60+ Years of Design + Innovation

DESIGN

Shaping the Future of Undergraduate Engineering Education

Recent advances in engineering and science are among the most impactful in recorded history. In their recent book, MIT Professors Erik Brynjolfsson and Andrew McAfee describe this era as "The Second Machine Age."

In the past, there was relatively little overlap between the occupational practices of engineers and those of theoretical scientists. Scientists, the "dreamers," made discoveries purely for academic advancement and then engineers used these findings to solve practical problems. That distinction is evaporating. The smartphone, for example, was designed and developed by teams of people from several disciplines—including many outside the world of science and engineering.

ENGINEERING TRENDS

Computing Power - Engineering calculations that just a few decades ago took months to complete can now be accomplished almost instantaneously. Sophisticated new technology tools and a blurring of the distinctions between scientific disciplines also have facilitated new ways for individuals and teams to solve problems previously considered unsolvable.

Big Data - Along with increased computing power, the capacity to amass and evaluate large amounts of data has allowed researchers to discover and analyze never-before seen patterns. The ability of researchers to understand relationships previously considered unknowable has directly impacted areas of science ranging from climate change to cancer.

New Tools - Computing power has helped create news tools of exploration like gene sequencers and NMRs for scientists and engineers.

Blurred Boundaries - There is a blurring of traditional discipline boundaries in science and engineering. We see this in the new collaborations between formerly distinct areas of engineering and science in research laboratories, as well as in the many multidisciplinary classes and degrees offered in academic institutions.

Internet - The Internet has enabled communication among researchers to occur almost instantaneously, regardless of location. This allows research groups from across the world to share ideas and solutions without ever meeting in person. The Large Hadron Collider (LHC) at CERN, for example, is the world's largest and most powerful particle collider and is shared by organizations from around the world, many of whom never actually travel to Switzerland.

Worldwide Competition and Collaboration - The explosion of the new tools of science and engineering in the last 30 years has occurred as former third-world countries such as China and India have made giant leaps forward. The struggle of countries to maintain growth and leadership has led to intense competition and collaboration. Reflecting this transformation, a large number of North American, UK and EU academic institutions have established educational and research institutions in Asia Pacific, the Middle East and other regions of the world.

HOW MILLENNIALS LEARN

As the pace of scientific change accelerates, young people are pursuing knowledge and experiences in dramatically different ways from previous generations. Today's undergraduate and graduate students arrive on campus with significantly different resources, skills and expectations:

- Growing up with computers, the Internet, smartphones and social media, they expect to be connected 24/7.
- They are multi-taskers and accustomed to juggling numerous activities and tasks.
- They tend to be very comfortable working collaboratively in teams.
- They are tech-savvy and embrace new technologies.
- They have a truly global worldview and expect to work across boundaries.
- They understand the importance of managing our environmental challenges and expect their educational institutions to respond accordingly.

NEW TEACHING APPROACHES

Educational institutions are experimenting with several emerging curriculum and teaching approaches to meet the preferred learning styles of science and engineering students:

Focus on Group Work - Designing lab and class work around team problem solving and experiments can be far more effective than more traditional methods.

Integration of Technology - Online experiences can illustrate key concepts before a student even arrives to class, making the classroom and lab experience more meaningful.

Innovation on Display - Allowing students and visitors to see into labs and workshops and identifying opportunities to display student-generated innovations can help them feel more engaged.

Cross-Pollination - Educators are discovering ways to share facilities, lectures, classes and labs with other scientific disciplines while also identifying opportunities for broader academic collaboration. Connecting a school of engineering and a school of business, for example, can facilitate synergies that will accelerate the next generation of startups.

Emphasis on Undergraduate Research - Undergraduate engineering students are increasingly involved in research to keep them more engaged.

Interaction with Faculty - A close connection with a passionate, inspired faculty member is one of the most important factors in student success.

Hands-On Interaction - Brief lectures interspersed with periods of hands-on experimentation and problem solving allow students to immediately apply the material presented.

RESHAPING FACILITIES TO SERVE STUDENTS

To support these new pedagogies and promote more effective, engaged learning, classrooms, laboratories and other learning spaces must be more dynamic and flexible than traditional facilities.

1. The **teaching laboratory** – the most important element of any undergraduate science or engineering building – must support evolving curriculum and more hands-on science.

