New links for learning in a changing profession

A conversation with Sean O'Keefe

Military networks take center stage
The decades ahead will witness revolutionary changes in aerospace and other high-tech systems, as well as in engineering environments. Future aerospace systems will include a spectrum of intelligent entities that can adapt, form, evolve, and generally deal with changes and unanticipated problems; and vehicles that can optimize performance, carry out complex maneuvers in complete safety, and repair themselves when damaged.

The future engineering environment will be saturated with communication. It will include pervasive computing devices, with a high degree of communication among those devices and users through wireless and optical network infrastructure. The environment will significantly enhance the collaboration among diverse, geographically dispersed teams and enable them to share and transform information into knowledge by analyzing and combining it in new ways.

The realization of future aerospace systems requires the synergistic coupling of a number of revolutionary and leading-edge technologies, including bio-, nano-, and information technologies, as well as a diverse technically talented science and engineering workforce that can work in a collaborative distributed virtual environment. Most current university curricula do not prepare learners for such environments.

The engineering profession resonates with rhetoric about the need for radical restructuring of engineering education, and for enhancing learning through the use of new technologies. Yet such rhetoric seldom includes strategies or practical plans. Current R&D activities in learning technologies are fragmented and disparate, focusing primarily on near-term development.

These activities have had little effect on engineering workforce training and are unlikely to offset the diminishing design team experience base in industry. Thus there is a need for exploring bold new approaches to this problem. One such approach is the creation of a knowledge organization that
would link diverse interdisciplinary teams from NASA, other government agencies, universities, the aerospace industry, technology providers, and professional societies into hierarchical research and learning networks.

A hierarchical learning network can be used for training engineering and science teams, not only in the component technologies but also in new approaches for collaborative synthesis and virtual product development. It may hold the key to realizing the full potential of distributed environments.

**A network of networks**

In April, NASA initiated and funded a university consortium led by Old Dominion University's (ODU) Center for Advanced Engineering Environments to develop the Hierarchical Learning Network. HLN will be a network of networks, arranged as a neural network. Its component networks will link diverse teams in revolutionary areas such as bionanotechnology and smart vehicles. The networks will provide advanced learning environments through the synergistic coupling of cutting-edge instructional, communication, and knowledge management and assessment technologies.

The technical content comprises modules developed by experts in the subject matter. Each module will use interrogative visualization, multimedia, intelligent software agents, virtual reality, multimodal, and adaptive human-computer/communication technologies. These will include perceptual and neural user interfaces as well as natural language communication.

The component networks will stimulate critical thinking and intelligent growth. They will promote the intermingling of emerging and traditional engineering and science disciplines. They will create a new generation of skilled engineers and scientists who can work across disciplines and perform in a rapidly changing environment. They will also bring collective intelligence, innovation, and creativity to bear on the growing complexity of future aerospace systems.
The simulator of the 1.4x22-ft subsonic wind tunnel at NASA Langley developed by the ODU Center for Advanced Engineering Environments covers all facets of the facility, including the control room.

will keep aerospace professionals abreast of technological and scientific advances on a global scale, supporting their lifelong learning needs.

Realization of the HLN will begin with the development of several learning modules, virtual classrooms, simulators of unique NASA facilities, an infrastructure for group distributed development and collaboration, and a telescience system. The latter is an online multiscale lab that allows real-time exchange of information and remote operation of instrumentation by geographically dispersed teams.

These facilities will be integrated into fully adaptive web learning portals. The portals will have customized communication, navigation, management, and decision support tools and will evolve into robust learning networks. These networks will then be integrated into the HLN. A hierarchy of test beds/prototypes will be developed throughout the project to serve as proof-of-concept and to evaluate the effectiveness of each component.

HLN's environments and facilities will take advantage of many recent advances in learning science: cognitive learning and thinking processes; effective learning strategies and mechanisms; brain-, inquiry-, and project-based learning; models of instructor-learner interactions; knowledge representation; and evaluation, assessment, and measurement tools.

