REPORT DOCUMENTATION PAGE	Form Approved OMB NO. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggesstions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA, 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any oenalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 06-10-2014	2. REPORT TYPE Final Report	3. DATES COVERED (From - To) 1-Sep-2010 - 31-Aug-2013

4. TITLE AND SUBTITLE Final Report ARO Research Report	5a. CONTRACT NUMBER W911NF-10-1-0379
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER 611102
6. AUTHORS Scott E Page, Jenna Bednar	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAMES AND ADDRESSES University of Michigan - Ann Arbor 3003 S. State St Ann Arbor, MI 48109 -1274	8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS (ES) U.S. Army Research Office P.O. Box 12211 Research Triangle Park, NC 27709-2211	10. SPONSOR/MONITOR'S ACRONYM(S) ARO
	11. SPONSOR/MONITOR'S REPORT NUMBER(S) 58267-LS.13

12. DISTRIBUTION AVAILIBILITY STATEMENT

Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES
The views, opinions and/or findings contained in this report are those of the author(s) and should not contrued as an official Department of the Army position, policy or decision, unless so designated by other documentation.

14. ABSTRACT

During the reporting period, we have continued our research combining experimental, computational, and mathematical methods to explore the interplay between cultural and institutions. We have written papers, given presentations both in the United States and internationally, hosted a conference, and presented parts of our findings to government agencies and members of the business communities.

Our findings demonstrate strong linkages between institutional choices and what is often characterized as cultural

15. SUBJECT TERMS
Culture, Games Theory, Institutions, Path Dependence

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	15. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Scott Page
a. REPORT UU	b. ABSTRACT UU	c. THIS PAGE UU	UU		19b. TELEPHONE NUMBER 734-763-3301

Report Title

Final Report ARO Research Report

ABSTRACT

During the reporting period, we have continued our research combining experimental, computational, and mathematical methods to explore the interplay between cultural and institutions.   We have written papers, given presentations both in the United States and internationally, hosted a conference, and presented parts of our findings to government agencies and members of the business communities.

Our findings demonstrate strong linkages between institutional choices and what is often characterized as cultural, i.e. non optimal behavior. Our research suggest an alternative to accounts of suboptimal behavior based on biases. Moreover, our research contributes to an understanding of how to choose institutions.

Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

(a) Papers published in peer-reviewed journals (N/A for none)

Received		Paper
08/29/2011	1.00	Jenna Bednar, Aaron Bramson, Andrea Jones-Rooy, Scott Page. "Emergent cultural signatures and persistent diversity: A model of conformity and consistency' , Rationality and Society 22: 4 pp 407-444, 2010 , (10 2010): 407. doi:
08/29/2011	2.00	Yan Chen, Tracy Liu, Scott Page, Jenna Bednar. "Behavioral Spillovers with Interdependent Institutions: An Experimental Study." , Games and Economic Behavior, (12 2011): 0. doi:
08/29/2011	3.00	PJ Lamberson, Scott Page. Optimal Forecasting Groups, Management Science, (09 2011): 0. doi:
08/29/2011	4.00	Scott Page, Jameson Toole, Jenna Bednar. Revised Path Dependence, Political Analysis, (10 2011): 0. doi:
TOTAL:	**4**	

Number of Papers published in peer-reviewed journals:

(b) Papers published in non-peer-reviewed journals (N/A for none)

Received		Paper
08/29/2011	5.00	Jameson Toole, Scott Page. Predicting Cellular Automata, Complex Systems, (09 2011): 0. doi:
TOTAL:	**1**	

Number of Papers published in non peer-reviewed journals:

(c) Presentations

Behavioral Spillovers, Learning, and Institutional Path Dependence (paper included in manuscript section)
Jenna Bednar and Scott E Page

Behavioral Spillovers in Sequential Game Experiments (in progress no paper yet written but results presented)
Jenna Bednar, Yan Chen, Tracy Liu Scott E Page,

