). Their views differ in the degree to which they view integration as the ultimate aim of interdisciplinary work or a means to deeper understanding. They also differ in their more linear and algorithmic versus more heuristic and iterative view of the process by which integration happens. For his part, Holbrook (2013) questions the centrality of cognitive integration in interdisciplinary work and its concomitant assumption of consensus. All too often, he explains, disciplinary insights prove simply incommensurable. His analysis, however, sidesteps the pragmatic disposition that often leads interdisciplinary scholars to find "workable" rather than idealized integrative solutions (Lamont 2010).

Philosophically inspired, Dominic Holland (2014) points to epistemological demands of successful interdisciplinary work—that is, uncovering, logical relations, alignments, and contradictions underlying different ideas and units of analysis. Holland recognizes scientific inquiry "presupposes an underlying context of (interdependent) social structures—such as recognition and reward, academic employment, the scientific division of labour" (Holland 2014, Kindle Locations 2384-2386), but he does not address how microsocial interactions shape and are shaped by the intellectual work pursued.

Also prioritizing cognition in social processes of knowledge, studies of *social cognition* and *distributed expertise* show how cognitive apprenticeships, such as collaborations in teaching, enable experts to learn intellectual practices in neighboring domains (e.g., analysis styles and disciplinary languages) essential for interdisciplinary exchange (Lattuca 2001; Lave and Wegner 1991). Studies highlight the role of metacognitive capacity in monitoring cross-disciplinary information processing within groups, integrative products (e.g., shared constructs and methods) that make tacit disciplinary knowledge explicit and enable integration (Bromme 2000, 119; Clark 1992; Derry, Schunn, and Gernsbacher 2005).

Science studies too have examined cross-disciplinary knowledge exchange. Galison's (1997, 783) concept "trading zone" describes how scientists and engineers from different disciplinary cultures collaborate. Studying the development of radar detectors and particle accelerators, he found that researchers in different communities developed a common local language to get around what Kuhn ([1962] 1996, 148) had described as

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"incommensurability" between research paradigms. Drawing on anthropological linguists' work on local language practices in border zones, Galison (1997) describes how researchers from "quasi-autonomous" domains with distinct scientific languages, subcultures, and institutional groundings coordinate intellectual exchange without having to establish comprehensive mutual understanding and agreement. In the trading zone, shared linguistic and procedural practices bind researchers together who can exchange ideas and practices, even when they may "ascribe utterly different significance to the objects being exchanged" or disagree about "global" meanings of constructs (Galison 1997, 783; Galison 2010).

In sum, much work on interdisciplinary collaborations examines their cognitive aspects. While some constructs extend beyond the cognitive realm and point to the role of social interactions in knowledge exchange, with a few notable exceptions (Parker and Hackett 2012; Thagard and Kroon 2008), this literature takes the emotional counterpart of cognition for granted.

Emotion

As Parker and Hacket (2012) point out, the emotional dimension of science was an important area of concern and inquiry for such earlier scholars as Weber ([1918] 1946) and Merton (1973), but research on emotions and research on science have since been done mostly separately, and very limited work has been done to theorize the relationships between the two. As notable exceptions, some students of knowledge production have followed Weber who viewed science as a passionate enterprise. Scheffler (1986, 348) has argued that certain emotional dispositions underlie commitments to rationality, suggesting that academic work is anchored in "cognitive emotions" such as "the joy of verification" (p. 354), while Neumann (2006) called this anchor "passionate thoughts" (p. 381). Elgin (1999) has pointed to the frustration of cognitive dissonance and the anxiety generated by cognitive overload, while Csikszentmihalyi (1990) discussed the satisfying peak experience of "flow" and the joy of engaging meaningful issues.

From a different approach, neuroscientists have argued that emotions serve an orienting function in cognitive endeavors, through selective attention and encoding memories in the brain (Immordino-Yang and Fischer 2009). Because emotions underlie prior experience, they orient researchers' sense of which lines of thought, theories, or questions are resonant and worth pursuing. During the moment-to-moment thinking in the creation of a framework or the resolution of a problem, emotions encode tacit knowledge; they offer visceral markers of "a sense that we are moving in the

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right direction" (Immordino-Yang and Fischer 2009, 313), "helping [researchers] to call up information and memories that are relevant to the topic or problem at hand" (ibid).

In social and cultural studies, in an emerging "affective turn" (Ahmed 2004, 2010; Harding and Pribram 2009; Gregg and Seigworth 2010; Liljeström and Paasonen 2010), more researchers are considering the role of emotions in shaping processes of collaboration. Attending to the unique demands of interdisciplinary collaborations, Griffin, Bränström-Öhman, and Kalman (2013) draw on cultural theories of affect to explore how emotions are articulated, mobilized, and practiced in research collaboration showing that how emotions work (Hochschild 1979) varies under different conditions. They describe their own experience of factoring time to negotiate differences in working styles, disciplinary paradigms, and institutional positioning. They also point to emotional tensions "experienced as stress, frustration and competitiveness" arising from the contradictory demands experienced by collaborating scholars (Griffin, Bränström-Öhman, and Kalman 2013, Kindle Locations 306-308). Interdisciplinary researchers must manage their intellectual excitement while recognizing that disciplines provide the conceptual structures for productive exchange (Hollingsworth and Hollingsworth 2000).

Characterizing the role of emotions beyond individual cognition, Thagard and Kroon (2008) have documented consensus building in a group as "the result of at least partial convergence of beliefs and emotional values" (p. 66). In their model cognitive consensus is complemented by "emotional consensus building," a process by which group members come to share positive and negative feelings about different actions and goals. Studying interdisciplinary funding panels, Lamont (2009) observed comparable calibration processes, arguing that emotions are an essential dimension of academic selves that shape the work of interdisciplinary panels: " . . . evaluation is a process that is deeply emotional and interactional. It is culturally embedded and influenced by the 'social identity' of panelists—that is, their self-concept and how others define them" (Lamont 2012, 8).

In their study of retrospective accounts of highly cited scientists describing aspects of their work, Kopmann, Cain, and Leahey (2015) show that norms for appropriate emotional expressions pervade researchers' accounts across hard and soft disciplines but vary in content. For example, psychologists associated emotion with having an original idea in contrast with physicists whose joy was expressed when verifying a hypothesis. Similarly, researchers studying organisms (people, animals, and plants) characterized these in more emotional terms than those who studied molecules, atoms, or particles (Kopmann, Cain, and Leahey 2015).