Advanced learning environments
Each of the HLN's component networks will integrate three categories of advanced learning environments: synchronous and asynchronous expert-lcd; engaging, adaptive, self-paced individual learning; and collaborative learning. Integrating these environments with diverse team collaboration and multisensory communication should reduce the cost of learning and increase worker competencies at NASA and other aerospace

NASA and the aerospace workforce
NASA's goals in aeronautics and space include new paradigms for a safe, secure, efficient, and environmentally friendly air transportation system; advanced concepts for the airspace system; understanding of the total Earth system and its response to natural and human-induced changes; radical expansion of the human ability to explore the universe and search for life; and extending human presence to the space frontier.

Achieving these ambitious goals within current budget constraints will require new kinds of aerospace systems and missions that use novel technologies. It will also require a new generation of skilled scientists and engineers who can work across traditional disciplines and perform in rapidly changing environments. Today, NASA employs over 10,600 scientists and engineers, of whom 24% will be eligible to retire within the next four years. In addition, the agency faces "skill gaps" in a number of revolutionary technology fields essential to the realization of future systems and missions.

The situation is similar in the U.S. aerospace industry, which contributes $1.45 billion annually to the GDP. More than 54% of the current science and technology workforce is over age 45 and nearing retirement. Other factors that threaten the U.S. industry and its leadership position include shifts in government and commercial investment in aerospace R&D; changes in the composition of the science and engineering workforce; industry consolidations and downsizing; technology transfer concerns; and foreign trade practices and competition, which result in a loss of global market share.

At the same time that NASA and the industry expect to lose much of the science, engineering, and technology workforce, U.S. colleges and universities are also experiencing a decrease in the number of undergraduate and graduate students in science and engineering. The number of science and engineering graduates has continued to decline since 1992.

Although NASA, the National Science Foundation, other government agencies, and industry have sought to remedy these problems, most current efforts are not likely to offset the diminishing design team experience base in industry. Thus there is a need to explore bold new approaches and to devise an integrated plan for education, training, and workforce development. All the stakeholders—government, academia, industry, technology providers, and professional societies—must be involved. The Hierarchical Learning Network project is a step in that direction.
organizations. The human instructors will play many roles—including motivation, observation, evaluation, and leadership—with both individual learners and teams.

- Instructors in expert-led distributed learning environments serve as facilitators and course managers. Using multimedia facilities, they begin with a broad overview of the topic and its diverse applications, and end with what-if questions that enhance critical thinking and creativity. Routine instructional tasks are relegated to the individual environment.

- The individual learning environment offers a high degree of tailored interaction, enabling self-paced learning of routine material absent in the expert presentations. It can enhance learning through the use of intelligent software agents serving as virtual instructors. It can be used to study physical phenomena coupled with engineering processes, via advanced visualization, multimedia, and multisensory immersive facilities.

This environment will include interactive simulators for unique NASA test facilities such as wind tunnels and acoustic labs. It will also feature interrogative visualization engines and innovative visualization paradigms such as computational steering and inverse steering.

- In collaborative learning environments, widely dispersed instructors and learner teams are brought together through immersive telepresence facilities. There they are able to share their experiences in diverse environments that use different computing platforms and software. Teams can collaborate to a far greater degree on designing complex systems, while also gaining experience in teamwork and problem-solving.

This virtual collocation will enable the formation of new university, industry, and government consortia. State-of-the-art knowledge representation technologies will support acquisition, storage, maintenance, retrieval, and application of digitally coded engineering expertise. Novel tools will enable planning, deployment, and life-cycle management of learning; learner performance assessment and support; and rapid deployment of just-in-time learning.

Collaborative learning environments will augment current distance learning facilities and enable engineering schools to offer multidiscipline courses with group distributed expert instructors. This will reduce the teaching workload and improve the quality of instruction.

Learning modules
Self-contained learning modules provide flexibility and may be packaged in different ways into disciplinary and interdisciplinary curricula. The initial set of HLN modules will focus on the application of nontraditional disciplines in solving the problems of future aerospace systems. They will also emphasize the synergistic combination and use of seemingly disconnected technologies not covered in current university curricula. Examples are flow sensing and intelligent control tools for future smart vehicles, biologically inspired structures and materials concepts, and conceptual design of future personal air vehicles.

