TRAINING FOR

By Ahmed K. Noor

The engineering profession is facing a number of major challenges. As technology advances, systems are generally reaching new levels of complexity. A modern aerospace vehicle, for example, is a system in which embedded devices are networked to sense, monitor, and control physical hardware components. More than half the cost of the vehicle is for embedded devices, software, and system integration. That is in addition to the traditional aerospace issues of structures, aerodynamics, propulsion, guidance, navigation, and control.

Design teams are also growing more complex as the variety of technology in a system requires increasingly interdisciplinary collaboration.

Interaction among the members of diverse teams can be further complicated by geography. During the course of a project key members may rarely, perhaps never, meet in person.

The workforce is short of people skilled to excel under these conditions. High-tech companies are having increasing difficulty filling positions of strategic importance to maintain their competitive position in the global market. This is particularly true for manufacturing of complex systems, requiring workers with competency in science, technology, engineering, and mathematics (STEM) to operate, maintain, and repair sophisticated computer-driven machinery or industrial robots. It is also true for workers servicing complex systems, such as advanced aerospace or automotive vehicles.

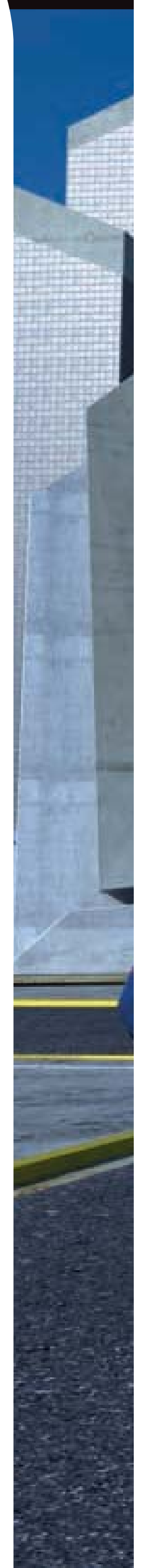
Traditional engineering disciplines and formal engineering programs have often proved to be inadequate for meeting the challenges of both the current and emerging complex systems and the workplace. For one reason, established disciplinary boundaries do not mix well with the interdisciplinary nature of complex systems. Also design approaches, based on traditional top-down systems engineering, which work for the fully predictable response of the system in a well-understood environment, break down.

New bottom-up engineering approaches are needed for complex systems consisting of many interacting components and operating in an unpredictable dynamic environment. Examples of complex systems range from smart vehicles to smart power grids, intelligent transportation and healthcare systems, and virtual enterprises.

Rather than attempting to design the system as a whole, the components of the system are equipped with needed capabilities, and their interactions are enabled to meet dynamic goals. The role of the engineer is that of an enabler to support and guide the evolution of the system.

Several STEM improvement and pilot academic engineering programs have been proposed to address some of the needs and challenges of the high-tech workforce. For example, the NSF Cyberinfrastructure Training, Education, Advancement, and Mentoring for Our 21st Century Workforce program was created for improving STEM competencies through collaborations among universities, schools, government, industry, professional societies, and international partners. The program aims at creating a comprehensive infrastructure for formal and informal learning, training, and professional development of engineers and other professionals working on future complex systems.

The nanoHUB, a multiuniversity network led by Purdue university, is one of the products of that program. It provides extensive online interactive



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THE NEXT WAVE

As the complexity of systems increases, the preparation of engineers and the workforce will need to keep pace.

Autonomous vehicles may cooperate in a new type of super-smart urban mobility network. Those who design, build, and maintain such complex systems will need advanced skills.

educational, simulation, and collaboration facilities for various aspects of nanoscience and nanotechnology, including manufacturing of complex nanomachines. Researchers and educators can access more than 160 on-line simulation tools, which let them analyze and visualize results through an ordinary Web browser.

Companies have launched their own educational programs to address some of the reskilling and large-scale system integration needs of complex systems. For example, Boeing manages about 12,000 engineering and other courses, for a total of 49,000 hours of instructional material. In 2009, Boeing instructors provided over 7 million hours of instruction to 150,000 employees in 45 countries. The courses are intended to complement, through practical applications and lifelong learning, the formal engineering education at academic institutions, and to provide the skills needed for the Boeing workforce.