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With a focus on the role of emotions in interdisciplinary work, Parker and Hackett (2012) liken interdisciplinary collaborations to intellectual social movements (Frickel and Gross 2005): "[emotions] catalyze and sustain creative scientific work and fuel the scientific and intellectual social movements that propel scientific change" (p. 1). Their microsociological case study shows that, to be successful, groups must produce specific forms of emotion: flow, "interpersonal trust," "commitment to ideas," and "grievances against dominant intellectual trends." Such emotions enable researchers to navigate the dual process of conceiving creative ideas and managing skepticism. Their work concurs with a renewed focus on *emotion* in hiring (e.g., Rivera 2012), culture (Illouz 2007), social movements (Goodwin, Jasper, and Polleta 2001), and knowledge-making practices (Camic, Gross, and Lamont 2011). Yet, how emotions shape cognitive innovation and social dynamics in interdisciplinary work remains underexplored, thus the importance of a close analysis of these relationships.

Interaction

Scholars studying academic collaboration have examined the social character of interdisciplinary work. Sociologists have studied the complex relationship between the steady growth in collaborative research in the social and natural sciences on the one hand and norms of productivity, originality, and individual career paths on the other (Jacobs and Frickel 2009; Leahey and Moody 2014; Rhoten and Pfirman 2007). In a comprehensive review of this research, Leahey and Moody (2014) identified contradictory trends: while organizational ecology research finds that individuals conduct collaborative interdisciplinary work at a cost (i.e., having to master multiple areas of scholarship and be reviewed across fields [Hannan 2010]), research on networks, diversity, and recombinant innovation shows high levels of productivity, originality, and growth associated with cross-disciplinary expert interactions (Hargadon 2002; Powell, Owen-Smith, and Smith-Doerr 2011). Leahey and Moody (2014, 14) calls for research on the "moderating conditions" that mediate collaborative arrangements and their outcomes, "We need to theorize (and [. . .] investigate) the role of mechanisms [e.g., cognitive integration, perceived novelty, institutional logic, or network position] in producing effects [e.g., productivity, academic careers, original work, diffusion of ideas]."

Scholars of the collective production of artistic, scientific, and interdisciplinary knowledge drew inspiration from the social movement literature (Frickel and Gross 2005). They have demonstrated how collaborators construct and sustain *collective effervescence* through face-to-face interaction

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(Parker and Hackett 2012) and share superordinate goals uniting their collective work while also maintaining disparate interests (O'Mahoney and Bechky 2008), and how power relations, networks, and institutional forces mediate success (Powell, Owen-Smith, and Smith-Doerr 2011).

Considering interaction and cognition, Collins and Evans (2007) focus on "interactional expertise"—the "kind of expertise that bridges distinct [disciplinary] practice through a deep sharing of discourse" (p. 53). It involves the capacity to "walk the talk of such expert community, just as one can watch, understand, and discuss a tennis match without being a great tennis player" (p. 7). It enables members of distinct disciplinary cultures to participate in productive conversations, without "contributory expertise" in each other's domain.

If sharing discourse is the cornerstone of interactional expertise, sharing objects is no less significant. Star and Griesemer (1989) coined the notion of "boundary objects" to describe shared cognitive/interactional foci of knowledge that are plastic enough to be interpreted differently by relevant actors, yet robust enough to maintain a unity across contexts. Extending this notion, Guston (2001) and O'Mahoney and Bechky (2008) examined how "boundary organizations" create more or less stable environments that enable collaborations across fields, providing "a mechanism that reinforces convergent interests while allowing divergent ones to persist" (p. 426): these organizations "trigger adaptation around key organizing domains; they delineate boundaries between convergent and divergent interests, and they provide a durable structure to reinforce mutual adaptation" (p. 452).

Finally, turning *emic* attention to the inner workings of expert collaborations, cultural sociologists have sought to understand social interactions from the perspective of collaborators themselves. Lamont (2009; see also Lamont, Mallard, and Guetzkow 2006) has shown how members of interdisciplinary review panels construe panel-specific notions of excellence and originality through the process of face-to-face deliberation (see also Hirschauer 2009). Panelists bridge disciplinary cultures and epistemological positions while together developing shared rules of deliberation that facilitate agreement—for example, respecting the sovereignty of other disciplines, deferring to colleagues' expertise, bracketing self-interest and disciplinary prejudices, and promoting methodological pluralism.

Multidimensional Approach

While studies of interdisciplinarity have generally examined the three crucial dimensions of collaboration by privileging one analytical dimension or

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two at a time, empirically based approaches are rare. As an exception, Stokols' ecological model of transdisciplinary science (Stokols, Hall, et al. 2008; Stokols, Misra, et al. 2008) provides an etic view of interdisciplinary collaborations, aiming to specify contextual factors that may promote or impede the success of collaboration. Stemming from studies of cancer research at the National Institutes of Health, this model identifies intrapersonal, interpersonal, and organizational factors and even considers physical–environmental, technological, and sociopolitical factors.

Yet no previous empirical study has considered in tandem the respective roles of cognitive, emotional, and interactional dynamics in successful interdisciplinary collaborations, taking the researchers' construal of their experiences as a point of departure. Exploring the researchers' lived experiences, this article complements the current literature on interdisciplinary collaborations by demonstrating their multidimensional character, the dynamics of their three dimensions, and the institutional conditions that shape such dynamics.

Methods and Data

We examined markers of and conditions for successful interdisciplinary collaborations by drawing on extensive case studies of nine research networks of the CIFAR, the MacArthur Foundation, and the SFI. A cross-case approach can capture each network's complexity and reveal contextual forces that shape individuals' experiences in them.

These three institutions were chosen based on their comparability: they are among the most renowned North American promoters of interdisciplinary research; they have brought together leading experts to conduct interdisciplinary research that has had a considerable impact on numerous fields in the natural and social sciences; and they incentivize participation with material support and opportunities to work with prominent researchers. Institutions enabled and nurtured collaborations, setting parameters for success. Their investments varied in amount and duration. They differed in how they put research teams together and the type of control they exercised on the networks. They also varied the conditions they set for teams. For instance, one funder encouraged the pursuit of "big questions," while another one expected collaborative outcomes to have a visible impact in society; still a third one sought projects that were innovative and exploratory, advanced by just-in time, established, smaller-scaled, and shorter-termed networks. As we will discuss, institutional support played a key role in setting up a context in which the collaboration took place.

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The research networks were selected in consultation with the funding institutions based on comparability, suitability, and willingness of researchers to participate. We also aimed to capture a broad range of disciplinary collaborations, while seeking cross-institutional comparability in themes addressed. Table 1 provides this information.

These networks had existed for one to eight years at the time of data collection. Each included eight to fifteen members and brought together scholars from at least three disciplines, qualifying as interdisciplinary by most standards and also being described as such by their members and funders. Most networks convened regularly in various locations to discuss ongoing research and to develop collaborations. Funders viewed such networks as tools for shaping the research frontier of particular fields and offered different types of compensation: some supported specific research projects and meeting costs, while others provided participants resources for their own work.

