FREE
Future Ready Engineering Ecosystems

Future-Ready Engineering Ecosystem (FREE) **Brochure**

Featuring the Competency Taxonomy and Rubric for Action

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AMERICAN SOCIETY FOR ENGINEERING EDUCATION

Publisher Information

Founded in 1893, the American Society for Engineering Education (ASEE) is a nonprofit organization of individuals and institutions committed to furthering education in engineering and engineering technology. ASEE develops policies and programs that enhance professional opportunities for engineering faculty members and promotes activities that support increased student enrollments in engineering and engineering technology colleges and universities. ASEE also collaborates with national and international organizations to advance its mission.

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Note: This is an abridged version of the FREE Report.
Please visit www.free.asee.org to view the FREE Report in full.

Executive Summary

In the context of rapid and radical changes in technology and industry, there is a pressing need to change the way we educate students for the future of work. The American Society for Engineering Education conducted a series of workshops to envision what competencies future engineers need to meet the challenges of new and different ways of living and working.

The workshops occurred in the spring and fall of 2022 and are described in this report. The first two workshops in May 2022 gathered about 50 people from various parts of the engineering ecosystem (e.g., higher education, industry). The goal was to envision what engineering might contribute to our future society, focusing on emerging technologies, such as artificial intelligence, machine learning, advanced manufacturing, quantum information science, data science and analytics, advanced communication networks/5G, biotechnology, and others. The participants in these workshops developed a taxonomy of the competencies and capabilities needed by engineers to meet the changing needs of society. The second two workshops in October 2022 gathered about 150 people from the engineering ecosystem to create action plans for changing engineering students' education to better prepare them for the future.

The Future-Ready Engineering Ecosystem (FREE) Competency Taxonomy was developed in the first convening in May and used to draft plans for change in the second convening. The FREE taxonomy is designed as a general guide on what abilities engineers need to meet future challenges. It focuses on future technologies and engineering practices, covering a wide range of competencies. The guide takes a holistic and human view of engineering based on emerging trends. As such, there is no expectation that any one individual can acquire the full range of competencies—especially in four or five years of schooling. However, it encourages educators to go beyond traditional views of what makes a competent engineer. Workshop participants believed that the future would need engineers with a broad range of abilities to collaborate and work beyond the disciplinary boundaries of engineering fields.

Introduction

The Competency Taxonomy (Table 4.2) and the Rubric for Action (Table 4.4) were developed to serve as a general guide for change in higher education to develop the Future-Ready Engineering Ecosystem (FREE).

The Competency Taxonomy is comprised of two sections: Technical and Personal/Professional. The Technical section is broken down into three parts: 1. Technical Knowledge, 2. Technical Skills, and 3. Technical Attributes. Similarly, the Personal/Professional section is broken down into three parts: 4. Personal/Professional Knowledge, 5. Personal/Professional Skills, and 6. Personal/Professional Attributes. Given the complexity of such change, the Rubric for Action was designed to address various levels of organizational change: individual, program, and institution.

It is understood that educational change is not a simple process of adopting new curricula or different pedagogies; rather, it requires programmatic and institutional realignments toward a competency-based education. This is controversial across higher education.

The Competency Taxonomy serves index of necessary knowledge, skills, and attributes of the future-ready engineer. The Rubric for Action serves as a map for the complex interplay of individual faculty, students, administrators, programs, and institutions.

Change can begin at different points and in various ways. It is expected that specific changes can be designed differently and no one organization can do everything all at once. The Competency Taxonomy and Rubric for Action are starting points on the journey of changing—even revolutionizing—the way we educate engineering students for the future.

Competency Taxonomy

Table 4.2 Competency Taxonomy (v.7)

TECHNICAL COMPETENCE: Characterizes a person as competent in a particular field of knowledge/technology (e.g., engineering)

1. TECHNICAL KNOWLEDGE

What you know and understand...

1.1. Know and understand emerging fields in engineering, including theoretical and practical knowledge of...

- 1.1.1. Data science, computer science, big data analytics
- 1.1.2. Artificial intelligence, machine learning, robotics, advanced manufacturing, automation, cyber-physical systems, cognitive agents, virtual and augmented reality
- 1.1.3. Connectivity, networks, integrated systems (iot, ios, iop), cloud computing, systems thinking, systems architecture, cyber-security, semiconductors
- 1.1.4. Bioengineering, biotechnology
- 1.1.5. Environmental engineering, climate science, sustainable materials
- 1.1.6. Quantum information science and technology

1.2. Know and understand existing fields in engineering, including theoretical and practical knowledge of...

- 1.2.1. Engineering sciences: mechanical, civil, electrical, chemical, systems, and industrial engineering
- 1.2.2. Design science
- 1.2.3. Systems science and systems thinking

1.3. Know and understand perspectives of multiple disciplines, stakeholders, and communities

- 1.3.1. Cross-disciplinary, organizational, environmental, and community issues
- 1.3.2. Leverage STEM expertise in multiple areas

1.4. Know and understand practical reasoning

- 1.4.1. Experiential knowledge, intuitions, biases, creativity
- 1.4.2. Natural decision-making, sense-making
- 1.4.3. Contextual understanding (business, economics, organizations, environment)

Table 4.2 Competency Taxonomy (v.7) (continued)

2. TECHNICAL SKILLS

What you can do...

2.1. Manage and perform the work of emerging technologies and engineering fields

- 2.1.1. Use, monitor, and control technologies
- 2.1.2. Design and enhance technologies
- 2.1.3. Model various systems and processes

2.2. Manage, model, and process data to create meaningful information and knowledge

- 2.2.1. Process data (envision, collect,analyze, evaluate, create, and synthesize)
- 2.2.2. Interpret, critique, and apply data-based knowledge for decision-making, quick responses, improved productivity, higher quality products, services, and solutions

2.3. Design, conduct, and communicate technical and scientific information

- 2.3.1. Collaborate in team science
- 2.3.2. Work with automated research workflows (ARWs)
- 2.3.3. Communicate with multiple stakeholders

2.4. Design solutions for people and planet

- 2.4.1. Develop creative, innovative, and intuitive solutions
- 2.4.2. Commercialize solutions and disseminate to professions and society

2.5. Design for sustainability

- 2.5.1. Use resources effectively and practically
- 2.5.2. Consider consequences of decisions

2.6. Design, change, and integrate multiple systems (technical, human, business/financial)

- 2.6.1. Analyze, improve systems, reduce risks
- 2.6.2. Effectively use tools and data

2.7. Manage multi-disciplinary projects

- 2.7.1. Apply PMI processes and engineering expertise
- 2.7.2. Lead teams, people, stakeholders
- 2.7.3. Manage project constraints
- 2.7.4. Meet goals and objectives

Table 4.2. Competency Taxonomy (v.7) (continued)

3. TECHNICAL ATTRIBUTES

Who you are...

3.1. A Scientist-Engineer

- 3.1.1. Curious, creative, innovative
- 3.1.2. Disciplined, analytical, evidence-based
- 3.1.3. Experimenter, explorer, inventor

3.2. A Problem-Solver

- 3.2.1. Realistic about constraints
- 3.2.2. Analytical, insightful, and decisive, even in uncertain situations
- 3.2.3. Adaptable and flexible
- 3.2.4. Action-oriented
- 3.2.5. Motivated to transfer knowledge/solutions to society

3.3. A Project Manager

- 3.3.1. PM process and technical expert
- 3.3.2. Leader, partner, manager, team player
- 3.3.3. Effective communicator and collaborator with multiple and diverse partners and stakeholders

PERSONAL/PROFESSIONAL COMPETENCE: Characterizes an individual as a competent, well-rounded person and professional (e.g., engineer, professional, group/organization member, community member, citizen)

4. PERSONAL/PROFESSIONAL KNOWLEDGE

What you know and understand...

4.1. Knowledge of general and multi-disciplinary knowledge

- 4.1.1. Humanities, psychology, sociology
- 4.1.2. Business, management, organization behavior

4.2. