Science of CI: Resources for Change

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If you are reading this book, then very likely you are a believer in collective intelligence (CI) – and likely a champion. My history begins in the mid-90s when a group of similar-minded scientists at Los Alamos National Laboratory considered the future of the Internet – the Symbiotic Intelligence Project.[2] Collectively we had a vision that individuals using the Internet for their own needs would create a new problem solving capability – a *symbiotic intelligence*, far greater than humankind had seen before. Why did we think a new resource was needed? Even a decade ago faster change and greater interdependency across the planet were creating challenges too complex for the current leaders and organizations. Many of the contributors to this book perceived the same needs and saw that some form of CI was the missing resource for organizations and humanity. At the time we absolutely believed in symbiotic intelligence, but we were deeply afraid that those in power would repress its development, because it could be viewed as a threat. Luckily this book and many efforts like it have proven that CI is alive, proliferating across many practices, and is promising to be the ultimate resource for change.

This contribution focuses on the science side of CI – necessary for the understanding and development of CI resources. The emphasis is on topics that have not been examined in other contributions, reflected in the following questions – each a section heading. 1) What is unique about the Internet that will enable CI to unite all peoples, worldwide? 2) Why is diversity essential for CI? 3) Must we all have the same vision and goals for CI to work? 4) How can the collective solve a problem when the individual can't even understand the solution? 5) Is CI a competitive, cooperative or synergistic process? 6) And finally how does CI fit into traditional models of leadership? A science

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[2] http://CollectiveScience.com/SymIntel.html

perspective provides much-needed tools for understanding the workings of CI and establishing a foundation for the next generation of CI resources.

1. Symbiotic Intelligence: The Future of Humans and IT systems[3]

As many contributors to this book observed, CI is not new – in fact, every social organism from slime molds to social insects to social primates have evolved social structures and the supporting dynamics which enable them to "solve" problems that threaten or limit their existence. What is new is that these CI processes, and new ones yet to evolve, are now applied at unimaginable scales (numbers and spatial extent) than previously observed. This is significant because self-organizing social organisms are observed in nature to have an upper limit in size and extent. For example, beehives will divide into two parts upon reaching a critical number, because above this size the performance of self-organizing processes decline. The cells in a heart above a certain volume cannot coordinate beating, and a heart attack is likely. Even the development of human languages may be driven by the size of the self-organizing social structure, as in India where 100s of incompatible languages occur even without geographic boundaries.

What is unique about the Internet that enables larger numbers over greater extent to self-organize? The Internet has three significant, arguably unique, capabilities beyond prior human-technology systems: 1) *breadth* – the ability to connect quickly, globally heterogeneous systems, 2) *depth* – the ability to capture and retain details of the access and use of information and 3) *accuracy* – the ability with minimal loss to relate and transmit information. All of the modern implementations of CI on the Internet exploit these unique capabilities. For example, the Amazon's product referral system requires rapid access to detailed purchasing histories of individuals (and not bestseller aggregations) with no loss of information. The same is true for Google's recommender system. These unique capabilities overcome the prior thresholds of size and extent previously observed in human-technology systems. And it captures knowledge that was previously lost: when you retrieve a reference from a book on our shelf, only you benefit from it – on the Internet, all can benefit from it. It is fortuitous that the same Internet that created the global challenges of faster change and greater interdependence also provides humans

[3] IT – Information Technology, see http://CollectiveScience.com/SymIntel.html

with the resources to meet these challenges. Or maybe it is not fortuitous – contingency planning is observed routinely in self-organizing systems that continually create innovations!

2. Collective Intelligence: Diversity, Diversity, Diversity

Other contributors to this book have documented how collectives can outperform the average individual and often the expert. Fig. 1 illustrates graphically the relative utility of the expert and the collective (the figure is modified from a book that examines CI in finance[4]). If the problem is simple, all individuals solve the problem well. But as complexity increases, the expert typically has skills or information that increase their utility. At some threshold of complexity – a complexity barrier – even the experts (or groups or organizations, depending on the scale of the problem) are challenged, the quality of the solution is reduced, and their utility declines. The notional curve for the collective captures why many think CI is important. But under what conditions does the collective have utility and what are the limits?