By comparing nine networks, we identify inductively markers and conditions that are salient across cases (Corbin and Strauss 1998), drawing on five types of data: (1) Internet information concerning our informants including publications, institutional affiliations, biography, and academic interests, (2) publications, particularly those written in collaboration with network members or that concern the network's focal topic, (3) observations of five networks' meetings, where they hosted external speakers, deliberated on their input to the problem under study and planned future meetings (4) questionnaires administered to network members concerning their involvement in the network, the perceived dynamics of the group at work, their efforts to integrate disciplines, and structures for support, and (5) semistructured interviews concerning markers and factors facilitating successful interdisciplinary collaborations. We asked respondents to describe their experience of collaboration, their objectives, how they defined a successful interdisciplinary collaboration, and what they believed affected their group in achieving such success. The interviews were conducted with fifty-seven network members[3] typically during or within two to three weeks following a network meeting.[4] Interview questions expanded the data from the questionnaire, allowing for multiple opportunities for deeper probing and clarification concerning markers and factors of SCEIs. While interviews constitute the article's primary empirical basis, respondents' perspectives were analyzed and interpreted in the context of the broader knowledge we acquired about each network. Even if the number of respondents in each network is small, we could identify the differences and similarities across

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Table 1. Selected Interdisciplinary Research Networks.

CIFAR	McArthur	SFI
Successful societies Seeks to understand the determinants of societal success. It builds on the premise that social experience is central to well-being and affected by both institutional arrangements and the cultural frameworks used to interpret it. This network seeks to inform policy on matters of a society's health.	**Early experience and brain development** The goal of this network is to study the relationship between brain and behavioral development, to clarify the role of experience in brain development, and to enhance the understanding of how neurobiological development and behavioral development are linked.	**Urban growth and social dynamics** Examines scaling patterns and projections of growth in social organizations and urban development. This network builds on a major SFI effort to understand the origin of scaling laws in biology and use the paradigm to formulate general principles of biological structure and organization.
Social interactions and well-being Seeks to investigate the social forces that are lacking in current economics and that affect people's happiness and well-being. The program seeks to extend the toolkit of economics and other social sciences, enabling a more comprehensive view of motivation and well-being that will in turn help people live more contented lives.	**An aging society** Examines many critical issues surrounding the social, economic, and institutional implications of an aging society. For instance, how will the aging of society impact those in various socioeconomic groups disparately? The network seeks to identify the modifications required in our major societal institutions to facilitate emergence of a productive, equitable aging society in the United States.	**Complexity and the gene concept** Examines the complex relationship between genome-level sequences and phenotypic structures and functions. The network seeks to establish a new conceptual model for genetics that is better able to account for the one-to-many and many-to-one mappings from sequence to structure and function, and better able to capture the dynamical and logical nature of gene expression.
Genetic networks Devoted to discovering how genes interact with one another, with the	**Adolescent development and juvenile justice** Seeks to expand the	**Geochemical origins of life** Seeks to understand the origins and essential

(continued)

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Table 1. (continued)

CIFAR	McArthur	SFI
hope of identifying the root causes of many genetic diseases and leading to new treatments and preventive measures.	base of knowledge about the origins, development, prevention, and treatment of juvenile crime and delinquency. The network also strives to disseminate that knowledge to professionals and the public and improve decision making in the justice system.	properties of life. Members ponder whether life is a natural and perhaps necessary outgrowth of first principles in physics and chemistry, whether life can be synthesized, and what can minimal life forms, like viruses, reveal about life's fundamental properties.

Note: CIFAR = Canadian Institute for Advanced Research; SFI = Santa Fe Institute.

networks, given the extensive case study of each network that we conducted (Boix Mansilla, Lamont, and Sato 2010).

We conducted two rounds of systematic content analysis of responses and transcripts. After the first round, we revised our coding scheme and the second round came to focus on explicit references to cognitive, emotional, and social markers and factors for success in interdisciplinary collaborations.[5] Employing a grounded theory approach to conceptualization and data reduction (Glaser and Strauss 1967; Miles and Huberman 1994), we constructed and revised our notion of SCEI platforms through iterative analyses. We then systematically compared networks, while triangulating qualitative elements that emerged from the analysis and the frequency each element was invoked.

Institutional Context: Shaping SCEI Platforms

Our three funding organizations set different objectives and use different approaches to fund and organize the work of their interdisciplinary research groups. Unsurprisingly these frame the networks' definitions of successful interdisciplinary collaboration, patterns of interaction, levels of mutual interdependencies, and modes and time horizons for product delivery and accountability. These, in turn, enable and constrain the cognitive, emotional, and interactional dimensions of collaborations, shaping the group's collaborative space.[6]

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The majority (56 percent) of our respondents discussed the funder's effective investment as a condition for their success. Modes of funding vary and are closely connected to different general objectives that funders pursue, which have significant ramifications for group dynamics, the qualities of leaders, and styles and practices of actual collaboration.

Respondents pointed to the importance of alignment between individuals, groups, and institutional missions for successful collaborations. For instance, one funder encourages the pursuit of big questions. While his organization does not require specific member collaboration or deliverables, its members are aware that they are expected to produce significant intellectual contributions together, necessitating several meetings a year. Its long-term funding commitment and explicit support for big questions afford network members the luxury of gradually zeroing in on shared problems of study, instead of starting with a narrow research proposal with predefined objectives. In the process they develop shared interests, a group identity, a common language, group rules, personal trust, and a sense of community. Funding to individual researchers allows them to hire postdocs, support their summer research, or reduce their teaching obligation at their home universities for their research. The emphasis on "big picture" questions certainly entails a risk of not producing coherent or policy-relevant research but encourages innovation in a unique way. One respondent shared:

> I must confess at first I was surprised at the lack of more concrete requirements and felt quite vague about what we were supposed to be doing, though I really enjoyed all the discussions and was getting lots of new ideas, etc. Now, I think that not imposing a set of specific deliverables is very freeing. There is more space to take academic risks.

In contrast, the second funder is more explicit about its expectation of collaborative outcomes having practical and direct implications for society. This is evident in how its members defined their success: their shared moral commitment to changing the world for the better fuels their collaborative efforts. One respondent said:

> I think everyone in the group was open to finding out new things, and ... using information and knowledge to have some positive effect. Part of that, I think, are the selection and the push from the foundation to do policy relevant work and to [do] work that matters in the real world. So that may be just a selection issue, but the group was composed of people who wanted to have their work make a difference ...

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Conversely, the third institution supports highly innovative exploratory research projects without imposing concrete deliverables, with smaller-scaled and shorter-termed networks created on the basis of specific demands. Its "venture-capital" approach and limited resources cultivate a distinct intellectual climate in its networks. Participants are highly dependent on each other for complementary expertise and put more emphasis on cognitive markers of success than members of other groups. While limited funding imposes challenges, it also fosters a certain sense of commitment ("I don't think anyone here does it for money") and allows a kind of flexibility only possible in the absence of onerous obligations to the funder. Many participants emphasize their enthusiasm about their pioneering work, embracing a distinct collective identity as institute affiliates. One respondent said:

> A lot of people here are very respectable and we do scholarly work. But the idea is that ... you're not stopped by the fact that there are questions outside your domain ... you just go, "OK, that's an interesting question. What do people know about that question?" You ask around ... And the big question is usually enough.

