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Scientific Convergence: Dealing with the Elephant in the Room

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Breakthrough innovations in science often require more than just interdisciplinary collaboration. Rather, they rely on the *convergence* of different tools, skill sets, knowledge, and problem solving approaches from complementary disciples to explore new areas of science.[1] Like the parable of the blind men and the elephant, scientists independently working in individual domains are each unable to see the full underlying nature and implications of a problem (isolated view, Figure 1a). Those who get input from or provide output to colleagues in other domains have a better but still limited understanding (coordinated view, Figure 1b), while those who wholly collaborate with colleagues and take collective action toward discovery have the best understanding of the problem's nature and complexities (convergent view, Figure 1c). We argue that decision-analytic techniques like multicriteria decision analysis which provide a mathematical approach to problem decomposition and preference ranking[2,3] can enable funding and academic institutions to more effectively promote convergence using the action alternatives available to them and fuel technology innovation.

Convergence has been used to describe a growing need for collaboration between different fields of inquiry to foster innovation on inherently interdisciplinary problems of increasing complexity. The National Science Foundation (NSF[1,4]) has acknowledged the importance of these efforts and has made recommendations to promote convergence, particularly among areas of research where nanotechnology can play a meaningful role. The National Academy of Science (NAS) has made sustained efforts to promote convergence as well, for example, within the natural sciences, and recently issued a report evaluating key challenge areas for convergence and provide practical recommendations to institutions.[5]

Two widely used institutional approaches to promote convergence, which are recommended in the NAS report include organizing scientists into committees and working groups, and colocating scientists from different disciplines to achieve innovations. The National Nanotechnology Initiative (NNI, www.nano.gov), a pioneering application of convergence within the government, is comprised of representatives from a variety of federal organizations (NIH, DOD, DOE, FDA, etc.) responsible for nanotechnology research and development, and regulation. The NNI provides a forum for coordinating funding priorities across agencies and organizing working groups to develop recommended actions to address a host of interdisciplinary issues in the area of nanotechnology. While the structure of NNI is well-defined, the way in which individual member organizations provide recommendations and decide on how best to coordinate their individual actions could benefit from prescriptive guidance in service of achieving mutually beneficial and convergent outcomes.

In another example, the MIT-Harvard Center of Cancer Nanotechnology Excellence, housed at the Koch Institute for Integrative Cancer Research (ki.mit.edu), promotes convergence by colocating scientists from different fields in the hopes of developing interdisciplinary solutions (e.g., cancer nanotherapies) through chance exposures to other researchers from other fields during the normal course of business. Researchers from complementary disciplines are sited strategically so they walk by each other to access shared resources (e.g., printers, lab space). Similar collaborative research facilities construct versatile working spaces to facilitate interaction between scientists and engineers with complementary research foci. This encourages scientists to be creative in connecting with others and move beyond the comfort zone of their limited disciplinary expertise. Both the composition of interagency committees and selection of scientists for centers were designed based on ad-hoc hypotheses on which disciplines would interface best with which others in the service of common goals.

Although both NNI and the MIT-Harvard Center are examples of successful institutional actions that promote aspects of convergence and are consistent with NAS recommendations, we believe initiatives like these could benefit from a deliberate decision-analytic process to evaluate options for fostering convergence. These processes can help identify and encourage the right scientists from the right disciplines to take collective action toward solving complex interdisciplinary

