SCIENTIFIC FOUNDATIONS: A CASE FOR TECHNOLOGY MEDIATED SOCIAL PARTICIPATION THEORY

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INTRODUCTION

New forms of technology-mediated social participation (TMSP) provide an unprecedented opportunity to increase the collective intelligence of our nation and the world. By enabling much closer coordination among far larger groups of people, new computing and communication technologies now make it possible to address an amazing range of problems in new—and often more intelligent--ways. Consider, for example, how vast groups of people have created massive intellectual products like Wikipedia, Linux, and YouTube and how they have successfully predicted election outcomes using the Iowa Electronic Market and detected earthquakes using Twitter.

There is now an immense opportunity to explore, exploit, enrich, and repurpose these novel architectures to transform healthcare, education, technological innovation, citizen science, energy and environmental sustainability, community safety, emergency response, and many other national priorities. To achieve this aim will require a deep scientific understanding of current and emerging systems and phenomena. Such understanding will provide a foundation for the design and engineering of powerful new architectures for social participation that achieve desired results in sustainable ways.

One way to proceed toward this goal, for example, is suggested by analogy to mapping the human genome. While there are no explicitly represented "genes" in systems for TMSP, there are certainly recurrent patterns in the design elements such systems include. Many of these systems, for instance, include various types of group decision-making patterns, such as voting or prediction markets, and many include other patterns such as contests or collections. [1]. Just as the biology research community developed a map of the human genome, we believe it would be possible for an interdisciplinary TMSP research community to collaboratively develop a comprehensive "map" of different design patterns like these. Such a map could include examples of each pattern, the conditions under which each pattern is useful, and the theories that apply to using each pattern effectively. Unlike the human genome map, a map of the "genomes" of TMSP would never be finished, because new design patterns and new combinations of old patterns could always be invented. But we believe the goal of mapping the scientific foundations for the most important existing examples of TMSP could help coalesce and inspire the nascent TMSP research community.

This report highlights some of the gaps in theory needed to achieve this goal. We emphasize the general need for theoretical integration across system levels (e.g., from individual psychology and behavioral economics up through social processes and dynamics), within levels (e.g., complexes of interacting mid-level social process mechanisms), and across theoretical frameworks and representations (e.g., dynamical systems; random graph theory; computational cognition). The report ends with challenges in bringing the TMSP research community together to work towards theoretical advances and structures.

THE ROLE OF THEORY

TMSP systems are typically valuable when they can collect the information and insight from a large and diverse user base. There are many successful examples of technology-mediation social computing that achieve various goals, such as: Wikipedia achieves the social construction of knowledge; Google Image Labeller achieves the social construction of image labels, TopCoder achieves social participation in the development of source code, NASA Clickworkers achieves social participation in identifying craters in scientific images. These systems have been developed without a theory of TMSP and have emerged from intuitive and insightful uses of internet and social technology that has motivated hundreds of thousands of people to participate in activities outside their professional or normal daily activities.

While these examples have been highly successful, many others fail: the success of Wikipedia is the exception and not the rule. Of the more than 9,000 wikis using the MediaWiki platform, more than half have seven or fewer contributors. The development of new social computing systems lack evidence-based, scientific guidance in building and managing online communities. To be successful, virtual communities must overcome challenges that are endemic to many groups and organizations. They must handle the start-up paradox, [2] when early in their life-cycle they have few members to generate content and little content to attract members. Throughout their life-cycle, they must recruit and socialize newcomers, encourage commitment and contribution from members, solve problems of coordination and encourage appropriate behavior among members and interlopers alike. This section explores the role of theory and claims that the early successes of technology mediated social participation provide the basis for developing that theory.

Theories are an important component of scientific research. In science, theory provides the explanation of past phenomena and a means for prediction of future events. In TMSP, we can describe the role of theory in both the science of TMSP and the design for TMSP. A theoretical basis for TMSP can explain why some examples of TMSP are successful and why many have failed; can provide a basis for simulating activity in existing examples of TMSP, and possibly predict whether a new TMSP example will be successful. Theories play an important role in informing the design of new TMSP: the theory can provide a framework for identifying important considerations and elements of TMSP design as well as provide a common understanding for applying TMSP to different complex problems: health, education, sustainability, government, etc.

Developing theories that are relevant and responsive to the emerging area of TMSP are essential for advancing our understanding of current and future examples of TMSP, and allow us to be deliberate on how to achieve positive outcomes for TMSP. Without relevant theories to describe or predict these phenomena, we will continue to be surprised at how this emerging technology makes radical changes in the fabric of our society and we will lack the potential to guide the technology towards effective and positive applications.

A NEW THEORY REQUIRING MULTIDISCIPLINARY INTEGRATION

Human social behavior is the result of multiple layers of organized systems rooted in physics and biology at one end of the spectrum and large-scale social and cultural phenomena at the other end [3]. This hierarchical organization produces layers of phenomena at which different mechanisms and factors tend to dominate: neural, psychological, economic, organizational, and social, just to name a few. This space is large, spanning 10 powers of 10 of time scale and 10 powers of 10 of organization (from individual people up to nation-sized collections) [4]. There are natural pressures in the sciences that create a division of labor in which causal processes are isolated and understood, often from different explanatory frameworks, in each of the systems layers. To understand and architect TMSPs requires

- *Within-level theoretical integration*. Dealing with complexes of interacting processes at each level, and so a need for within-level theoretical integration. For instance, participation and contribution rates in an online community are not the result of a single isolated social process, but a complex of interacting cognitive, economic, and social processes [2].
- *Across-level theoretical integration*. Microscale factors at the level of the individual user can percolate upward to affect emergent macroscale phenomena (e.g., the effect of interaction effort on tagging rates) [5], and embedding in macroscale social fabric can affect the individual [6-11]. There is now an opportunity to synthesize psychological, organizational, economic, and social theory that can be tested against the empirical behavior of online communities, and that can be used to navigate the complex trade-offs needed to design socio-technical systems that improve individual and community performance.
- *Deepened understanding of classes of socio-computational processes*. The science must provide the foundations for new systems that build upon diverse socio-computational processes as collective intelligence, collective action, spreading influence and preferences, game-theoretic interactions and trade-offs, etc.
- *Metrics*. There is a need to identify key metrics that indicate the ongoing viability and evolution of TMSP systems, and support ongoing organization, management, and decision processes. More generally, models are needed to form the basis for measurement and to identify key metrics such as community efficacy [12] conversion rates from readers to contributors [13], type and degree of cooperation (Nowak, 2006b), and network structure and dynamics [14].

Understanding and designing for TMSP will depend on integrating a variety of (sometimes competing) theories in the cognitive and social sciences that provide partial explanations for contribution behavior and how group membership changes it. A new theory or set of theories needs to emerge from the synthesis of theories from different perspectives. Examples of relevant disciplines and some of the theories they can contribute include:

- Political science – theories of democracy and voting

- Economics – theories about how to design optimal incentives for various group decision-making situations (mechanism design) and theories about how human decision-making often differs from the theoretical optimum (behavioral economics)

- Social psychology – theories about various forms of biases in group decision-making (e.g., information cascades, risky-shift)

- Individual psychology – theories about human motivation

- Organizational design – theories about the tradeoffs involved in various ways of grouping and linking activities in organizations

- Sociology – theories about many non-economic factors that facilitate and inhibit community formation and the social factors that shape collective action

- Law – theories about effective ways of balancing the rights of individuals and groups (e.g., managing intellectual property rights)

This section highlights just a few of the relevant theories or studies that provide a starting point for a theory of TMSP, while pointing out that we have a long way to go to have robust theories for TMSP. Each of these areas is already witnessing new development because of the interdisciplinary work among computer and social-behavioral scientists.

Behavioral Economics

Behavioral economics has been explored in the development of incentive mechanisms for enhancing participation [e.g., 15]. Network scientists have explored incentive mechanisms for optimal structuring of effective social networks [16, 17]. Theories of social evolution build upon iterative game theory [18-20] to predict evolutionary stable strategies for social ecologies,. These approaches hold promise because of their generality, but they have yet to be applied to large-scale complex online communities.

Relation of Offline to Online

Social systems and networks are not new, but technologies change the conditions and constraints in which social processes operate. People can now network--i.e., communicate, collaborate, interact--with anyone, anywhere, anytime in the world. Our social and cultural worlds have evolved offline, and these worlds remain primary. However, the virtual environment is essentially a new niche for social and cognitive adaptation and evolution. To understand the evolution of new forms of social interaction in the online world, we need to understand their historical and continuing relations to the offline world. Echos of the ongoing activity in the offline world are reflected in the activity of the online, and vice versa. Research has begun to show how how the "online" and "offline" social worlds are related--and how they are different [21, 22].

Social Capital

Social participation and social connectedness can create better or worse advantages for individuals and groups. This is the notion of *social capital* [6]. The concept of social capital includes the accrual of benefits associated with increased common ground (including shared tacit knowledge, language, trust, norms, etc.) that improve the efficiency, productivity, and civility of society [12]. Social capital also includes the effects that accrue with diversity (improvements in innovation, decision making, problem solving, and visions of otherwise unseen opportunities). New ways of measuring the impact of social structure and dynamics on social capital are emerging from the computational and network sciences [e.g., 17, 23].

Socio-Cognitive Mechanisms and Dynamics

Just as the internet is an abstraction implemented in the mechanics of different layers (application, transport, TCP/IP) that ultimately get realized in computers, routers, cables, and wireless, so too are social networks and processes a theoretical abstraction that is realized by the social-cognitive and cognitive mechanisms of people. Numerous network science studies have now illustrated phenomena such as idea contagion [24-26], the network spread of obesity, smoking, and happiness [7, 8, 10], effects of social brokerage on innovation [6], effects of network closure on reputation [6, 12], and so on. However, the mechanics that underlie these phenomena at the level of individual psychology and interpersonal interaction are largely a mystery. For instance, it is not clear how dispositions for smoking and obesity might actually transfer from one person to another, or how digital representations of others and their behavior are processed by individuals to judge trust [27].

Motivation and Incentive Structures

Theories of motivation can provide a better understanding of the technologies and organizing principles that attract people to participate in TMSP. Motivation theories have been developed from a range of perspectives: from Darwin's evolutionary theory contributing a biological basis for human motivation to intrinsic motivation as described in Maslow's hierarchy of needs which spans from the purely physiological to self-actualization. Malone, Laubacher, & Dellarocas, [1] present an analysis of mechanisms that induce mass-individual participation in several computer-enabled collective intelligence systems. Maher, Paulini, and Murty [28] develop a set of motivation categories to characterize a range of successful examples of collective intelligence, showing that successful collective intelligence appeals to several categories of motivation. Ren and Kraut [2] have explored an interactive complex of psychological, technical, and social factors that shape online participation and contribution rates. While these approaches to understanding motivation provide a start for a theory of motivation in TMSP, they are still anecdotal and lack the rigor of a theory.

HOW WE GET THERE FROM HERE? THE RELATIONSHIP BETWEEN THEORY AND PRACTICE.

In this section we outline the relationships among theory, practice, and observation; explicate the various types of theories; and propose some principles for the construction of a decentralized multi-centered collaboratory [29].

An oversimplified model of science suggests that theories are tested by controlled experiments and when the theories have been sufficiently refined by this process they are then used as a guide for the design of systems in the real world. More recent studies in the history of science demonstrate that, in fact, practice as often leads theory as follows from it. In the domain of social participation with increased collective intelligence, the problems humanity faces are so pressing that we have no time to wait for fully developed theories before attempting designs. A decentralized multi-centered, multidisciplinary collaboratory can provide a focus that will enable advances in theory to be matched with successes in practice, and also provide a range of forums for tools and communication that is itself an example of TMSP.

Collaboratories [29] are collections of researchers working together on a set of common problems, not collocated, coordinating their researcher through a set of supporting technologies and social practices. A Collaboratory for Research on Technology Mediated Social Participation can facilitate researchers in different locations, using different methods and theories, to advance research on ways to better use social participation to problems of global importance. This Collaboratory can consist of a collection of smaller, more focused centers. At the core, however, is what is called a "Distributed Coordination Center," made up of the coordinating and cooperative superset of researchers and providing a place for researchers to gather to share their ideas, tools, and findings. The Distributed Coordination Center would provide infrastructure for the smaller centers, much like the Biomedical Informatics Research Center did for its associated collaboratories. The Distributed Research Center would be the coordinating node for more focused centers: that are discussed in the related reports in the this collection--centers aimed at fostering design research and research in specific domains such as health care and education. The collaboratory for TMSP would include research infrastructure (access to a server farms, data sources, subject pools, etc.) and technically-based tools (wikis, discussion forums, digital library, etc.) that can be customized to fit a collaboratory's needs and content, plus a recommended set of policies and best practices that had been used in the past in successful collaboratories. A collaboratory would require "data depository" centers to house large data sets made available to researchers (e.g. from Google or Yahoo!), and well "living laboratories" of participants engaged in TMSP projects (see the report by Chi et al.).

We envision that theoretical work on technology mediated social participation will involve multidisciplinary work at all levels from theories of

- the individual (e.g. theories of motivation for participation)
- the dyad (e.g. theories of reciprocity, trust, of conversation, common ground),
- small groups (e.g. theories of coordination, leadership, diversity)
- organizations (e.g. more macro theories of coordination, governance)
- communities (e.g. theories of growth of membership, diffusion of innovation),
- society (e.g. theories of the tipping point, viral marketing).

We expect that advances in the kind of multidisciplinary integration and deepened understanding discussed above, will depend in part on the emergence of computational social science [30] and the translation of TMSP science into practice. To foster this we suggest

- The Simulation Center to provide an extensible simulation capabilities that allows researchers to model and reason about the underlying behavioral mechanisms of communities and to test design ideas (e.g. about incentive structures) for intended and unintended consequences.

The Simulation Center would provide shared tools, much like a wind tunnel, for testing design decisions before implementing them.

- Translational Centers, which will bridge scientific research and practice, much like translational medicine centers bridge research results and clinical practice. This Translation Centers would provide technology-based tools for social participation efforts, infrastructure for empirical research, and support for the development of new design and engineering approaches such as the design pattern languages that we discuss in more detail below.

The issue of a mapping foundational science and theory onto a design approach is central for TMSP. Pattern languages [e.g., 31, 32, 33], for instance, provide a useful way to generalize "what works" from numerous cases and to provide useful guidelines for designing real systems. A Pattern is the named description, at a general level, for a recurring problem. A Pattern Language is a lattice of Patterns that pertains to and covers a particular domain. Patterns typically exist at a variety of levels; for example, in physical architecture, there are patterns about overall city design as well as patterns dealing with much lower level details of specific buildings such as floor plan layout. Besides covering a domain in this way, a Pattern Language also thus allows something positive to be done at many levels of control. In many cases, a designer will not have the power or resources to build complete complex systems, *de novo,* but can nonetheless make important changes or additions within their power to do so. This makes them particularly useful in a domain like social participation where designers will have a wide range of scope of control Pattern Languages can serve as a *lingua franca* among professionals and non-professionals from a variety of backgrounds, again making them suitable both because many relevant formal disciplines must be brought to bear on social participation and also because in most real-world design settings, there will also be a wide variety of stakeholders. We suggest that the science of social participation is also at the appropriate point of development where enough knowledge exists to construct the beginnings of a Pattern Language for social participation. The proposed collaboratory would include *tools* to help scientists jointly construct, link, edit, visualize, search, and discuss individual Patterns and the Pattern Language as well as to link designs and outcomes back to the Patterns used in the design of particular systems.

While Pattern Languages are useful in guiding design, they do not "specify" a design. Typically, where possible, investigators need to develop one or more prototypes to test out designs in the small by observation and experiment, and/or, as theory building becomes more formal, test designs by using simulations. In some cases, *both* observations and simulations can be applied to the same design and the results can be used to refine both the simulations and the methods of observations. In addition to the refinements to general theory provided by simulation and observation, the specific design is also improved. In some cases, observation and simulation may also suggest refinements to existing Patterns or even suggest new Patterns.

Of course, observations can also be taken for the primary purpose of refining theory or simulation techniques and need not always be associated immediately with a "real-world" design. Modeling and simulations can also be useful in determining what observations are likely to prove useful and how many of them must be made. In a similar way, the attempt to design a system to solve a real world problem can also shed significant light on issues currently unaddressed by theory.

The construction of a common Pattern Language could be associated with common data sets, simulation tools, and observation tools making both the design of particular systems more efficient and effective as well as the further development of theory. Many research participants will be remote from each other and in any case, even physically co-located participants will find the associated tools useful. To provide one important proposed test-bed for the development of theory of effective social participation, this tooling will also be *instrumented* and initially designed by the very processes described above. In this way, the collaboration efforts of the scientists involved will themselves be one important source of data.

CONCLUSIONS

Twenty-five years ago, in a prescient article about foundations for a science of human-computer interaction, Allen Newell and Stuart Card [34] declared that "nothing drives science better than a good applied problem". Technology mediated social participation systems present not only good scientific problems, but truly grand challenges that—if solved—could aid in addressing problems of national and even global importance, including healthcare, education, climate change, security, and commercial innovation. The challenge is multidisciplinary and complex, and consequently we believe that advances in computational thinking, modeling, and methodology will be required to support scientific understanding of the social, economic, and behavioral phenomena surrounding TMSP systems. New theories of design and engineering will needed to move us from ad hoc approaches to predictable and sustainable socio-technical systems. Because of the complexity of TMSP systems, and the opportunity to address national priorities in new and powerful ways, we have outlined the need for multidiscopinary collaboratories on the scale of efforts in other sciences.

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REFERENCES

[1] T. W. Malone, *et al.*, "The collective intelligence genome," *Sloan Management Review,* vol. 51, pp. 21-31, 2010.

[2] Y. Ren and R. E. Kraut, "Simulating newcomer socialization in online communities," 2009.

[3] A. Newell, *Unified theories of cognition*. Cambridge, MA: Harvard University Press, 1990.

[4] P. Pirolli, "Powers of 10: Modeling complex information-seeking systems at multiple scales," *IEEE Computer,* vol. 42, pp. 33-40, 2009.

[5] R. Budiu, *et al.*, "Remembrance of things tagged: How tagging effort affects tag production and human memory," in *CHI 2009 Conference on Human Factors in Computing Systems*, Boston, MA, 2009.

[6] R. S. Burt, *Brokerage and closure: An introduction to social capital*. Oxford: Oxford University Press, 2005.

[7] N. A. Christakis and J. H. Fowler, "The spread of obesity on a large social network over 32 years," *New England Journal of Medicine,* vol. 357, pp. 370-379, 2007.

[8] N. A. Christakis and J. H. Fowler, "The collective dynamics of smoking in a large social networks," *New England Journal of Medicine,* vol. 358, pp. 2249-2258, 2008.

[9] N. A. Christakis and J. H. Fowler. (2008, Social networks and happiness. *The Third Culture*. Available: http://www.edge.org/3rd_culture/christakis_fowler08/christakis_fowler08_index.html

[10] J. H. Fowler and N. A. Christakis, "Dynamic spread of happiness in a large social network: Longitudinal analysis over 20 years in the Framingham Heart Study," *British Medical Journal,* vol. 337, 2008.

[11] M. J. Salganik and D. J. Watts, "Web-based experiments for the study of collective social dynamics in cultural markets," *Topics in Cognitive Science,* vol. 1, pp. 439-468, 2009.

[12] R. Putnam, *Bowling alone: The collapse and revival of american community*. New York: Simon and Schuster, 2000.

[13] J. Preece and B. Shneiderman, "The reader-to-leader framework: Motivating technology-mediated social participation," *AIS Transactions on Human-Computer Interaction,* vol. 1, 2009.

[14] M. Newman, *et al.*, Eds., *The structure and dynamics of networks*. Princeton, NJ: Princeton University Press, 2006, p.^pp. Pages.

[15] R. Farzan, *et al.*, "Results from deploying a participation incentive mechanism within the enterprise," presented at the Proceeding of the twenty-sixth annual SIGCHI conference on Human factors in computing systems, Florence, Italy, 2008.

[16] V. Buskens and A. v. d. Rijt, "Dynamics of networks if everyone strives for structural holes," *American Journal of Sociology,* vol. 114, pp. 371-407, 2008.

[17] J. Kleinberg, *et al.*, "Strategic network formation with structural holes," *SIGecom Exch.,* vol. 7, pp. 1-4, 2008.

[18] R. McElreath and R. Boyd, *Mathematical models of social evolution: A guide for the perplexed*. Chicago: University of Chicago Press, 2007.

[19] M. A. Nowak, "Five rules for the evolution of cooperation," *Science,* vol. 314, pp. 1560-1563, 2006.

[20] M. A. Nowak, *Evolutionary dynamics: Explorinhg the equations of life*. Cambridge, MA: Harvard university Press, 2006.

[21] S. P. Borgatti, *et al.*, "Network Analysis in the Social Sciences," *Science,* vol. 323, pp. 892-895, February 13, 2009 2009.

[22] J. Kleinberg, "The convergence of social and technological networks," *Commun. ACM,* vol. 51, pp. 66-72, 2008.
[23] L. Wu*, et al.*, "Vaue of social network -- A Large-scale analysis on network structure impact to financial revenue of information technology consultants," presented at the Winter Information Systems Conference, Salt Lake City, 2009.
[24] D. Liben-Nowell and J. Kleinberg, "Tracing information flow on a global scale using Internet chain-letter data," *Proceedings of the National Academy of Sciences,* vol. 105, pp. 4633-4638, March 25, 2008 2008.
[25] D. J. Watts, "A simple model of global cascades on random networks," *Proceedings of the National Academy of Sciences of the United States of America,* vol. 99, pp. 5766-5771, April 30, 2002 2002.
[26] F. Wu*, et al.*, "Information flow in social groups," *Physica A: Statistical and Theoretical Physics,* vol. 337, p. 327, 2004.
[27] J. Golbeck, "Weaving a Web of Trust," *Science,* vol. 321, pp. 1640-1641, September 19, 2008 2008.
[28] M. L. Maher*, et al.*, "Scaling up: From individual design to collaborative design to collective design," in *International Conference on Design Computing and Cognition*, 2010.
[29] J. S. Olson*, et al.*, "A theory of remote scientific collaboration," ed, 2009.
[30] D. Lazer*, et al.*, "Computational Social Science," *Science,* vol. 323, pp. 721-723, February 6, 2009 2009.
[31] C. Alexander*, et al.*, *A pattern language : towns, buildings, construction*. New York: Oxford University Press, 1977.
[32] J. O. Coplien and D. C. Schmidt, *Pattern languages of program design*: Addison-Wesley, 1995.
[33] J. Borchers, *A pattern language approach to interaction design*: John Wiley & Sons, 2001.
[34] A. Newell and S. K. Card, "The prospects for a psychological science in human-computer interactions," *Human-Computer Interaction,* vol. 2, pp. 251-267, 1985.