Furthermore, institutional expectations can be a productive catalyst for integration. One network published a book that recapitulated the intellectual advances from their first five-year term to facilitate the renewal for a second term. The book's deadline served as a powerful incentive to intensify integrating efforts and emotional and interactional connections among the members, helping develop a stronger collective identity.

Writing on epistemological cultures, Knorr-Cetina (1999) discusses the "technologies" that constrain and enable research in the case of high-energy physics and molecular biology. She addresses modes of coordination and evaluation, such as peer review, processes by which various resources are distributed, organizational supports, and requirements for group meetings. Similarly, we find that institutional factors have direct impact on the composition and sustenance of interdisciplinary collaborations. Respondents considered effective management and investment as a critical condition for their group's success. Characteristics of funding practices and foundation expectations crucially shape intellectual enterprises, group culture and identity, and working styles of interdisciplinary collaborations. As such, they are constitutive of the successful collaborations here examined.

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Three Dimensions of Successful Interdisciplinary Collaborations

> I strongly believe that a common language needs to be developed within any group undertaking interdisciplinary research. Our group, I think, is an excellent example of a successful group as we are able to discuss topics with different disciplinary viewpoints [e.g., psychology versus economics]. The key in our group is that the main directors are willing to let go of the reins and let the group discover questions, topics, and criticisms of research. There is no domineering personality or "research turf" needing defending.

> I found it really nice to be with a whole group of economists who were willing to talk about things like well-being and identity. . . . It just felt really, kind of, affirming.

Descriptions such as these were common among respondents depicting successful interdisciplinary collaboration. Success is associated with cognitive qualities of the collaboration, such as the richness of diverse disciplinary viewpoints, commonly constructed research questions, and a common language. They refer to positive feelings of openness and self-affirmation and interactional aspects of success including the group's capacity to exchange and explore together. Cognitive, emotional, and interactional dimensions are fundamental aspects of interdisciplinary collaboration and of the shared working space that researchers create and sustain—our SCEI platforms. While arguably, these three dimensions might be present in all collaborations, interdisciplinary or not, how such dimensions are interpreted and configured by participants to address specific demands of interdisciplinary collaborations are of interest here.

Below, we summarize our empirical results. We show that, as the quotes above suggest, markers of success and conditions for success as defined by researchers themselves concern all three dimensions of collaboration. These dimensions are present for all our networks, albeit in varying degrees, suggesting variations across SCEI platforms. We also show how, while analytically distinguishable, the three dimensions are deeply intertwined and mutually constitutive in reality. Tables 2 and 3 indicate the relative frequency with which members discussed nine markers of success and sixteen factors of success, which we have identified through inductive analysis and intercoder validation. Markers and factors are arranged by their primary SCEI dimension, with reference to secondary dimensions.[7] For instance, Table 2 shows that across networks, most researchers (67 percented) pointed to the quality of cross-disciplinary exchange as a marker of success.

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Table 2. Markers of Success.

Groups \ Dimensions[b]		Primarily Cognitive[a]					Primarily Emotional		Primarily Interactive	
		Cross-disciplinary exchange C, (I)	Generativity beyond program C	Shared intellectual tools C, (I)	Excellent and relevant expertise C	Knowledge advancement C	Collective excitement E, C, I	Joy in collaboration E, I	Group deliberation and learning competency I, C	Meaningful relationships I, (C), (E)
A	$n = 11$	5	0	2	0	6	3	0	7	6
	%	46	0	18	0	55	27	0	64	55
B	$n = 9$	5	3	3	1	3	3	2	7	2
	%	56	33	33	11	33	33	22	78	22
C	$n = 7$	6	5	3	4	3	4	4	4	3
	%	86	71	43	57	43	57	57	57	43
D	$n = 6$	5	5	3	6	2	4	0	4	2
	%	83	83	50	100	33	67	0	67	33
E	$n = 5$	5	5	4	2	3	4	1	4	2
	%	100	100	80	40	60	80	20	80	40
F	$n = 7$	7	1	3	5	0	5	4	2	2
	%	100	14	43	71	0	71	57	29	29
G	$n = 7$	2	4	2	1	0	3	2	0	0
	%	29	57	29	14	0	43	29	0	0
H	$n = 5$	3	2	3	2	3	3	3	2	1
	%	60	40	60	40	60	60	60	40	20
Total	$N = 57$	38	25	23	21	20	29	16	30	18
	%	67	44	40	37	35	51	28	53	32

Note: Most relevant dimensions are listed first; secondary dimensions are listed in parentheses.
[a]Each marker is heuristically categorized for its most relevant dimension.
[b]Dimensions are cognitive (C), emotional (E), and interactive (I).

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Table 3. Factors that Facilitate Success.

Groups	Dimensions[b]	Primarily Cognitive[a]						Primarily Emotional	Primarily Interactive							
		Relevant cognitive qualities C	Clear collective mission C, I	Productive problem framing C	Shared intellectual tools C, (I)	Iterative knowledge construction C, I	Search for interdisciplinary integration C	Positive feelings about project members and self (e.g., trust, respect, admiration, and recognition) E, I, (C)	Climate of conviviality I	Social-interactive qualities of participants I	Effective leadership I, (C)	Meaningful personal relations I, (C), (E)	Group Identity I, C, E	Complementary team roles I, C	Socializing outside meetings I	Group working styles and routines I, (C)
A	$n = 11$	5	1	3	1	2	4	4	2	3	2	1	1	1	2	2
	%	46	9	27	9	18	36	36	18	27	18	9	9	9	18	18
B	$n = 9$	5	2	2	3	0	0	6	6	4	5	2	2	2	3	1
	%	56	22	22	33	0	0	67	67	44	56	22	22	22	33	11
C	$n = 7$	4	5	4	3	3	3	3	2	4	3	4	2	3	3	3
	%	57	71	57	43	43	43	43	29	57	43	57	29	43	43	43
D	$n = 6$	5	6	6	4	5	5	6	5	5	6	1	3	3	2	5
	%	83	100	100	67	83	83	100	83	83	100	17	50	50	33	83
E	$n = 5$	5	4	3	4	3	3	5	4	4	4	4	3	0	3	2
	%	100	80	60	80	60	60	100	80	80	80	80	60	0	60	40
F	$n = 7$	7	6	4	4	5	1	6	7	7	6	6	2	6	2	0
	%	100	86	57	57	71	14	86	100	100	86	86	29	86	29	0
G	$n = 7$	4	6	6	2	2	2	1	2	1	2	1	0	0	0	0
	%	57	86	86	29	29	29	14	29	14	29	14	0	0	0	0
H	$n = 5$	2	3	3	3	3	3	2	2	1	0	1	0	0	0	1
	%	40	60	60	60	60	60	40	40	20	0	20	0	0	0	20
Total	$N = 57$	37	33	31	24	23	21	33	30	29	28	20	13	15	15	14
	%	65	58	54	42	40	37	58	53	51	49	35	23	26	26	25

Note: Most relevant dimensions are listed first; secondary dimensions are listed in parentheses.
[a]Each factor is heuristically categorized for its most relevant dimension.
[b]Dimensions are cognitive (C), emotional (E), and interactive (I).

