Convergence education—an international perspective

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Abstract The US National Science Foundation defines convergence as the deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks for addressing scientific and societal challenges and opportunities. Because convergence research is progressing at a rapid clip, the quick evolution of non-traditional perspectives that it engenders will present a number of challenges/opportunities to education. NSF, the Organization for Economic Cooperation and Development; the US National Academies of Sciences, Engineering and Medicine; and the University of Southern California sponsored a workshop, with global participation, to explore actions that

would facilitate convergence in education. A descriptive of the workshop and the key action items it identified are presented.

Keywords Convergence · Education · Nanotechnology · STEAM · Global · Workforce

This is a summary of the workshop report “Global Perspectives in Convergence Education,” available on the website www.nsf.gov/nano/ConvergenceEducation

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Introduction

The field of Nanoscale Science and Engineering is a “poster child” for examining the educational issues/challenges associated with convergence. So, attention to Convergence Education is highly pertinent to nanoscale science and engineering, as well as addressing the larger societal implications.

Education is imposing a growing cost to society (~\$1 T/year US) and to students (~20% of one’s life devoted to formal schooling). The challenges/opportunities raised by convergence include:

1. How to incorporate the growing amount of new knowledge—must either pare/compress existing course material, extend the time at school, or build on a convergent educational paradigm that synergistically leverages formal and informal educational infrastructures.
2. Convergence accelerates the creation of new knowledge that does not fit neatly into traditional curricula
3. There are language barriers between disciplines

4. The existing teacher cadre in K-12 not appropriately trained in STEAM (Science, Technology, Engineering, Arts, Mathematics)
5. Paper-based textbooks have a 20-year lifetime, due to cost recovery, which makes them hard to keep timely
6. Careers are extending in length and thereby require continuing education to keep current
7. The education/workforce development appropriate to future needs is hard to project
8. Entrenched bureaucracy and business interests protect the status quo and slow progress
9. New technologies and approaches are coming available with the potential to transform education

The workshop participants examined and discussed these issues with a global perspective and then provide prioritized, actionable items to address the challenges.

Defining convergence

NSF defines convergence as the deep integration of knowledge, techniques, and expertise from multiple fields to form new and expanded frameworks for addressing scientific and societal challenges and opportunities (<https://www.nsf.gov/od/oia/convergence/index.jsp>). Convergence refers to not only the convergence of expertise across disciplines but also the convergence of academic, government, and industry stakeholders to support scientific investigations and enable rapid translation of the resulting advances (NASEM 2014). With the continued growth in science and engineering knowledge and the growing evolution toward deep interactions among and between the various academic disciplines, convergence is becoming a real challenge to the formal and informal education communities.

Previous work

There have been prior efforts toward exploring convergence education. In 2003, a book, *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science*, was published with eight contributions addressing education (Roco and Bainbridge 2003). In 2013, a book, *Convergence of Knowledge, Technology, and Society: Beyond Convergence of Nano-Bio-Info-*

Cognitive Technologies, summarizing the results from a series of international workshops, was published with Chapter 8 providing an extensive discussion on “Implications: People and Physical Infrastructure” (Roco et al. 2013). In 2014, the US National Academies of Sciences, Engineering and Medicine (NASEM) released a report *Convergence: Facilitating Transdisciplinary Integration of Life Sciences, Physical Sciences, Engineering and Beyond* (NASEM 2014). This was followed in 2016 by an MIT study on “Convergence: The Future of Health” (Sharp, Jacks, and Hockfield 2016). Also in 2016, a Handbook of Science and Technology Convergence was published, including twelve contributions addressing education needs (Bainbridge and Roco 2016). NSF identified “Growing Convergent Research at NSF” as one of its “Big Ideas” (NSF 2017). In March of 2018, NSF released NSF 18-058, a Dear Colleague Letter: Growing Convergence Research (NSF 2018).

Convergence integrates knowledge, tools, and ways of thinking and communicating from life and health sciences, social sciences, the humanities and the arts, physical, mathematical, and computational sciences, engineering disciplines, and beyond to form a comprehensive framework for tackling scientific and societal challenges that exist at the interfaces of multiple fields. But it is not just research discoveries that are motivating convergence. By merging these diverse areas of expertise in a network of partnerships, convergence stimulates transitions from basic science discovery to practical, innovative applications. As just one example of the ongoing commercial impact of convergence, nanotechnology presently has a ~\$1.5 billion annual US Federal investment, with equivalent amounts being spent in other sectors of the world. A recent National Academies of Sciences, Engineering and Medicine (NASEM) report on the National Nanotechnology Initiative (NNI) cites ~\$200 billion annual growth in nano-enabled commercial products in recent years (NASEM 2016). Similar results can be expected from convergent-enabled biomedical technologies; this assertion is a premise of the MIT study, which states that more than \$3 trillion per year—17.5% of US gross domestic product—is spent in national healthcare expenditures (Sharp et al. 2016). These two examples highlight the fact that there will be new products, and thereby workforce education needs, caused by convergence in science, engineering, and technologies.

