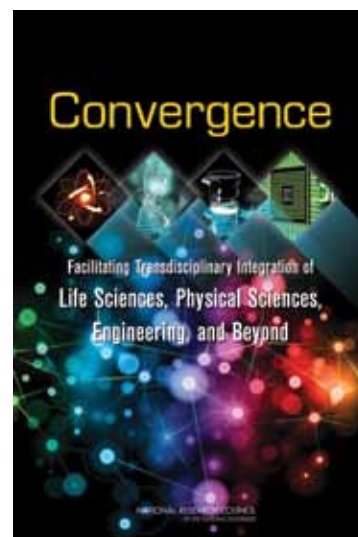


## Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond

**NEW BIOFUELS, 3-D PRINTING OF HUMAN TISSUES,** and more precise drug delivery systems are just a few examples of innovations that combine insights and approaches from the life and health sciences with those from the physical, mathematical, and computational sciences and engineering. This report focuses on the need for “convergence”—an approach to problem solving that integrates the knowledge, tools, and ways of thinking from multiple scientific disciplines, including economic, social, and behavioral sciences. “Convergent” research could lead to many more breakthroughs that improve lives and strengthen the economy, but cultural and institutional barriers hamper its development. This report examines lessons learned from an analysis of approaches for fostering convergence in different types of research institutions. The report calls for sustained national coordination to build the infrastructure needed to solve problems that transcend traditional disciplinary boundaries.



**It has been said that the 21st century** will become the “century of biology,” enabled by the impressive progress made in understanding the molecular basis of life. Fifty years after Watson and Crick determined the structure of DNA, the ability to sequence, computationally compare, and interact with the complexity of the human genome at relatively low cost has spawned revolutions ranging from genomics to bioinformatics. A critical dimension of this new century will be the further integration of life sciences with other disciplines, and vice versa.

Convergence is an approach to problem solving that cuts across disciplinary boundaries. It integrates knowledge, tools, and ways of thinking from life and health sciences, physical, mathematical, and computational sciences,<sup>1</sup> engineering disciplines, and beyond to form a comprehensive synthetic framework for tackling scientific and societal challenges that exist at the interfaces of multiple

fields. In this report, convergence also refers to the formation of the web of partnerships needed to support convergent scientific investigations and translate the resultant advances into new products and innovations.

Convergence can represent a culture shift for academic organizations that are traditionally organized around discipline-based departments. Consequently, the challenges inherent in creating the necessary administrative, research, teaching, partnership, and funding structures can be significant. Based on a workshop in September 2013 that brought together many members of the community interested in fostering convergence, this report identifies common challenges and explores lessons learned from efforts to date.

### CONVERGENCE TO DATE

The goal of merging expertise is not new, and there are myriad examples in which researchers from multiple disciplines have worked together to solve problems. This “interdisciplinary” approach has been a common feature of industrial research laboratories since the 1920s. An array of reports from the National Research Council (NRC) has examined

<sup>1</sup> Throughout the report, the term “physical sciences” is commonly used as shorthand to include fields such as physics, chemistry, materials science, and the mathematical and computational sciences.

opportunities enabled by science that occur at the intersections of disciplines.

The key message of convergence, however, is that merging ideas, approaches, and technologies from widely diverse fields of knowledge at a high level of integration is one crucial strategy for solving complex problems and addressing complex intellectual questions underlying emerging disciplines and new technologies (see Box 1). For example, the combination of genetics, chemistry, optics, and bioinformatics produced genomics. Of necessity, convergence requires an open and inclusive culture, and for practitioners to become conversant across disciplines and common set of concepts and metrics and understanding of goals.

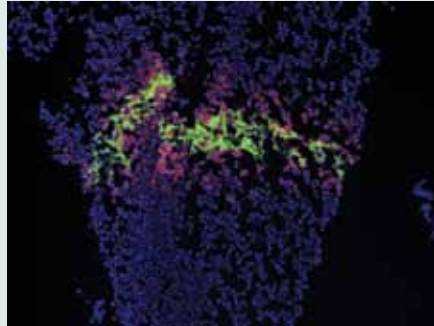
Several U.S. academic institutions already have set up programs to support convergent research. Convergence is also embedded in innovative government programs. The Department of Energy's Advanced Research Projects Agency—Energy (ARPA-E), which was authorized under the 2007 America COMPETES Act and established in 2009 has had several successful research efforts during its short history. One such project bridges the fields of synthetic biology, microbiology, and chemistry to develop electrofuels, a potentially more efficient type of renewable fuel produced by microbes from electricity and feedstocks such as carbon dioxide and hydrogen.