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Asked about contributing factors, most (65 percent) also pointed to group members' intellectual stature and composition as Table 3 shows.

Table 4 presents the percentage of our respondents who touched on each of the three dimensions at least once in describing what constitutes successful interdisciplinary collaboration (markers) and what facilitates it (factors). This corroborates that the majority of respondents addressed the three dimensions of SCEI platforms when characterizing markers of success. It also shows varying degrees of convergence on informants' perceptions of collaborative success.

Markers of Success

Cognitive Markers

> Successful collaboration, for me, does not necessarily involve coauthorship. Indicators of successful collaboration would also include individual new ideas/projects that are influenced by the group discussions and activities.

Predictably, our respondents mentioned various cognitive elements as markers of successful interdisciplinary collaboration: (1) cross-disciplinary exchange that transforms individual research, (2) the project's intellectual generativity beyond its formal purpose and funding period, (3) the development of shared intellectual tools that serve as the common ground for exchange, (4) excellence and relevance of the disciplinary expertise contributing to the collaborative research, and (5) knowledge advancement through integrating different disciplinary perspectives. (These five cognitive markers of success were mentioned by between 67 percent and 35 percent of our respondents. See Table 2.)

This emphasis on collaborative platforms that enable knowledge advancement is expected, as the networks are created explicitly for cognitive advancements. The use of relevant disciplinary expertise and shared intellectual tools was also important for our respondents. For instance, in describing a successful investigation, a pediatrician pointed to the complementarity of various types of disciplinary expertise feeding the project:

> The [existing members of the network] were serious neurobiologists, right? And we had people who study human attachment … [We had the] right developmental psychologists, who studied fully social development, [and] who then would be interested in [the] brain.

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Table 4. Three Dimensions in Markers of and Factors for Success.

Groups	Dimensions	Markers of Success			Factors of Success		
		Cognitive	Emotional	Interactional	Cognitive	Emotional	Interactional
A	$n = 11$	8	3	9	6	5	9
	%	73	27	82	55	45	82
B	$n = 9$	7	3	7	7	6	7
	%	78	33	78	78	67	78
C	$n = 7$	7	5	5	6	4	5
	%	100	71	71	86	57	71
D	$n = 6$	6	4	6	6	6	6
	%	100	67	100	100	100	100
E	$n = 5$	5	4	4	5	5	5
	%	100	80	80	100	100	100
F	$n = 7$	7	5	6	7	6	7
	%	100	71	86	100	86	100
G	$n = 7$	6	2	4	7	1	7
	%	86	29	57	100	14	100
H	$n = 5$	3	3	3	3	2	3
	%	60	60	60	60	40	60
Total	$N = 57$	49	29	44	47	35	49
	%	86	51	77	82	61	86

Note: This table presents the number and ratio of our respondents who invoked markers of and factors for success that encompass each of these dimensions. For instance, a respondent is counted if any of the markers of success she mentioned touched on an emotional dimension. To gauge the prevalence of each dimension conservatively, we have only counted a dimension when it is considered one of the "primary" dimensions, that is, those that are not in parentheses in Tables 2 and 3.

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Emotional Markers

Respondents also brought up emotions as means to gauge collaborative success. They discussed pleasure in revisiting topics of long-term interest through a new lens or in experiencing the "steep learning curve" in learning another discipline. More than half (58 percent) of informants mentioned collective intellectual excitement resulting from commitment to interdisciplinary collaboration as a marker of success, while a quarter (28 percent) mentioned the joy of collaboration itself. A geriatric expert stated:

> It was a very compatible group. I think everyone liked each other and the meetings were enjoyable, and it was really quite a collegial, and also, just a sort of a socially compatible group. So we really jelled as a very successful group of colleagues. . . . It was just a lot of fun.

The salience of the emotional dimension in interviews is noteworthy, given the limited attention on emotions in the literature on collaboration (Kellogg, Orlikowski, and Yates 2006), the sociology of higher education, and the sociology of science, where noncognitive factors have often been described as "subjective" or as "corrupting" science (Merton 1973), that is, as orthogonal to rationality (see Lamont 2009; but see Shapin 1995).

Emotions are also a powerful source of cognitive and interpersonal bonds, as argued below. Not surprisingly, emotional markers were rarely mentioned in isolation, given the social nature and explicit cognitive objectives of interdisciplinary collaborations. In fact, intellectual substance and social relations provided the context of emotions.

Interactional Markers

As shown in Table 4, 77 percent of respondents mentioned interactional markers of success at least once. As shown in Table 2, half (53 percent) of them highlighted the group's growing competency for deliberation and learning from each other, and 32 percent mentioned the development of meaningful social relations with group members. For instance, a respondent stated:

> [The collaboration] allowed me to establish *deep and lasting interactions with the members of the network* (our emphasis). Because I know their research very deeply and I know where it interfaces with mine, and because I'm very comfortable in talking with and interacting with these people, it really has opened up these paths of communication with people in areas of

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> research that I would normally have no contact at all with. . . . We know about each other's histories and families and where we're coming from and things. That just improves *the quality with which we can interact* (our emphasis) and it also increases the longevity of the interaction. We just want to stay in contact with these people.

Factors for Success

Conditions for successful interdisciplinary collaboration also embodied cognitive, emotional, and interactive dimensions. Respondents mentioned mostly cognitive and interactive factors but also highlighted the role of positive emotions as facilitating forces in collaborative space.

Cognitive Factors

As shown in Table 4, the majority (82 percent) of our respondents mentioned cognitive factors at least once. In particular, 65 percent of them explained the success of interdisciplinary collaborations with cognitive qualities of participating members such as intellectual open-mindedness and specific disciplinary expertise essential for the project (see Table 3). They valued having a clear collective mission (58 percent) and a productive problem framing (54 percent) as key for productive exchange. Many (42 percent) also highlighted the importance of shared intellectual tools in creating a *common ground* for interdisciplinary exchange. Yet depending on the networks' experience, intellectual objectives, the level of cross-disciplinary coordination, and the dominant disciplines, "common ground" meant different things, from a shared language to a space for individuals to encounter new ideas for their own work to the coconstruction of a shared methodology.

Respondents frequently discussed other cognitive factors such as iterative processes of knowledge production (mentioned by 40 percent), including an ongoing calibration of interpretive frames and the weighing of multiple interpretations of a construct (e.g., "culture"), and an explicit search for interdisciplinary integration to gain new insights (37 percent).