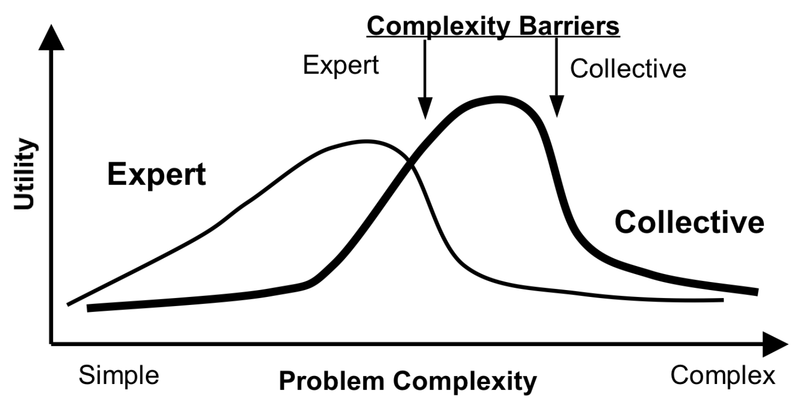

Figure 1: The utility of the expert and collective with increasing complexity

In 1998, this author did an extensive study[5] of how the combined information from a collective of independent individuals can solve a hard

[4] Mauboussin, M. J. (2006). "More than you know: Finding financial wisdom in unconventional places." New York: Columbia University Press.
[5] Johnson, N. L. (1998). *Collective problem solving: Functionality beyond the*

problem – a maze – better than the average individual and often better than the best individual in the group. An analysis found that this CI performance correlated with the uniqueness of each individual contribution to the collective information or, in general, the diversity of the individual contributions. In fact, the study found that diversity, even in performance, was more important than having the best performers in the group. This conclusion reflects the intuition and empirical studies captured in many chapters of this book where diverse groups solve problems better than experts – for complex problems, as reflected in Fig. 1. This result was so unexpected that a reviewer of this paper stated in 1998, "I don't see what is wrong, but it can't be right." Some good ideas are before their times.

A familiar example captures how this form of CI occurs. We all have observed that ants have a remarkable ability to find the shortest path between the dropped potato salad and their nest and that they use their pheromone trails (not their odometers or GPS units!) to accomplish this. Suppose that every ant took the same, non-optimal path initially between the food and the nest. Of course, this collective can only find one path – the wrong one, so it is easy to see that a diversity of path solutions is essential for the ants to find the shortest path. *The maze study also discovered that when the collective finds the shortest path, no one individual is actually taking that shortest path. Instead, the collective shortest path is a composite of diverse individual contributions.* In the ant foraging, only later does one ant and all take the shortest path.

In the maze study, the CI of the group was also found to decline as either the individual performance declined or as the complexity of the problem increased. A way to view this is that the collective solution amplifies the weak signals of the individuals. If the problem is too complex, individuals only contribute noise, and CI is not observed. The collective curve in Fig. 1 captures these conclusions. If the problem is simple, any individual can solve the problem so there is no utility in CI. But as the problem becomes more complex, the individual is challenged by the individual complexity barrier and requires CI to find the optimal solution. And finally, if the problem is too difficult then even the collective hits a "collective" complexity barrier, and the utility of CI declines.

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individual. http://CollectiveScience.com/Documents_1/NLJsims_AB_v11.pdf

Scott Page in his book, *Differences*[6], captures these results in a general "diversity prediction theorem" (a rearrangement of the variance theorem):

Collective error = {Average individual error} – {Prediction diversity}

This theorem illustrates the importance of diversity in the CI solutions. The collective error is reduced as the prediction diversity increases. And why the collective utility declines as the complexity increases: if the individual error increases as the complexity increases, then the collective error also increases. These are powerful and general conclusions about the utility of CI.