Number of Presentations: 2.00

Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received   Paper

        TOTAL:

Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

Peer-Reviewed Conference Proceeding publications (other than abstracts):

Received   Paper

        TOTAL:

Number of Peer-Reviewed Conference Proceeding publications (other than abstracts):

(d) Manuscripts

Received		Paper
02/13/2013	6.00	Scott Page, Andrea Jones-Rooy. `Systems Effects Revisited', Critiqcal Inqury (08 2012)
02/13/2013	9.00	Jenna Bednar. "Prosociality, Federalism, and Cultural Evolution." , Cliodynamics: The Journal of Theoretical and Mathematical History (10 2011)
02/13/2013	8.00	Lu Hong, Scott Page, Maria Riolo. ncentives, Information and \\Emergent Collective Accuracy, Managerial and Decision Economics (10 2011)
02/13/2013	7.00	Evan Economo, Lu Hong, Scott E Page. Cognitive Ecologies, Social Structure and Collective Wisdom, Under Revision (08 2012)
10/18/2013	10.00	Scott E Page. A Complexity Perspective on Institutional Design, Politics, Philosophy and Economics (01 2012)
TOTAL:	**5**	

Number of Manuscripts:

Books

Received	Book
TOTAL:	

Received	Book Chapter
TOTAL:	

Patents Submitted

Patents Awarded

Awards

American Academy of Arts and Sciences -- Scott E Page 2011
Guggenheim Fellowship - Scott E Page 2013

Graduate Students

NAME	PERCENT_SUPPORTED	Discipline
Jean Clipperton	0.50	
Jessica Steinberg	0.50	
Andrea Jones-Rooy	0.50	
Maria Puccio	0.25	
Richard Anderson	0.50	
FTE Equivalent:	**2.25**	
Total Number:	**5**	

Names of Post Doctorates

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Faculty Supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Names of Under Graduate students supported

NAME	PERCENT_SUPPORTED
FTE Equivalent:	
Total Number:	

Student Metrics
This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: 0.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 0.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 0.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense 0.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields: 0.00

Names of Personnel receiving masters degrees

NAME

Total Number:

Names of personnel receiving PHDs

NAME
Andrea Jones Rooy

Total Number: 1

Names of other research staff

NAME   PERCENT_SUPPORTED

FTE Equivalent:
Total Number:

Sub Contractors (DD882)

Inventions (DD882)

Scientific Progress

See attachment

Technology Transfer

ARO Summary Research Report

Scott E Page[*]   Jenna Bednar [†]

October 3, 2014

Overview

Our primary research goal in the grant was to investigate the relationship between institutions and behavior. We combined experimental, computational, and mathematical techniques to explore how behavior in one institution can influence behavior in other institutional settings and impact institutional design and sequencing. Over the course of the project, we have focused on eight tasks (1) developing mathematical models of these spillovers, (2) creating agent based implementations of those models, (3) leveraging other grants to do experimental tests of these results (4) pushing these ideas into new fields and problem domains including collective wisdom, philosophy, law, and psychology (5) organizing conferences, (6) connecting to other relevant research projects (7) engaging in outreach both within the United States and globally, and (8) training graduate students. To date the project has resulted in (i) fourteen completed research papers, (ii) substantial external funding including direct and indirect funding from three other NSF funded projects, involvement in an IARPA project and a Guggenheim Fellowship (iii)

---
[*]Center for the Study of Complex Systems, Departments of Political Science and Economics, University of Michigan. Email: scottepage@gmail.com

[†]Department of Political Science University of Michigan. Email: jbednar@umich.edu

the organization of multiple conferences, (iv) dozens of paper presentations in more than a dozen countries. In addition, (v) three of the graduate students involved in the project are now tenure track faculty at leading research institutions and (vi) research from the grant occupies a central role in an online course that has to date attracted approximately half a million students.