Emotional Factors

In describing their motivation for interdisciplinary research, their views about their peers or the climate of exchange, 58 percent of our informants referred to emotional factors for successful interdisciplinary collaboration. Joy, passion, and excitement were often associated with the experience of and intellectual motivation for their work. One informant discussed his

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network thus, "We do it ... because we *really enjoy it*. [...] you can call us cowboys or something, but that's the spirit." Positive emotions played a central role in helping investigators navigate the intellectual complexity of their shared enterprise. One neurobiologist stated:

> It is important to keep people receptive to new ideas and this requires a certain balance of chemicals in the brain, which can be achieved through emotion: smiling, fighting and making up, and having a good time at the pub.

Yet, the role of emotions in SCEI platforms cannot be reduced to cognitive objectives. Emotions such as pleasure and a sense of affirmation were often discussed as an end itself. For example, belonging to an esteemed collection of peers positively feeds researchers' concept of self. Identification engenders trust and feelings of solidarity. Respected peers are viewed as essential in the emotionally charged search for new paradigms and innovative solutions. One informant said, "I was impressed by the quality of the scholars around the table, [their] competence, open-mindedness, curiosity, kindness. I sensed that these people had the possibility to achieve something original and remarkable."

Interactional Factors

The interactive dimension also figured prominently among conditions for success, mentioned at least once by the majority (86 percent) of all respondents (see Table 4). As shown in Table 3, this includes mentions of a climate of conviviality (53 percent), the social-interactive qualities of participants, such as sociability and communicative styles (51 percent), and effective leadership (49 percent). Conviviality is built in interactions and serves as evidence of positive intellectual synergy. As one economist explained:

> In a sense, we're creating a community ... you can tell when things happen that build trust [...] a sequence of positively shared experiences and exchanged views just raises the trust level and engagement to a higher level, and that means it's working.

Sociability and communicative styles are also essential dimensions of interaction. For example, a political scientist pointed to productive female styles:

> It is good, for instance, that our network has a good gender balance. The women tend to bring a bit more of empathy and maybe are less status minded.

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> [. . .] they have a better way of making relations more agreeable. And many of the men sort of strut and sort of blow up their feathers [. . .]. But that's not really the case in our network. [You] have to like being with the others.

As Table 3 shows, informants also attributed the collaborative success to meaningful personal relations (35 percent), solid group identity (23 percent), complementary team roles (26 percent), socializing outside project meetings (26 percent), and the development of group working styles and routines (25 percent).

Mutually Constituting Dimensions

As noted above, most of the markers of and factors for success identified engaged with more than one dimension: the cognitive, emotional, and interactional dimensions of SCEI platforms shape and are being shaped by one another or are "mutually sustaining cultural schemas and sets of resources" (Sewell 1992, 27). Indeed, we understand shared intellectual agendas as being constructed through interactions between network members developing a program of research together. Emotional experiences associated with collaborative success (and failure) fuel or constrain cognitive activity. Meaningful personal relations, in turn, are enabled by and build feelings of belonging, respect, trust, admiration, and self-validation, exemplifying the mutual dependence of the interactive, and the emotional dimensions. The interaction of the cognitive, emotional, and interactive dimensions of SCEI platforms is manifested in the collective excitement that our informants described as a marker of intellectual success and formation of group identities. Below, the intersections between dimensions are examined and illustrated with qualitative data.

The Cognitive and the Interactional: Weaving Together Knowledge and People

> [In] productive work, [there is] a learning phase, where it just takes a while to come to the same terms and the same understanding, and to have somebody explain why this policy matters or doesn't matter, or why this approach to research does or doesn't matter to a policy person. [Socializing] creates occasions for casual conversations about the substance that then maybe inform the more formal conversations.

In SCEI platforms, topics of inquiry—central to the cognitive dimension—are framed in interdisciplinary terms with the goal of capitalizing on the

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varied member expertise and of yielding insights not possible through a single discipline. To do so, members seek to define their collective foci and intellectual agendas in shared but "optimally ambiguous" terms: open to invite and facilitate participation and multiple ownership of a problem, and circumscribed to empower meaningful exchange. This ambiguity is an important characteristic of SCEI platforms, as it allows for forms of engagement adapted to the needs and intellectual commitments of each participant, and facilitates alignment between their interests. It also encourages emotional and interactional engagement, as a researcher is unlikely to want to contribute to an inquiry utterly outside their intellectual interests or identity.

For example, in one network, members agreed that if "successful societies" stood as a broad and unmanageable construct to define the network's focus, the subtitle "how institutions and cultural repertoires affect health and capabilities" sufficiently disambiguates it. Each construct included in this frame serves as an entry point for scholars with different disciplinary backgrounds, expertise, research agenda, and intellectual commitment to join the collective conversation. Instead of a single "unifying research question," these scholars opt for a more flexible model oriented toward "multiple promising areas of convergence" that are interrelated, thus allowing each individual to connect pragmatically to the group on their own terms.

Such proclivity for intellectual integration requires an ability to understand colleagues' research preoccupations and to give and take and be generous team members, which cannot be captured by cognitive traits alone. Repeatedly, respondents described problem framing as an iterative *process* occurring at the intersection of prior knowledge, its gaps, and new problems requiring an interdisciplinary approach but also involving group interaction, appreciation, and openness to others.

Deliberations about member recruitment underscored the significance of the interactive dimension. The cognitive traits of each candidate, such as disciplinary excellence and intellectual openness, were described as essential for group membership and so were their interactional strengths such as good teamwork. For instance, an expert in human development mixed considerations of expertise, "congenial" style of engagement, and responsive interaction when he said:

> What we really are interested in is not just people who can bring a particular expertise, or even who have a kind of a style that's congenial to collaboration, but also who think in penetrating ways about topics that are not their own area of expertise, so that their mind is engaged in the process of integration. [. . .]

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> It's a matter of how much are they willing to put their mind into the collective enterprise.

This quote illustrates that markers of success such as effective cross-disciplinary exchange pivots on a capacity to interact. Furthermore, such conditions for success as the establishment of a common ground and a clear sense of a collective mission point to the interactive undercurrent of successful cognitive activity. In all cases, the cognitive and interactional are mutually constitutive in the sense that they coevolve and reinforce each other as conditions for successful collaboration.

The Cognitive and the Emotional: Ideas "So Exciting!!"

> I was extremely excited, actually. So it was a really phenomenal opportunity to take the kinds of issues that I actually worked on for 20 odd years and be able to move them to a level that you couldn't arrive at in any other way. [We were] thinking in an interdisciplinary group of very high level, [examining] what societal issues are in a [changing] society, and drafting the agenda together of what questions to address and [what] answer to give.