Effective teaching laboratories should:

- Promote faculty interaction with students.
- Provide clear sight lines for students and faculty.
- Accommodate student group work.
- Encourage interaction.
- Offer flexible infrastructure with excellent voice and data connectivity.
- Provide access to easy-to-use, high-quality audiovisual systems.
- Support convenient experiment preparation and storage.

One successful strategy places all student team work areas at the perimeter of the lab, with the center of the room left clear for group gatherings and demonstrations. This arrangement allows the instructor to monitor how each group is progressing and to provide immediate help as needed. Placing most utilities overhead allows the room to remain flexible while accommodating demonstrations in the middle of the room.

2. Flexibility should drive the design of traditional **classroom space**. One successful model for tiered classrooms places two generous tables per level, allowing every other row to turn around and form a small group for discussions and problem solving. For flat-floor classrooms, active learning is encouraged through small group tables and technology integrated throughout the room. In all situations, classroom tables need to be sized to accommodate the laptops that most students bring to class.

3. Maintaining **dedicated undergraduate research labs** sends a strong message to students that research is an essential part of the learning process. While many institutions depend on the off-hours use of teaching labs for student research, providing dedicated labs eliminates scheduling conflicts and allows students to set up long-term experiments. In addition, having dedicated undergraduate labs for non-majors conveys the message that all students can learn from the research process.

4. **Practice facilities**, or large multipurpose work areas surrounded by technical shops, equipment and tools, engage students by supporting hands-on engineering.

5. **Faculty research laboratories** encourage staff to continue their research efforts, but not at the expense of student involvement. Ideally, these labs should be intermingled with the rest of the teaching and undergraduate research labs to inspire interaction among faculty members and between faculty and students.

6. The location and design of **faculty offices** can influence collaboration among faculty members, departments and students at every level. One successful strategy involves placing most faculty together in a suite that breaks down departmental boundaries and silos. The configuration should provide areas outside individual offices that encourage conversations and spontaneous discussions. Supplying a variety of comfortable seating options, convenient whiteboards and community coffee areas will help build these interactions.

ORGANIZING BUILDINGS AND COMMON SPACES

In both research and education, it is frequently the **spontaneous interactions** among researchers and research teams that lead to significant breakthroughs. Teaching facilities of the future must foster this casual collaboration.

Beyond a building’s individual components, the spaces in between – the corridors, corners, nooks and crannies – are where students often hang out between classes to talk, study and participate in the community of discovery. The goal is to create a facility that makes students feel welcome, comfortable and interested in staying after hours.

A useful metric compares the number of seats outside of labs and classrooms to the number of seats inside those spaces. The closer to a one-to-one ratio that a facility can achieve, the more likely it is to encourage organic student engagement.

Facilities also should take advantage of opportunities to **showcase engineering and science** for students, faculty, the university and surrounding community. Collections and lab results can be displayed in compelling ways, and live feeds from local or remote experimental areas as well as prerecorded and interactive displays can bring the building’s activities to life.

Science and engineering facilities should **advance sustainability** through their design, construction, operations and eventual reuse. These structures have the inherent advantage of being populated with individuals who understand and embrace environmental issues as part of the curriculum and have the capacity to become part of the solution. The buildings themselves should be teaching tools as well as healthy places to work and study.

These facilities also can be designed so that the building embodies its pedagogical mission:

- Building systems can be exposed, labeled and explained.
- Material selections can demonstrate life-cycle implications.
- Real-time displays can depict the building's performance, energy and water consumption, emissions avoided and daylight contributions.
- New technologies, photovoltaics, fuel cells and new-generation wind generators can contribute to energy efficiency while demonstrating their engineering value.
- More conventional technologies such as water harvesting, daylighting and natural ventilation systems can be part of the building and its mission.
- If land is available next to the building, demonstration gardens, water features, test plots and native plantings can extend the environmental mission outside the building.
- New experimental technologies developed at the school should be shared and displayed.

PREPARING STUDENTS FOR POST-UNIVERSITY LIFE

Beyond the goal of retaining students so they complete their academic degree, science and engineering departments are responsible for equipping students with the broad-based skills, adaptability and critical thinking necessary to solve the world's scientific and engineering challenges.

Well-designed science and engineering buildings must support these goals by facilitating a collaborative curriculum, supporting modern teaching methods and accommodating the constant evolution in how students learn.

Today's young people have enormous potential to change the world. With access to amazing tools and resources, they are poised to emerge as the world's most innovative generation. Fully unleashing that potential, however, requires us to rethink and reshape our educational environments. The future depends on it.