### **BARRIERS TO IMPLEMENTING CONVERGENCE**

Many institutions are interested in how they can better facilitate convergent research. Even with the presence of institutional models for convergent research, cultural and institutional roadblocks can slow the creation of self-sustaining ecosystems of convergence. Institutions often have little guidance on how to establish effective programs, what challenges they might encounter, and what strategies other organizations have used to solve the problems that arise.

### **Box 1. Why convergence? Applying 3d printing to biomedical uses**

Applying 3D printing to the creation of functional, living tissue requires integrating knowledge from life sciences on how to sustain the viability of cells throughout the printing process, from material science on biocompatible scaffolding to support the cells, and from electrical and mechanical engineering to design and construct the device. Academic, industrial, clinical, and regulatory partnerships are required to transition printed tissues from the laboratory to health system use. Addressing this research frontier by bringing together multiple fields has led to progress that no single discipline could have achieved alone.



*Convergence-led advances in 3-D printing have allowed scientists to generate layers of different cell types to replicate the structure and function of human liver tissue. This cross-section of bioprinted human liver tissue shows hepatocytes (shown as blue nuclei), endothelial cells (red), and hepatic stellate cells (green). SOURCE: Courtesy of Organovo*

Stakeholders across the research enterprise will need to think strategically about the policies that support such efforts and how to implement and sustain them. For example, how can students be trained to work on challenges that cross disciplinary boundaries? How can recruitment take place across department and college lines? How can faculty members engaged in convergent research be properly evaluated if promotion and tenure is obtained through a primary departmental affiliation?

Fortunately, the toolkit to foster convergence can be informed by the base of existing literature on establishing interdisciplinary cultures, supporting team-based science, and revising science, technology, engineering, and mathematics (STEM) education and training. It can also be informed by examples drawn from industry, which has a tradition of integrating expertise to tackle complex challenges.

### **STRATEGIES FOR FACILITATING CONVERGENCE**

If the United States wishes to capture the momentum generated by convergence and foster its further development, the committee recommends a set of actions that involved parties could take to achieve desired outcomes (see Table 1). The report identifies strategies and practices used by institutions to facilitate convergence endeavors (see Box 2), such as designing educational modules,

## Box 2. Strategies and practices used by institutions to facilitate convergence endeavors

- Organizing around a common theme, problem, or scientific challenge;
- Implementing management structures tailored to the challenges to convergence in each institution;
- Fostering opportunities to interact formally and informally;
- Changing existing faculty structures and reward systems;
- Working with and across existing departments;
- Embedding support for convergence in the promotion and tenure process;
- Designing facilities and workspaces for convergent research;
- Designing education and training programs that foster convergence;
- Establishing partnership arrangements across institutions; and
- Exploring sources of funding within and beyond government agencies.