Activities

Our primary activities during the grant involved conducting research, meeting in research groups, engaging in outreach, and making connections to related researchers in other fields. On this last point, we leveraged research from this grant to gain funding from the National Science Foundation, NiMBioS (the National Institute for Mathematical and Biological Synthesis which is funded by the NSF, IARPA, the University of Michigan, and the Guggenheim Foundation. The funds from the University of Michigan were awarded by the Rackham Graduate School to fund a conference in which graduate students played a central role.

In this report, we first list the scientific advancements. We then describe those achievements in the process of listing our eight main activities: developing mathematical models, developing agent based models, experiments to test those models, interdisciplinary writings, organizing conferences, connecting to new projects, outreach, and graduate student development. The first four of these we group into the category of *scientific contributions*. The latter four we collect under the heading of *connections and outreach*.

0.1 Scientific Advancements

As this is the final report of what has been a wide ranging methodological and substantive inquiry, we include here a list of what we believe to be the primary scientific advancements accomplished during this project. We note first that advancements in social science research differ from advancements in the physical sciences where a new particle might be discovered or engineering where a new method for infrared detection is developed. In the social sciences, an advancement will typically broaden, deepen, problematize, or find connections within the existing state of knowledge.

Many of our advances have been described in previous reports. For completion's sake, we include a summary here. In parentheses, we denote the number of the paper in the bibliography in which that contribution can be found. We also describe the advances in more detail in our description of activities to follow.

1. Development of a formal mathematical model of behavioral spillovers and institutions (6)

2. Formal characterization of concept of Revised Path Dependence (7)

3. Formal classification of Tipping Points (8)

4. Elucidation of formal linkages between behavioral spillovers and path dependence in a learning model (5)

5. A richer elucidation of the connection between behavioral diversity and macro phenomena (1)

6. A characterization of the benefits of *positive dissensus* on complex policy issues (2)

7. Development of a theoretical connection between cultural evolution and the robustness of federal systems, with an application to the current situation in Afghanistan

(3)

8. Discovery of experimental support for behavioral spillovers (4)

9. Exploration of effect of linkages on institutional performance and design (6,3,9,10,12,13)

10. Linkages between diversity and signals (2,11,14)

Scientific Contributions

The scientific advancements described above fall into four categories: mathematical models, computational models, experiments, and interdisciplinary investigations. We discuss each in turn. The development of the theoretical model involved workshopping ideas at conferences in the United States, Europe, and Asia. We have completed and are about to submit a paper entitled "When Order Affects Performance: Institutional Sequencing, Cultural Sway, and Behavioral Path Dependence." We are scheduled to present the paper at a conference at Duke University in October and will submit the paper following feedback from that conference.

In the paper, we derive eight main results. The first five concern cultural sway and institutional performance and three consider the related question of optimal sequencing. First, we find that cultural sway can produce suboptimal equilibrium strategies. Here we're leveraging the logic of the Folk Theorem. This logic enables multiple strategies, including Pareto inferior strategies, to be equilibria of repeated games. Second, we demonstrate that any set of institutions that admit multiple equilibria will be subject to some degree of behavioral path dependence. Third, we relate the level of cultural sway and the set of previous games to the extent of path dependence. Fourth, we show that increasing cultural sway can decrease path dependence because only the initial institutional choice matters. Thus, the *path doesn't*. Finally, we show for a general class of games that optimal institutional designs create strong incentives to choose an equilibrium

but weak punishments for deviating from that equilibrium. Such a design enables more exploration.

The first of our three results on optimal sequencing concerns efficient paths. We show that they include diverse games early and then rely on incrementalism. Second, we show that optimal sequences enable the possibility of path dependence but then avoid it. Third, borrowing the quasi-parameter model of Greif and Laitin (2004), we find that negatively reinforced institutional drift leads to institutional change at an inefficient moment. We have received invitations to discuss this paper at Duke, Penn, and at the American Economic Association Annual Meetings.

Our mathematical contributions also include a formal characterization and categorization of Tipping Points. In that work, we distinguish between tips in parameter space, what we call *contextual tips* and actions that cause the state of the system to change, *direct tips*. In that paper, we also clarify a common conflation of tips with a maximal rate of change. Instead, tips should be seen as changes in the likely state or path of a system. We also mathematically explored a class of models that allowed for paths to be revised. This paper, *Revised Path Dependence*, was coauthored with an undergraduate who is not pursuing a PhD.

During the project we also undertook a variety of computational investigations. The most recent of these are collected in a paper with former student Andrea Jones-Rooy entitled "Choosing a Future based on the Past: Institutions, Behavior, and Path Dependence." This paper was invited for submission to the *European Journal of Political Science.* In the paper, we link institutional features to individuals' behavioral repertoires and then connect those behaviors to choices over future institutional choices. We find that the spillovers often lead to path dependent behaviors, outcomes, and choices over new institutions. The latter effect arises because some subsequent institutions are better able to make use of existing behaviors than others. Further, some behaviors are
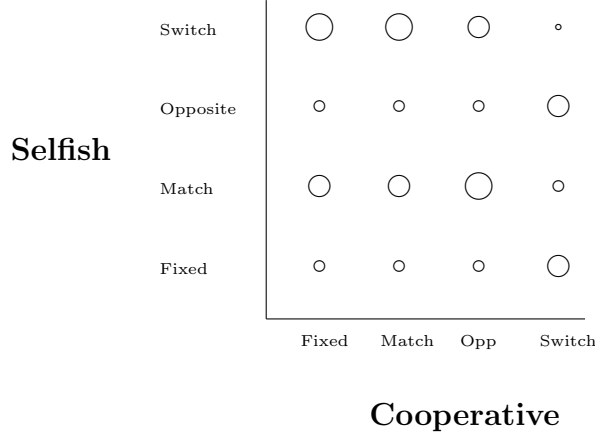
Figure 1: A Randomly Drawn Population of Initial Behaviors

more easily leveraged, i.e. they create more efficient learning environments and therefore reduce path dependence and allow for greater flexibility in future choices.

One of the innovations developed in this paper was a classification of strategies that allows readers to see how institutions influence behaviors. In Figure 1, we show a random configuration of strategies for an automata that has two states, a cooperative state and a selfish state.

In Figure 2, we plot the average of the automata after the agents have learned to play the Knife Edge game (a game in which agents are indifferent between alternating and cooperating). As can be seen in the second figure, the agents tend to evolve: *(match, fixed)*, *(match, match)*, and *(switch, match)* strategies. These correspond to *grim trigger* (assuming the agents cooperate in the first period, which they do), *Tit for Tat* and an *Alternation* strategy.

By comparing such plots over time, we can both statistically measure the degree of spillovers and communicate their magnitude and direction to readers. We see this innovation as substantial.
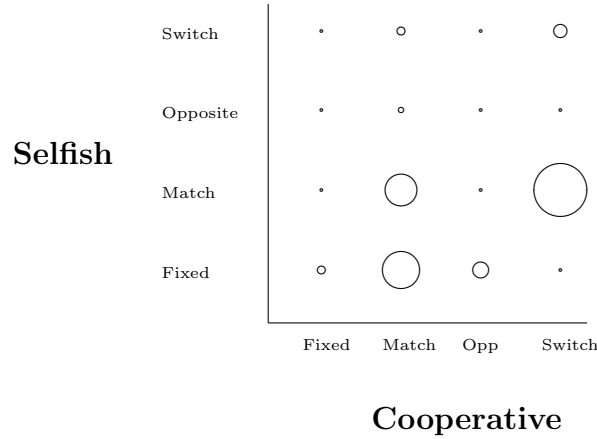
6

Figure 2: Behavior: Knife Edge (100 Trials)

The experimental work that complements these theoretical findings we have discussed at length through the annual reporting process. The most important finding of that work is that the behavioral assumptions that we make in these models are supported by the experiments. Perhaps even more important they have also found support in work by other experimentalists. As evidence accumulates for cross game spillovers in the laboratory, we expect the theoretical project to make an even larger echo.

The ideas that we have developed have gained an audience in other disciplines. Scott Page was invited to write a piece for a leading social psychology journal about diversity, spillovers, and aggregation. In that paper, he describes results from this project and their implications for psychology. Most notably, he focuses on the functional role that diversity might play at the aggregate level.

In addition, he and Helene Landemore, a political philosopher at Yale, explored the implications of diversity of mental models on consensus and showed why consensus may not be an ideal outcome. Instead, meaningful debate may lead to positive dissensus. The connections between this paper and the core project are deep but subtle. Our project

7

considers how institutions influence behavior and how that behavior spills across contexts. That behavior could be one of always reaching consensus, or it might not be. Consensus minded behavior is one of the many types of behavior that could spill from one context to another. The point of the Landemore paper is that while consensus may be good in some settings, it is not good in others and we should not unthinkingly allow consensus behavior to spill from one context to another.

As an aside, we should note that prior to this project, Scott had written in neither of these disciplines. Those projects are a direct result of the expansive inquiry encouraged by this grant and representative of the silo breaking power of funding opportunities such as this.

Relatedly, Jenna Bednar took ideas developed in this project and applied them to constitutional theory with a focus on the current situation in Afghanistan. In her paper, "Prosociality, Federalism, and Cultural Evolution," she argues that constitutions create a culture and that this culture and the law coevolve. She then takes up the question of whether a federal system of government encourages prosocial behavior and applies that framework to the current situation in Afghanistan, a country racked by violence in which individuals lack security. Her goal is not so much to come up with definitive conclusions but to raise the appropriate questions to ask when considering the prospects for constitutional success.

Connections and Outreach

The connections and outreach opportunities that have resulted from this grant exceeded our expectations. We begin with a discussion of conferences. As detailed in earlier reports, we ran a large, successful conference on Culture and Institutions at the University of Michigan in May of 2013. In 2011, Scott Page became the super organizer for the

NSF-NBER Decentralization Conference, the premier economics conference on mechanism design. This position enables him to choose the organizer and the theme for the conference. Next year's theme will be on the future of mechanism design and several of the ideas generated in this project will be among those discussed. Scott also served on the program committee of the 2014 Collective Intelligence conference and this year has been appointed organizer of that conference as well.

We have also made connections to other research groups and projects. The breadth and depth of these connections also surpass expectations. Jenna Bednar is now an organizer of one working group at NIMBioS, and a member of another group. Through that involvement she has developed dialogues with people across disciplines with overlapping interests. These include Peter J. Richerson, Environmental Science and Policy, at the University of California, Davis and Peter Turchin, Ecology and Evolutionary Biology, Mathematics at the University of Connecticut - Storrs. In addition, Scott has been part of IARPA's project on collective wisdom.

Our outreach activities have been substantial. We presented these ideas at conferences and seminars in England, Brazil, Mexico, Poland, Singapore, Malaysia, France, Italy, Sweden, Argentina, Switzerland, Canada, and Germany. We have presented this work at several conferences including at the Priorot Conference on Political Economy and the Venice Conference on Behavioral Political Economy. Among other highlights, were presentations by Jenna Bednar in Brazil at a major conference on law, and a series of lectures by Scott Page in Mexico City in a forum that had previously been afforded to Elinor Ostrom.

In addition to academic talks, Scott Page presented portions of this work to government audiences, including to upper management at the United States Federal Reserve, to leadership at the United States Office of Personnel, and to current and former members of the Singapore civil service. He also presented work from this project at a conference

at Oxford on financial stability partly funded by the Bank of England. He also spoke to corporate audiences, including talks at Google and Boeing. At the time of the grant's completion he was scheduled to give talks to the US Department of Justice, NASA, and both the Chicago and New York Offices of the Federal Reserve. Also, Jenna Bednar had been invited to talk about this work as well as her work on federalism in the U.A.E. at their National Defense College.