The OECD Working Party on Biotechnology, Nanotechnology and Converging Technologies (BNCT) has identified a number of convergence instances as part of a

general development of the fields of biotechnology and nanotechnology over the last two decades; the BNCT found that the field of biotechnology broadened to include a growing area of topics, while the field of nanotechnology shifted from its original focus on metallurgy- and engineering-centric topics toward the biological sciences (Friedrichs 2018).

Overview of the workshop

The goal of an “up-to-date” STEAM education is a moving target; the global investment in science and engineering research leads to the continual development of new information and knowledge. The scope of the problem is highlighted in Fig. 1.

According to Richey, it is of utmost importance to stay abreast of this development, in order to adequately prepare society for the disappearance of old jobs and the arrival of new ones.

Building on a workshop addressing “Nanoscale Science and Engineering Education—The Next Steps” (Winkelmann and Bhushan 2016), the National Science Foundation (NSF), the Organization for Economic Cooperation and Development (OECD), the US National Academy of Sciences, Engineering and Medicine (NASEM), and the University of Southern California (USC), sponsored a second workshop “Global Perspectives in Convergence Education.” It addressed the outlook and needs across the stages of education; an integrated approach is necessary since the stages of education—from K-12 through adult continuing education—are highly interrelated. Given the already extensive number of years needed to complete formal education and the ever-growing extent of knowledge to be imparted to ready students to be a fully functional adult, it is important to make learning more effective. It is also important to engage continuing education since an individual’s time in the workforce, and the knowledge needed to be effective there, will both be continuously growing. Finally, education has become more global than ever, so participants from around the world participated in the workshop to share experiences and lessons learned.

The workshop included plenary sessions to set the stage and provide context on the current state of convergence and convergence education. The plenaries were followed by breakout sessions with both formal presentations and group discussion. Each breakout session emphasized developing prioritized, actionable

recommendations to address the challenges of convergence education. These sessions were focused on:

- Teaching convergence and responsible science via the concept of “grand challenges;”
- Incorporating convergence into curricula and continuing education programs;
- Developing mechanism(s) to keep abreast of the changing workforce education needs;
- Identifying how best to “synchronize” or properly coordinate changes in educational institutions and society with changes in funding agencies;
- Understanding the science of team science and its role in convergence education;
- Elucidating new technologies and approaches for advancing convergence in education and training; and
- Coordinating and fostering global convergence education via enhanced communication among national science funding agencies and multilateral fora to coordinate and foster global convergence education.

The presentations at the workshop were:

- *Convergence science for Societal Progress and Education*, Mike Roco, NSF
- *Learning in a World of Convergence*, Susan Singer, Rollins College
- *Convergence in Professional Education*, Michael Richey, The Boeing Company
- *AAC&U Perspective*, Amy Jessen-Marshall, Assoc. of American Colleges and Universities
- *OECD Perspective*, Steffi Friedrichs, OECD
- *Convergence Education in Synthetic Biology/Engineering Biology*, Richard Kitney, Imperial College of London, UK
- *Three Universities, One MSc Program*, Olof Emanuelsson, Royal Institute of Technology, Sweden
- *Convergence Education: A Korean Perspective*, Y. Eugene Pak, Seoul National University, South Korea
- *The Roles of Convergence and Responsible Research in Education*, Dan Herr, Joint School of Nanoscience and Nanoengineering
- *Research-based Insights for Teaching Convergence via Grand Challenges*, Heidi Schweingruber, National Academy of Sciences
- *POSTECH CITE: Creative Convergence Education*, Jin-Taek Kim, Pohang University of Science and Technology

Fig. 1 Timeline for information convergence and complexity (from workshop plenary presentation by Dr. Michael Richey, The Boeing Company)

- *Convergence Education Initiatives in Mexico*, Fernando Quezada, Biotechnology Center of Excellence Corp
 - *Strengthening Research Capacities in Nicaragua: A Convergence Research Approach*, Jorge Huete-Perez, University of Central America
 - *Keeping up with Changing Workforce Education Needs for Convergence*, Margaret Hilton, Board on Science Education, National Academy of Sciences
 - *A Framework for Convergence Learning*, Robert Chang, Northwestern University
 - *Artificial Intelligence and Converging Technologies: How to Prepare Students and Society for the Fourth Industrial Revolution*, Eleonore Pauwels, S&T Innovation Program, Woodrow Wilson Center for Scholars
 - *Science of Team Science: Informing Convergence Education*, Kara Hall, Behavioral Research Program, NCI, NIH
 - *Six Insights from Developing Digital Education Tools at MIT*, Chris Kaiser, MacVicar Faculty Fellow, MIT
 - *The NSF Science of Learning Program*, Kurt Thoroughman, NSF Program Director, Science of Learning
 - *Capacity for Convergence Science in STEM Education Research*, Finbarr (Barry) Sloane and Anthony Kelly, Education and Human Resources, NSF
- The key observations from the workshop include:
- Education Level
 - K-12
 - Observation: Teachers and other educators are struggling to implement convergence education and, in the USA, the STEM education framework advanced in the Next Generation Science Standards (NGSS) which addresses convergence.
 - Action Item: Develop communities of practice that enable educators and community members to discuss challenges, share best practices, and implement changes in a structured, controlled fashion. For example, consider opportunities to bridge, leverage, and build upon informal and formal educational experiences.
 - Community Colleges/Technical Colleges
 - Observation: Community Colleges/Technical Colleges are often models of industry-academe collaboration. But to be most effective at incorporating convergence into their curricula, they must sharpen their efforts.

Action Item: Work toward educating community college/technical college instructors in STEM fields to promote involvement in societal Grand Challenges and to share the potential benefits to their students, their institutions, and their own professional development.

Undergraduate

Observation: One of the fastest ways for universities to bring out new knowledge to society is via the students and their entrance into workplaces.

Action Item: Develop a conceptual framework that would draw on the expertise from transdisciplinary fields to explore the details of a unified program center focused on addressing the challenge of convergence, learning, data analytics, and workforce. The NSF Engineering Research Centers could provide a prime opportunity for such an effort. The NSF Research Experiences for Undergraduates (REU) awards, as well as other related training awards, also provide an untapped opportunity. They are currently managed within individual NSF directorates and few are focused on convergence.

Graduate

Observation: The “Molecular Techniques in the Life Science” masters program, a collaboration among three Swedish universities, is an example where there is an explicit tie of convergence to pedagogical research. This linkage provides an opportunity to identify new convergence competencies for higher education programs.

Action Item: Add a component of pedagogy evaluation/documentation to existing center-scale convergence education programs.

Continuing Education

Observation: Many private industries, professional societies, and some pockets of academia are quite good at developing teams of collaborative researchers and providing training in communication, management, and leadership. Some of these stakeholders have developed hubs for educating and training researchers on best practices.

Action Item: Develop mechanisms for the gathering and dissemination of best practices; coupling these best practices with funding agencies or other hubs for training could be transformative. Further, opportunities exist to leverage resources, such as the National Cancer Institute’s Team Science Toolkit and the nationwide museum education outreach infrastructure.

– Overarching opportunities

Convergence Ecosystem

Observation: STEAM encompasses science communication, in all forms, as an effective vehicle for sharing the joy and wonder of engaging in discovery, and for communicating a compelling need for tinkering, critical thinking, and the creative process throughout the formal and informal educational ecosystem, e.g., families and communities. Additionally, attributes of innovative ecosystems, i.e., convergence, synthesis, and emergence, are well designed and positioned to anticipate and address future convergent educational needs and to catalyze discovery (Winkelmann and Bhushan 2016, Chapter 3).

Action Item: Focus on holistic convergence education, which creates future workers with enhanced technical and communication skills, instills context, i.e., a holistic awareness of convergent opportunities and engagement with key stakeholders, and creates an understanding of their creations’ potential implications.

Teaching Aides/Technology

Observation: Accessibility of digital teaching aids is constrained by cost and teacher familiarity.

Action Item: Develop guidance on how best to leverage informal educational experiences and to use most effectively the various teaching aids in a convergence environment, thereby minimizing the constraints and instilling an internally motivated convergence mindset. Identify lessons learned that could be shared.

Teaming

Observation: The role of team science competencies should be incorporated into educational and training strategies for convergence research.

Action Item: Provide faculty and senior researchers with training to prepare themselves to do collaborative science. Encourage researchers to include this training in their funding requests and urge funding agencies to pay special attention to these types of requests. Exercise and nurture inclusive team science in all aspects of education.

International Collaboration

Observation: The OECD can be an effective contributor toward understanding the implications of convergence education.

Recommendation: Prepare background information on convergence education to connect with ministers and policy-makers; identify the potential impact on socioeconomics.

Funding

Observation: Partnerships among the many education stakeholders (parents, educators, science and engineering communities, government, industry, academe, and foundations) are needed to better identify the changing needs in student knowledge, including the creation of models to assess competency needs and personal learning graphs that address lifelong/life-wide learning needs.

Action Item: Explore with industry and foundations the possibilities for government/academic/industry/community partnerships to develop new, affordable (including at the K-12 levels and in underserved populations) educational devices and approaches that could provide individualized instruction, would instill and intrinsically motivate a convergence mindset and would better enable convergence education.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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