This use of superlatives exemplified by a geriatrician was not uncommon among respondents. Intellectual excitement permeates descriptions of the opportunities afforded by network participation, from discovering neighboring fields to learning new methods to developing alternative perspectives. Conversely, negotiating differences in disciplinary expertise presented cognitive and emotional challenges. Respondents had to readjust their perceptions of other disciplines or explain their own discipline while resisting stereotypical views. The cognitive success of an SCEI platform was seen as fueled by participants' emotional engagement with ideas and their capacity to manage negative emotions produced by intellectual disagreement, information overload, competition, or being overextended.

The connection between the cognitive and emotional is especially evident when a theoretical physicist described his love of scientific inquiry:

> . . . the thing that excites me, as a scientist, is finding commonalities, unity and sort of underlying, I call them laws . . . . And the thing that's made me so excited is that all that stuff out there, which is now very relevant, which looks like a big mess, has an extraordinarily elegant structure to it, which I never realized. And that is to me just so exciting. If I were religious, that's what I would pray to. It's very spiritual actually.

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Again, emotions have a key role in shaping participants' engagement with new interdisciplinary topics. *Cognitive emotions* (Scheffler 1986; Elgin 1999), associated with ideas and experiences in knowledge production, arise frequently in interdisciplinary exchange. The "joy of discovery" in recognizing that scholars in different disciplines share one's problem of study can be mitigated by the "frustration of incoherence" from failing to align approaches to the same problem. The emotional experience of "surprise" and "painful disorientation" that takes place when new theories or findings conflict with prior expectations may lead researchers to recommit themselves to collaborating or to become more reluctant about it.

Cognitive emotions or *passionate thoughts* (Neumann 2006) are often rooted in internalized academic norms and intellectual values such as love of truth, concern for accuracy, and disdain for error or lie. They filter participants' experiences and orient their behavior in a research network, thus constituting the intellectual dimensions of interdisciplinary collaborations. Successful framing of intellectual agendas involves not only consideration of extant knowledge, leveraging innovations, and strong disciplinary grounding but also the frame's capacity to engage investigators' past intellectual identity, research agenda, and love of work. The interdisciplinary nature of the work can amplify opportunities for surprise and discovery as well as cognitive dissonance, overload and confusion, and sense of competition. Navigating the cognitive aspect of an SCEI platform involves managing content and cognitive emotions.

The Interactive and the Emotional: "People You Would Want to Dwell With"

As we demonstrated, emotions function cognitively in successful interdisciplinary collaboration, for instance, by helping sustain intellectual engagement. Yet, their role in SCEI platforms cannot be reduced to the cognitive objectives: researchers experience a repertoire of emotions that are both a by-product of, and a lubricant or obstacle to, regular interaction among collaborators. They include feelings that one's expertise, judgment, and interpersonal skills are appreciated or honored by others, or conversely, feelings that one is "dissed," not valued or not fully integrated in a collective project.

Our respondents' emphasis on meaningful personal relations captures the mutual constitution of interactive and emotional dimensions of spaces for successful interdisciplinary collaborations or SCEI platforms. Through interactions, both within and outside the context of formal deliberations, our respondents often developed a sense of belonging and attachments that

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mark the "extraordinary commitment to one another necessary to overcome barriers of language and disciplinary cultures." One physicist said:

> The thing that made [the network] succeed in the end was the real commitment we made that we were going to try to do this and work on it together and really try to understand each other. I often liken it to a marriage. That's a real commitment! You love them, you hate them, they drive you absolutely up the wall. They do things that piss you off, but they also do some of the most wonderful things, you know.

Many respondents acknowledged such interpersonal chemistry, especially regarding recruitment. An informant said, "I don't want somebody who is going to trade on status ... someone who feels like their comment is more important." Effective leaders contribute to the establishment of personal relations and bonding among intellectually diverse peers. Some leaders facilitate the creation of a productive group climate by establishing horizontal and democratic dynamics (e.g., between a Nobel laureate, senior and junior scholars, and postdoctoral researchers); others ensure that enough time is spent outside of official meetings to enable members to get well acquainted.

In sum, meaningful personal relations, which are at once interactive and emotional, help establish a convivial climate, openness, and trust necessary for cognitively fertile relationships. They enable individuals to "park their ego at the door" to "build trust and well-being at the interpersonal level," and set safe conditions for participants to move beyond their comfort zones.

In general, informants seemed keenly aware of the particular demands and opportunities embedded in interdisciplinary collaboration. Their characterizations of markers and factors of collaborative success moved beyond generic descriptors to capture the epistemological and social complexity of the interdisciplinary space. They emphasized markers ranging from *cross-disciplinary* exchange to *common ground* (e.g., shared frameworks, objects, and tools), *disciplinary excellence,* and *leveraging integrations* enabled by factors such as participants' *intellectual open-mindedness*, *productive interdisciplinary problem framing*, and a sense of *collective mission.* They discussed emotional aspects of their collaboration, such as *intellectual excitement* experienced in working across domains to tackle complex problems and *joy in collaborating* with people whom they could learn from and develop *meaningful relations* with. Such emotional success was enabled by *feelings of group belonging* and *respect and admiration of peers,* a *climate of conviviality*, and *effective leadership* by individuals who understand the demands (cognitive, emotional, and social) of successful interdisciplinary collaboration.

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Across networks, informants also discussed *unsuccessful* interdisciplinary collaborations they experienced whether temporarily in their networks or in other collaborations. Their markers for lack of success often corroborated their view of success. For example, they were concerned with failure to *frame a problem* for study clearly or in ways that were shared by network participants, failure to establish a *common mission or methodology*, or associated failure to establish relatively shared *expectations*. They pointed to disciplinary barriers such as "individual [i.e. self interested] fishing," "disciplinary close-mindedness," "disciplinary languages," "conflicting epistemologies," and "divergent communication styles."

Reflecting on an exchange about the definition of a common concept, one informant portrayed a colleague's position as "too dogmatic" and him as "unwilling to take one step back from his point of view." He explained the need to frame the problem more pluralistically:

> Personally I didn't find [the proposed view] too constructive because it doesn't really produce an inroad to actually doing something. It may actually be right eventually but if you look at it close enough, the whole program falls apart. My disappointment was that somehow in the conversations, we couldn't get past the point to say OK, to acknowledge the fact that we will look at it instead from a purely fundamental logic.

In describing failures, respondents highlighted emotional and interactive qualities including persistent *interpersonal tensions* and feelings of *being disrespected* and *mistrusted* by others. They saw *membership instability* as impeding the construction of a group identity and brought up *ineffective group working styles* and the lack of a leader able to recast and refocus the groups' attention. As one informant stated:

> If there is not someone (or sometimes two individuals) who step forward at the right time to more or less lead the group to focus on the objectives rather than the points of divergence, interests, or perspectives that have surfaced in the collaboration, it is likely that those will continue to stand in the way of pushing forward to the (intended) objectives of the meeting or collaboration.