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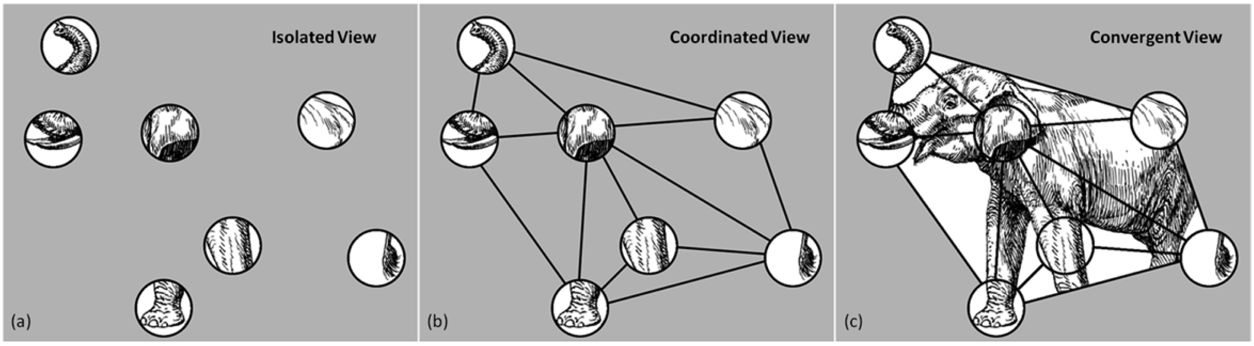

Figure 1. Isolated, coordinated, and convergent views of science collaboration. Circles represent independent views of individual disciplines. Scientists operating under the convergent view wholly collaborate with colleagues from other disciplines, fully integrating and coordinate their research activities. The distinct scientific disciplines converge here to provide the greatest understanding of the underlying problem.

scientific problems by giving institutions the tools needed to create and strategically evaluate actions related to coordination, colocation, grant funding, etc. Decision-analytic approaches guide organizations in identifying and prioritizing their common objectives and identifying specific criteria and metrics that can support those goals. Through this framework of objectives and supporting factors, the decision-analytical process enables transparent evaluation of alternative ways to indirectly influencing scientists from the desired disciplines to work together in a manner that provides the best chance of developing new knowledge about the problem and solving it. In the analogy outlined in Figure 1, this would be similar to taking actions that would engage the best combination of nodes in the "Convergent View" (Figure 1c) to reveal the largest and most appropriate area of the problem between network edges.

Multicriteria decision analysis (MCDA),[2] one of several formal decision-analytical techniques,[3] is ideally suited for promoting convergence and provides a structure that institutions can use to evaluate different actions based on the following:

- The *objective(s)* they would like to achieve, in this case solving one or more scientific problems requiring convergence of experts from different disciplines;
- The *criteria* which contribute to achieving objectives, here the collection of disciplines which the institution hypothesizes are required to achieve the objectives;
- and *metrics* that can be used to quantify the relative effectiveness of any one *alternative* in addressing the criteria and therefore objectives. Alternatives in this context are different institutional actions which promote convergence, e.g., an interdisciplinary institute with colocated scientists engaging in strategically funded collaborative investigations.

The MCDA process should be incorporated into the process of designing and evaluating institutional convergence efforts actions either formally when selecting among actions, or informally to facilitate the design and development of convergence actions in a way that directly address convergence objectives and relevant constraints. This process will help institutions like funding agencies, universities, and other research organizations to evolve beyond historic research approaches that focus on identifying which discipline should be responsible for solving a specific problem. It promotes an approach where different unique disciplinary synergies and perspectives can be leveraged to solve breakthrough problems. The result of implementing these processes over time will be a research environment that through careful reflection and prioritization and positioned itself to better promote convergence and to be more productive with respect to the hard problems facing the scientific and technological community now and in the future.

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Notes

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REFERENCES

(1) Roco, M. C.; Bainbridge, W. S.; Tonn, B.; Whitesides, G. *Convergence of Knowledge, Technology, and Society: Beyond Convergence of Nano-Bio-Info-Cognitive Technologies*; Springer: New York, 2013.

(2) Linkov, I.; Moberg, E. *Multi-Criteria Decision Analysis: Environmental Applications and Case Studies*; CRC Press: Boca Raton, FL, 2011.

(3) Clemen, R. T.; Reilly, T. *Making Hard Decisions with DecisionTools*; Duxbury/Thomson Learning: New York, 2000.

(4) Roco, M. C.; Bainbridge, W. S. *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science*; Kluwer Academic Publishers: Dordrecht, The Netherlands, 2003.

(5) National Academies. *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond*; National Academies Press: Washington, DC, 2014.