However, despite these and other efforts made over the last decades, the inadequacy of engineering programs to meet the challenges of complex systems and a general decline in STEM skills among high school graduates persist.

Recently, holistic approaches were proposed for addressing the engineering and STEM education needs for the workforce. The holistic approaches address some of the needs for the workforce, including interdisciplinary collaboration, new design approaches for complex systems, and the characteristics of entrants to the workforce and their learning styles.

Learning science experts such as the late Craig Newell of Simon Fraser University, in Burnaby, B.C., have suggested viewing education as a complex adaptive system, in which individual components are people—instructors and learners—who interact and communicate with each other. They adapt to changes within the system, such as the changing composition of the groups, or in the environment, as learning technologies or spaces change.

Over time, an emergent organization develops, taking a shape that cannot be fully predicted at the start. If the components and their interactions with each other and the environment are properly designed, the system dynamically evolves into a coherent, effective learning experience. For example, groups of geographically distributed learners need not be restricted to receiving knowledge, but they can be trained to work as teams, and encouraged to generate new knowledge.

Last year, senior managers at Boeing proposed an ecosystem approach for addressing the challenges facing the engineering workforce, and accelerating STEM capacity. The development of such an ecosystem requires interdisciplinary collaborations among teams from academia, industry, research, and government organizations. The proposal was motivated by research at Boeing, and other organizations, on engineering education and training. The proposed ecosystem uses a complex adaptive systems perspective for learning. It will connect formal and informal learning, through linking the competencies and learning strategies taught in the formal environment with learning and performance in the workplace. It provides an engaging learning environment which supports learning by doing (applying the knowledge acquired in assigned projects at the company).

The proposed ecosystem and complex system approach for training and education are steps in the right direction for addressing challenges of the workforce. However, there is a need for a panel of thinkers from academia, industry, professional societies, and government to develop a more comprehensive education and training strategy for complex systems.

The overall goal of the strategy should be to enable generating, analyzing, and sharing information pertaining to complex systems on a much larger scale, and in much less time than is currently possible. Such activity would foster innovation, discovery, and economic development.

Intelligent Ecosystems

A step towards the implementation of the comprehensive strategy is the development of Intelligent Cyber-Physical Engineering Ecosystems to advance collaboration among engineering and research institutions, industry, professional societies, and other stakeholders working on complex systems.

The ecosystems will consist of large numbers of distributed interacting components that are continually updated and expanded. They include networked smart devices, cognitive robots (with high-level reasoning, planning, and decision- making capabilities), cyber collaboration and collective intelligence facilities, blended physical and immersive virtual environments, and novel interaction technologies.

The ecosystems are expected to grow and to reach unanticipated levels of complexity because of the relations among the continually expanding individual components. The ecosystems cannot be fully defined *a priori*, but rather emerge from the interactions among the components, as well as with the environment. Therefore, the design of the ecosystems cannot be based on the traditional top-down systems engineering approach. Rather, a bottom-up emergent engineering approach is used, in which the components are designed and the interactions are engineered to enable the system to change and expand as needed.

Specifically, the ecosystems would provide knowledge-rich, immersive environments for integrating engineering practice with learning, training, and workforce development needed for complex systems. They will also serve as platforms for developing new interdisciplinary fields and for expanding the scope of current ones. A new interdisciplinary field, for example, is cyber engineering for future smart vehicles, which will require integrating novel electronic devices and sensors with communication networks and mechanical components.

Some of the key components of the ecosystems, which are not currently available in the NSF-supported cyberinfrastructure, are knowledge customization and information visualization facilities, visual simulation tools with 3-D stereo capability, and advanced multimodal interaction with the digital environment.

The knowledge-customization facilities should provide the right knowledge for the right purpose at the right time. They should incorporate intelligent question-answering systems that go beyond the capabilities of the current search engines to provide answers to technical questions, in an intuitive man-

Connected *(Possibly Driverless)* Vehicles

Increasingly modern vehicles are growing in complexity with integrated sensors, electronics, software, and mechanical components. Options have been demonstrated that will allow drivers to hear Twitter updates read aloud. Such features are entertaining at best and distractions at worst. But technology can also increase the safety and efficiency of driving.