3. Compatible Worldviews – A Requirement for CI Synergy

While diversity of the individuals is the primary requirement of the self-organizing CI, another requirement is that the diverse contributions must be compatible. Many facilitators can relate horror stories how major conflicts arise in groups that are "too" diverse. This requirement is often captured as: the individuals agree on goals or objectives. Certainly this is one way to achieve compatibility, but in a complex world where individuals come together with different starting and ending points, a less restrictive requirement is essential. In the maze study discussed above, the conclusion was that compatibility is only required at the decision points where diverse information is combined.

A simple example of this is the foraging ants. Suppose there are multiple food sources that are sufficiently close such that part of the optimal path overlaps. In this example, even though the goals (food sources) may be different, the ants can benefit from the commonality in parts of the path. The human equivalent is commonly called the "water cooler effect": how often do you run into someone that has exactly the piece of information you need for your problem, often by accident, even though your savior does not have the same goal as you. Something to consider: is it possible that it's not an accident, and our gregariousness is designed to make this magic happen?

A way to capture this common "worldview" is to agree on options at each decision point. This does not mean that every individual must have the same preferred option, just that they agree on the set of options. When two

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[6] Page, S. E. (2007). *The Difference: How the power of diversity creates better groups, teams, schools, and societies*. Princeton, NJ: Princeton University Press.

individuals have a different set of options, then the options that are not common often become the source of conflict. As many facilitators know, often restating the problem (and creating a different decision path) can create worldviews that are compatible. For example, consider the following two problem statements. Unwanted births can be achieved by terminating pregnancy. Healthy communities value all their members. The first leads to an immediate disagreement on options, while the second invites synergy of ideas.

4. Sweet Spot of CI: Between Competition and Cooperation

The main reason that the many believe that a diverse collective cannot outperform an expert is because the dominant paradigm for group performance is from competitive processes: competition between smart individuals finds the best solution – the social equivalent of Darwinism. Doesn't your organization hire the best and reward the top performers? So it is unthinkable that a diversity of individual performance is preferred over a team of high performers. Yet, every manager that I've met can relate an instance where magic happened in a diverse team. Part of the answer to resolving this conflict between paradigms lies in Fig. 1: for problems of moderate complexity, engage the expert to solve the problem, but as the complexity increases beyond the ability of the expert, a diverse collective is needed to solve the problem. But here's the problem: we think the way to get a diverse collective working well together is through cooperation. But many contributors of this book warn of the hazards too much cooperation: group-think and herd mentality. Herein lies the challenge: how are the different collective performance paradigms related and how does a group transition from competitive to cooperative?

In studies of self-organizing systems[7], three different mechanisms for collective performance are observed and typically are sequential in a developmental process: 1) *Formative*: the group improves by the improvement of individual performance via competitive processes, 2) *Synergistic*: the group improves by the synergy of individual differences via the diverse CI processes discussed above, and finally, 3) *Condensed*: the group converges on an optimal solution, through cooperation and often codification. In the ant foraging

[7] Johnson, N. L. (2002). *The Development of Collective Structure and Its Response to Environmental Change*. *S.E.E.D.* Journal, ***2*** (3), 84–113. http://www.library.utoronto.ca/see/SEED/Vol2-3/2-3%20resolved/Johnson.htm

example and in Fig. 1, all stages are captured. For moderate complexity problems, individuals can competitively solve their local path problem, while the collective "synergistically" discovers the global optimal path, and later most individuals "condense" to the best collective solution. For simple problems, one ant finds the best solution, and the collective condenses to this one solution – the synergistic stage is skipped. Or for difficult problems, the synergy of the diverse group may never occur and the individuals will remain competitive.

The above reinforces the earlier guidance of matching the performance processes to the complexity of the problem. The developmental view of self-organizing systems provides additional guidelines: 1) collective performance develops in predictable stages – enable rather than fight these – for example, if the problem is challenging for the individuals, then competitive processes may dominate even when synergistic or cooperative processes are desired, 2) increasing rates of change (a type of complexity) will force a self-organizing collective to earlier developmental stages, 3) in dynamic environments the performance and robustness of the synergistic stage is a sweet spot and, 4) beware of the lack of robustness of the optimized, low-diversity condensed stage, e.g., one failure in an assembly line will bring down the whole system.

5. Emergent CI: When the Individual Is Clueless & the Collective Is Smart

Many of the above science-based concepts of CI are intuitive and are aligned with the observations found in other chapters. But there is also an aspect of the above studies that is profoundly challenging, yet at the same time, possibly the greatest potential of CI. Again, we use the ant foraging example to illustrate the concept of *emergent CI*. As mentioned earlier, the collective finds a shortest path even though an individual does not have the resources to know if their path is optimal or even better. In essence, the individual is contributing to a global collective solution – the shortest path – that cannot be understood by individual. This is a classic example of an *emergent property* commonly used in complexity studies: when a global property cannot be determined from knowledge of the components. In the foraging examples, the shortest path is an emergent property. But because the individuals cannot comprehend a shortest path, these systems also express emergent problem definition, where even the global problem definition is not understood at the individual level.

Some examples of human emergent problem definition and solution are illustrative. The first example is the Bali water distribution system[8] where along a typical river, small groups of farmers meet regularly in water temples to locally manage their irrigation systems. What is remarkable is that the distribution of water is globally optimized by these local rituals to large changes in the total water flow, ensuring water for everyone along the river. Interestingly, there is no evidence that the local rituals were planned to have global optimization. While it is an outstanding research problem of how such an emergent CI system evolves, the two essential observations are that 1) by each group focusing on their own problem, the system self-organizes to a global optimum – to the benefit of all and 2) the local groups are not aware of the global optimization, although all the groups of farmers benefit from this emergent CI. A second example is the fall of Berlin wall – one that caught the world by surprise. It was not predicted, nor was it planned in any localized sense: the individuals that participated in the process that led up to the event never had that goal, nor knew that this was a possible outcome of their activities. It just happened as an emergent CI solution to a collective problem. There are likely many examples of emergent problem definition and solution in the history of humans, but because historians are not generally appreciative of CI, these emergent CI solutions are attributed to the "leaders".

6. Leadership and Collective Intelligence

Collective intelligence is a threatening concept to many leaders: how can a leader be a leader if they defer their intelligence to the collective? One way of packaging CI so that it is more acceptable is to capture it as another form of leadership. This repackaging of CI has proven to be readily digestible to a wide variety of particularly diehard leaders, such as physicians and scientists, possibly because traditional forms of leadership are being challenged and the availability of more powerful resources for leadership is attractive, if not essential. The following builds on the concepts discussed above.

Many lament the lack of clarity in the field of leadership, for example, Cecil Gibb: "The concept of leadership has largely lost its value for the social

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[8] Lansing, J. S. (2006). "Perfect order: Recognizing complexity in Bali." Princeton, N.J., Princeton University Press.

sciences, although it remains indispensable to general discourse."[9] To stay above this swamp the approach taken here is to observe the broad shifts in leadership theories:[10] 1) the shift of the basis of leadership from power or structure (sustaining a leadership position by rules) to performance and 2) the shift from localized leadership to more distributed leadership. Two conclusions directly result, respectively: 1) leadership should include all processes that lead to higher performance – specifically CI, and 2) CI is the best framework to understand distributed leadership.

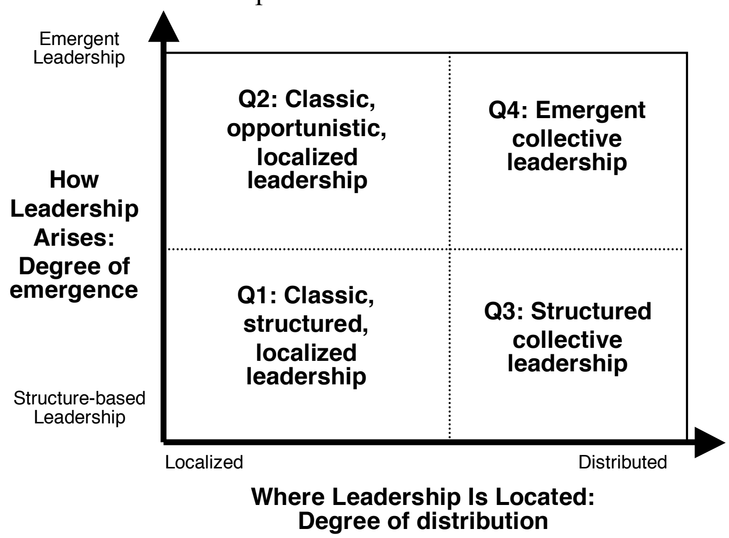

Figure 2: A Leadership Landscape with CI included (right column)

To capture the intersection of CI and leadership, a landscape, as in Fig. 2, is defined[11] with one axis being "*How leadership arises: degree of emergence*" and the other "*Where leadership arises: degree of distribution.*"

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[9] Gibb, C. (1968). Leadership: Psychological Aspects. International Encyclopedia of the Social Sciences. D. L. Sills. New York, Macmillan. **9**, 91-101.
[10] Hazy, J. K., J. A. Goldstein, et al. (2007). Complex Systems Leadership Theory: New Perspectives from Complexity Science on Social and Organizational Effectiveness. Mansfield, MA 02048, ISCE Publishing.
[11] Johnson, N. L. and J. H. Watkins, "Emergent Collective Leadership: The Next Frontier of Decision making", in progress

The *degree of distribution* is the number of individuals required for a leadership decision (the emphasis is on the decision and not the execution of the decision) and ranges from one for a single leader to the entire group. A quantitative measure for emergence is challenging at best and is a controversial topic of research. For the current context, the *degree of emergence* is defined as the difference between the number of flexible, synergistic, or unpredictable interactions needed for the leadership decision minus the number of prescribed interactions supporting the decision, all divided by the sum of these two numbers. This emergence metric ranges from -1 for rigid, rule-based leadership to a number approaching +1 for highly emergent leadership. For simplicity, as in Fig. 2, the landscape is divided into four quadrants. The quadrants Q1 and Q2 represent respectively the classical types of leadership: localized power or structure and emergent leadership as in a hero. The quadrants Q3 and Q4 capture the two extremes of CI: the structural-based CI[12] such as democracies or information-enabled CI to the emergent forms of CI discussed above.

This leadership landscape is an ideal framework to summarize the science-based CI discoveries presented in this chapter. We began with research on how the synergy of humans and the Internet may solve the hardest problems facing humanity, captured by the CI leadership resources (Q3-Q4) in Fig 2. We then found that diversity is the essential requirement for CI performance. Therefore, as leadership resources move to the right of the landscape, diversity of the collective must be developed and expressed, and “leaders” will become facilitators of the collective wisdom. We also found that as the complexity of problems increases, the collective will perform better and be more resilient to change. Therefore, to better address the modern challenges of faster change and greater interdependence, the CI leadership resources (Q3-Q4) must be better understood, developed and utilized. And finally, the greatest challenge but also the greatest opportunity is to enable the leadership processes of emergent CI (Q4) where global solutions are found by individuals solving their own local problems, but where the emergent solution is possibly beyond individual understanding. To enable emergent CI, individuals must not only express their diversity, but also share a common worldview – developed by greater understanding, openness, and acceptance of each other.

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[12] Watkins, J. H. and M. A. Rodriguez (2007). "A Survey of Web-based Collective Decision Making Systems." Submitted for publication.