As mentioned in the overview, several of the models and ideas developed in this course became part of a highly successful online course called Model Thinking, which has drawn, at last count, approximately half a million students. Scott has given invited talks at the University of Wisconsin and the University of Nebraska related to this experience. We could never have anticipated such an impact.

Finally, we would be remiss if we did not comment on how the grant influenced the lives of the graduate students involved. Three of those students have now completed their PhD's and have taken tenure track positions at major universities. Jessica Steinberg (Indiana University), Tracy Xiao Liu (Tsinghua University), and Andrea Jones-Rooy (NYU-Shanghai) were all involved in projects included in this grant.

Summary

This project has produced a diverse array of scientific advancements methodologically (mathematical, experimental, computational, and interpretative) and when categorized by discipline. Results from this project have been published in political science, engineering, philosophy, policy, and social psychology. This diversity of outlets notwithstanding, all of the research papers address a common core set of issues: the diversity of behavioral repertoires and mental models and how they interact with the performance, design, and choice of political institutions. These advancements align with the original goals of the

project, but the contributions in the form of more than a dozen papers are much broader than we would have dared anticipate.

In addition, the research undertaken in this proposal has created unexpected opportunities: a massive online class with half a million students, leadership on an important NiMBios initiative that furthers this work, a Guggenheim Fellowship, NSF awards, and internal funding to run conferences that further the work. The outreach activities included a large number of academic presentation but they also included opportunities in two domains we could not have anticipated. First, the work attracted interest internationally. And second, the work connected directly to policy issues gathering interest from government agencies. We view all of the opportunities as signals of the quality and value of the research.

Research Output to Date

1. Scott E Page "Where Diversity Comes From and Why it Matters?" *European Journal of Social Psychology* forthcoming

2. Helene Landemore and Scott E Page "Deliberation and Disagreement" *Politics, Philosophy, and Economics* forthcoming

3. Jenna Bednar, "Prosociality, Federalism, and Cultural Evolution." *Cliodynamics: The Journal of Theoretical and Mathematical History* 3(1):81-93, 2012.

4. Jenna Bednar, Yan Chen, and Xiao Liu and Scott Page, "Behavioral spillovers and cognitive load in multiple games: An experimental study." *Game and Economic Behavior* 74:1 pp 12-31,2012.

5. Jenna Bednar, Andrea Jones-Rooy, and Scott E Page "Choosing a Future based on the Past: Institutions, Behavior, and Path Dependence." submitted to the

European Journal of Political Science.

6. Jenna Bendar and Scott E Page, "When Order Affects Performance: Institutional Sequencing, Cultural Sway, and Behavioral Path Dependence" working paper 2014.

7. Jenna Bednar, Scott E Page and Jameson Toole, "Revised Path Dependence" *Political Analysis* 20:2 pp 146-156, 2012.

8. PJ Lamberson and Scott E Page, "Tipping Points" *Quarterly Journal of Political Science* Vol. 7:No 2, pp 175-208, 2012.

9. Scott E Page, "A Complexity Perspective on Institutional Design." *Politics, Philosophy and Economics* Vol 11: 5-25, 2012.

10. Scott E Page, "Aggregation in Agent Based Models of Economies" *Knowledge Engineering Review* 27, 151-162, 2012.

11. Lu Hong, Scott E Page, and Michael P. Wellman, "The Structure of Signals: Causal Interdependence Models for Games of Incomplete Information", 2012.

12. Lu Hong, Scott E Page, and Maria Riolo, "Incentives, Information, and Emergent Collective Accuracy" *Managerial and Decision Economics* 33:5 pp 323 - 334, 2012

13. Scott E Page and Andrea Jones-Rooy, "Systems Effects Revisited" *Critical Review* 2012

14. Evan Economo, Lu Hong, and Scott E Page, "Cognitive Ecologies, Social Structure, and Collective Wisdom" 2013