**Table 1. Summary of Recommendations**

Actors	Actions	Desired Outcomes
National vision-setting body	<ul style="list-style-type: none"> <li>• Foster coordination on convergence</li> <li>• Build public and professional awareness of convergence as a catalyst of new scientific and technical knowledge and applications</li> </ul>	<ul style="list-style-type: none"> <li>• Accelerated innovation and economic growth</li> <li>• A national infrastructure that can solve emerging problems which transcend traditional boundaries</li> </ul>
Funder of science and technology innovation	<ul style="list-style-type: none"> <li>• Identify problems that would benefit from convergence approaches</li> <li>• Address barriers to effective convergence, both within and across institutions</li> </ul>	<ul style="list-style-type: none"> <li>• Expanded mechanisms for funding convergent research</li> <li>• Collaborative proposal review across funding organizations when needed</li> </ul>
Academic leader	<ul style="list-style-type: none"> <li>• Address barriers to effective convergence partnerships, both within and across institutions</li> <li>• Develop policies, practices, and guidelines to support and evaluate convergent and disciplinary research equally</li> <li>• Utilize the expertise of economic, social, and behavioral sciences, as well as program management and strategic planning fields when planning an initiative</li> </ul>	<ul style="list-style-type: none"> <li>• Recruitment practices, cost-recovery models, and research support policies that facilitate convergence, including catalytic seed funding</li> <li>• Promotion and tenure policies that recognize the importance of convergence and have unique evaluation criteria for those faculty</li> <li>• Evidence-based practices for facilitating convergence effectively</li> <li>• More convergence efforts, partnerships, synergies, and collaborations, particularly at small universities and institutions that serve traditionally underrepresented groups</li> </ul>
Government laboratory	<ul style="list-style-type: none"> <li>• Develop partnerships, synergies and collaborations with colleagues across institutions and from a wide range of fields</li> <li>• Facilitate efficient transfer of technologies derived from convergence research</li> </ul>	<ul style="list-style-type: none"> <li>• Evidence-based practices for facilitating convergence effectively</li> <li>• New products and services derived from convergent research</li> </ul>
Industry, medical, or regulatory stakeholder	<ul style="list-style-type: none"> <li>• Address barriers to effective convergence partnerships across institutions</li> <li>• Facilitate efficient transfer of technologies derived from convergence research</li> </ul>	<ul style="list-style-type: none"> <li>• Expanded mechanisms for funding convergent research</li> <li>• New products and services derived from convergent research</li> </ul>

hiring faculty in transdisciplinary clusters, and establishing new research institutes. The report also provides examples of relatively simple and low cost practices to consider as first steps in fostering convergence, such as hosting social events to discuss convergent research.

Because institutions range widely in characteristics such as missions, sizes, and available budgets, no single template can be followed in establishing convergence efforts. However, essential cultural and structural elements in successful convergence ecosystems include:

- **People:** A commitment to supporting convergence from all levels of leadership is key, as is the involvement of students, faculty members and staff, department chairs, and deans.
- **Organization:** Inclusive governance systems, a goal-oriented vision, effective program management, stable support for core facilities, and flexible or catalytic funding sources are all critical to organizations seeking to build a sustainable convergence ecosystem.
- **Culture:** The culture needed to support convergence, as with other types of collaborative research, is one that is inclusive, supports mutual

respect across disciplines, encourages opportunities to share knowledge, and fosters scientists' ability to be conversant across disciplines

- **Ecosystem:** The overall ecosystem of convergence involves dynamic interactions with multiple partners within and across institutions, and thus requires strategies to address the technical and logistical partnership agreements required.

## NATIONAL COORDINATION IS NEEDED

The scientific opportunities enabled by convergence will make fundamental contributions in our drive to provide creative solutions to the most difficult problems facing us as a society. To move beyond the patchwork of current efforts, national coordination on convergence is needed. A national focus would accomplish several goals. It would catalyze stakeholders to identify emerging topics at the frontiers of science where convergence will be critical to achieving new insights and would engage the vibrant community of institutional leaders and interested researchers, both younger and senior, who are already undertaking convergence. Community input on the investment priorities in research, education, and infrastructure will help maximize the benefits of convergence to society.

Locate additional information, including related reports, at <http://dels.nas.edu/bls>

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The National Academies appointed the above committee of experts to address the specific task requested by the Raymond and Beverley Sackler Science Fund of the National Academy of Sciences, Burroughs Wellcome Fund, Kavli Foundation, Research Corporation for Science Advancement, the National Science Foundation, National Institutes of Health, William R. Kenan, Jr. Institute for Engineering, Technology & Science of North Carolina State University, Frank Hawkins Kenan Institute of Private Enterprise of the University of North Carolina at Chapel Hill, and Connecticut Institute for Clinical and Translational Science at the University of Connecticut. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

For more information, contact the Board on Life Sciences at (202) 334-2638 or visit <http://dels.nas.edu/bls>. Copies of *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering, and Beyond* are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; [www.nap.edu](http://www.nap.edu).

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