Module development will be a collaborative effort by university faculty and researchers, NASA scientists and contractors, and learning technology providers. Concept maps will be used for eliciting knowledge and for its logical representation. For each topic, an attempt will be made to capture the best expert knowledge available.

Virtual classrooms
Online training and virtual classrooms provide environments with custom self-instruction, flexible tutorial support, and a choice of both the place and time of learning. Three types of facilities will be used in the HLN's virtual classrooms. The first, instruction, will include multimedia lectures; visual tools for searching, browsing, and using archived knowledge; and links to other resources. The second category, communication, will include email, Usenet chat centers, video, and internet conferencing and
University consortium

The ODU Center for Advanced Engineering Environments is working with a university consortium and other partners on the development of HLN. Consortium members initially include faculty and researchers from Old Dominion University, the University of Florida at Gainesville, the University of Illinois at Urbana-Champaign, George Mason University, the MIT Media Lab, Cornell University, and Syracuse University. Faculty from other universities will be added as needed. By combining the strengths of all these institutions, including faculty expertise and research facilities, the consortium will provide world-class service to aerospace workforce development and engineering education.

HLN activities will be closely coordinated with NASA's newly established University Research, Engineering, and Technology Institutes and with government activities in advanced learning technologies.

The consortium is also working with the Florida Space Research Institute on creating an advanced learning curriculum for cryogenics, and with the University of Mississippi on developing a comprehensive curriculum for geospatial information technologies.

The various forms of propulsion considered by NASA for RLVs are included in the prototype learning module with multimodal interfaces and intelligent agents.
The telescience facility will be integrated with the virtual classroom and used for training. In the future, unique and high-end facilities at other participating universities will be connected as well.

**Simulated test facilities**

Few facilities are currently available for simulating large-scale experiments. However, modeling and simulation capabilities, combined with advanced microprocessors and computers with motion video instruction, are approaching real-time modeling.

As part of HLN activity, simulators for NASA wind tunnels and test facilities for landing dynamics and for testing large structural components are under development. They will use intelligent software agents and advanced visualization engines such as Virtual Reality Modeling Language and computational steering.

Interactive uses of simulators include virtual tours of the facility, tutorials on its operation, and learner training and certification. Other uses include physical test simulation using codes to predict the measurements from physical tests, and the coupling of physical experiments with simulation.

The coupling of near-real-time physics-based system-level simulations with physical in-the-loop testing of hardware components will be synergistic. It should significantly increase the knowledge gained from these experiments and reduce dependency on expensive, time-consuming, full-scale, system-level validation testing associated with complex aerospace systems.

**Infrastructure for collaboration**

To enable geographically dispersed teams to collaborate on activities such as development and instruction, an infrastructure is created consisting of groupware suites and information and knowledge tools. Groupware—software that helps groups communicate and coordinate their activities—includes multipoint audio and videoconferencing systems, messaging, and workflow. Information and knowledge tools enable configuration and data management as well as knowledge creation, sharing, and discovery. They include whiteboards, synchronous and asynchronous tools for application sharing, threaded messaging, and file archiving.

Initially, the infrastructure will be provided by the global multipoint videoconferencing facility of the National Computational Science Alliance at the University of Illinois, the iCom communication portal of the MIT Media Lab, and the WebEx Meeting Center. Subsequently, partnership with technology vendors will be established to develop an adaptive, customized, secure collaboration infrastructure. This will include communication portals, virtual meetings, and a knowledge repository.

**Intellectual product**

The HLN team will work for continuous improvements, probing for weak components and fixing them. The project’s activities will enable participating schools to restructure their learning strategies and set a framework for future engineering education. They will expand the scope and quality of research and create new partnerships among diverse engineering and science communities. They also will enable multiuniversity, distributed group teaching of new courses.

The learning facilities developed as part of HLN will help to create an intellectual environment where academic and experiential learning are advantageously combined. Academic rigor will be learned in concert with professional job performance, and academic complexities will be addressed within the industrial setting. The new learning environments will increase creativity and knowledge, dissolve cultural barriers among engineering and science teams, promote lifelong learning, and produce high-performance organizations that take maximum advantage of their knowledge resources.