SCEI Platforms as a Heuristic Frame for Interdisciplinary Collaborations

Our examination of investigators' experience of successful interdisciplinary collaborations revealed the construction of a shared space within which

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researchers defined problems to study, exchanged expertise, built personal relations, projected and maintained academic self-concepts, and yoked for position. References to such shared spaces were common—for example, "sandbox," "network," "ideas space," "reunion," "safe haven," and "platform." We use "platforms" to characterize this shared space. The construct encompasses both a *dynamic space* where researchers engage one another to work on a common problem and a *basis* that organizes their collaborative behaviors and activities.

With the construct of SCEI platforms, we highlight the multidimensionality of successful interdisciplinary collaborations and variations in markers of and factors for success across networks. The construct allows the differing relative salience of a specific dimension in each network's unique emerging working cultures. For instance, some are more aware of the role of social interactions in successful collaboration, while others place a lower emphasis on intellectual excitement or meaningful relation as factors for success (see group variation in Tables 2 and 3). The construct can also capture different levels of agreement revealed by researchers within a network—an indicator of cohesion in the ways the platform and its associated notions of success are collectively construed. Some networks (D, E, and F) exhibit high convergence around particular markers and factors, while others (A and G) show a looser configuration with greater variations in participants' representation of success.

The concept of SCEI platforms also illuminates how these dimensions are intertwined: the framing of research problems occurs in the context of social interactions—for example, give and take, construct negotiations, and efforts to consider perspectives other than one's own. Optimal interdisciplinary frames are not found but *constructed*, dialogically, at the intersection of the repertoire of individuals and disciplinary ideas available on the platform, reinforcing certain aspects of the platform in turn. Similarly, we have seen the affective constitution of the SCEI platform through the shared pursuit of "exciting ideas" in the company of people "worth dwelling with" and the emotion work associated with moments of frustration, boredom, and disrespect. At this dynamic intersection, collaborators work to advance their shared research agendas while attending to the construction, repair, and sustenance of the platform—at once cognitive, emotional, and interactive—that makes this work possible and rewarding.

Arguably any successful collaboration, interdisciplinary or not, pivots on the construction of a shared space for cognitive, social, and emotional transactions. Central to our SCEI platforms, however, is the particular configuration of spaces for interdisciplinary success—where disciplinary paradigms,

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integrative frameworks, disciplinary passions, academic cultures, and identities play leading roles.

Importantly, SCEI platforms offer a novel and integrative unit of analysis to understand and assess interdisciplinary collaborations. They are not static or formulaic, but an emerging property of collaboration, dynamically co-constructed and pragmatically maintained through social interactions. They change over time, requiring the reframing of problems to maintain collective effervescence or reflect a new line of research or novel members. They accommodate multiple degrees of participation, from peripheral to central. They support—as springboards—further activity within and beyond home disciplines.

Observed through the lens of SCEI platforms, the success of an interdisciplinary collaboration cannot be reduced (as it often is) to intellectual productivity. Building a successful research network hinges on qualities such as the group's growing capacity for disciplinary exchange, the construction of a cognitive common ground, emerging group identity, and development of trust. In SCEI platforms, such aspects are *constitutive of* the cognitive dimension of interdisciplinary collaborations. They explain a sustained intellectual exchange or the shared problem framing. The construct thus opens the black box of interdisciplinary collaboration processes as experienced by its actors pursuing success.

Conclusion: The Road Ahead

This article proposed the notion of SCEI platforms as a heuristic tool to capture multiple dimensions of successful interdisciplinary collaborations. We described SCEI platforms as collectively constructed space where researchers engage with one another, mobilizing skills and generating new things in each dimension—cognitive, interactional, and emotional. For instance, a successful framing of a shared problem involves not only innovative consideration of extant knowledge but also the capacity to engage emotionally and interact effectively with collaborators. The interactive and emotional dimensions are constitutive of the cognitive life of an SCEI platform.

More work will be needed to tease out exactly how the cognitive, emotional, and interaction dimensions of SCEI platforms can also act as enabling and constraining factors in specific decision-making episodes or around concrete collaborations. While our study is based on a sample of particularly prestigious and "successful" networks, we still have to compare various mechanisms identified here to those at work in less successful networks as well as in interdisciplinary collaboration in general. Moving

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forward, we need to complement our analysis of the markers and conditions of SCEI platforms with a finer consideration of factors hindering success (power struggles, negative emotions, etc.) as well as a comparative analysis of interdisciplinary projects considered "failure." Nevertheless, shedding light on the multidimensionality of interdisciplinary collaboration is an important step in a context where noncognitive factors have often been described as subjective or as corrupting, that is, as orthogonal to rationality and the production of knowledge.

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Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: Michèle Lamont is a program director and fellow of the Canadian Institute for Advanced Research. She is associated with one of the networks studied in this paper and thus abstained from providing, collecting, and analyzing the data pertaining to that network.

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Notes

1. This definition focuses on researchers' capacity to ground their work in disciplinary expertise and integrate perspectives effectively (Boix Mansilla 2010). It does not portray interdisciplinary work as a post- or antidisciplinary (Fuller 2010; Funtowitz and Ravetz 1993; Gibbons et al. 1994). For a perspective that

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problematizes the centrality of integration in interdisciplinary work, see Holbrook (2013).

2. For elaboration of platform as a concept, see Keating and Cambrosio (2000). We echo their appreciation of its "semantic reach" that covers various dimensions and their definition of it as "less a thing than a way of arranging things" (p. 346). While their analysis of "biomedical platforms" addresses new configurations of instruments, individuals, and programs in medicine, our platforms are created by interdisciplinary collaborators and are group specific.
3. We interviewed between four and six members of each network, plus their leaders. These members were chosen to reflect different disciplinary perspectives and levels of seniority. We are also drawing on six interviews with administrators and two off-the-record interviews.
4. One of the authors is associated with one of the networks studied and thus abstained from providing, collecting, and analyzing the data pertaining to this network.
5. For full information on the coding manual, please visit http://scholar.harvard.edu/files/lamont/files/successful_interdisciplinary_collaborations-additional_materials.pdf. In each round, we first analyzed sample data to establish intercoder reliability. Two pairs of researchers coded a subsample of interviews separately using basic codes (e.g., "motivation for participation" and "processes of collaboration"). The pairs discussed differences until they reached a shared understanding of each code. The four coders discussed revisions to the codebook, adding disambiguating detail, creating new codes, or merging existing ones where necessary. Researchers integrated their analysis in the production of summative network-specific case studies. A second round of analysis focused specifically on markers and conditions for success repeating the analysis approach.
6. In line with our confidentiality agreement with participating organizations, this section discusses only publically available information concerning the latter. While the following sections are based on our interviews with researchers, including project leaders, this section also draws on interviews with representatives of funding organizations.
7. A respondent is counted as one for referring to each of the markers and factors once or any number of times. Our categories are mostly analytically distinct (to see our coding manual please visit http://scholar.harvard.edu/files/lamont/files/successful_interdisciplinary_collaborations-additional_materials.pdf), but one sentence might have multiple components and be therefore coded into multiple categories.

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