Major automotive companies are working on enabling cars to communicate information about road conditions, weather, and traffic problems with one another. Starting next August a number of automakers, including Ford, will be testing vehicle-to-vehicle communication to enhance safety and reduce accidents. The study will include 3,000 cars able to broadcast their position, speed, and direction, to other vehicles over a Wi-Fi network. The Wi-Fi signals, which go out in all directions, would warn the driver of pedestrians, other vehicles, immediate stops, or dangers in the way of the vehicle.

A future possibility is a driverless car—an autonomous robotic vehicle capable of fulfilling the human transportation capabilities of a traditional car. The car integrates a number of sensors, technologies, and hardware to navigate and drive itself, and passengers, around with no human input.

An early concept of a driverless car was presented by the industrial designer Norman Bel Geddes in the Futurama exhibit sponsored by General Motors at the 1939 World's Fair in New York. Recently, there has been an increasing interest in developing and testing driverless cars by the Defense Advanced Research Projects Agency, Google, and several automotive companies, including, Mercedes-Benz, General Motors, BMW, and Audi. Google has developed a test fleet of autonomous cars that have driven over 140,000 miles. It has now been awarded a patent on some of the technology used in the driverless car. The patent application outlines sensors used to identify when the vehicle stops on a so-called landing strip, then a second set of sensors take over and receive data that tells the car where it is positioned and where it should go.

In addition to the enhanced safety, and the convenience of relieving the occupant from driving and navigation, autonomous cars have a number of other advantages, including alleviating the problems associated with parking. The car can park itself away from the passengers and return, as needed, to pick up the passengers.

ner, using the available digital information. It could leverage the technologies developed by the research teams at Wolfram Research for the computing search engine, Wolfram Alpha; and the IBM Watson project.

Three-D stereo provides for interactive experiences with visual simulations of complex systems.

Multimodal interactions might include new mobile and wearable devices, interfaces using voice or gesture, and media-rich communication tools.

The ecosystems would amplify human cognitive and perceptual capabilities, revolutionize learning, and enable the engineering workforce to perform increasingly complex and imaginative tasks of synthesis and creativity. Engineers can be working with experts in artificial intelligence and other technology teams on transforming many current products, industries, and practices into complex adaptive systems. Some day, bridges and oil platforms may be able to alert their human minders that they need repair before failure occurs.

Smart Transportation

New concepts of complex adaptive systems-of-systems, such as urban mobility and intelligent transportation, can emerge. The concept is based on networking autonomous vehicles and equipping them with sophisticated sensors, machine learning, information processing, built-in custom software, and other technologies. The cyber-connected vehicles can access, create, and share real-time traffic, and other information, with passengers, public infrastructure, and other vehicles. The cars can be aware of their locations and the location of other vehicles, and can "self-organize" to avoid collision, optimize traffic flow, and increase general mobility. The experiences provided by the networked vehicles can go well beyond driving, with several significant benefits, including enhanced safety, faster transportation, improved productivity (turning commute into productive time for the passenger), and lowered emissions.

Networked autonomous vehicles will provide all the benefits of individual autonomous vehicles and will also offer individual mobility to people who cannot or should not drive. For example, a person unable to drive because of age-related infirmities can remain mobile over long distances in a driverless vehicle. Automakers can work with healthcare companies to develop in-vehicle health-monitoring sensors to transmit data about the passenger's health in case of emergency.

New business models may be possible, as in a new mobility-provider industry for shared cars. The result would be the convergence of digital lifestyles and cars. Vehicle navigation systems will incorporate up-to-date maps and real-time traffic information. New business opportunities will emerge from adapting the relevant digital technologies to the car.

The proposed ecosystem can accelerate the training that the engineering workforce needs to realize and sustain the intelligent transportation and urban mobility concept. It can provide timely, engaging training needed for follow-up development of integrated multimodal transportation systems.

The innovations that can be realized in the proposed ecosystems extend well beyond anything we can currently imagine. New patterns of organized culture, new interdisciplinary fields, new paradigms of engineering practice, and new models for virtual universities and organizations may emerge within these ecosystems, and support those in the real world. ■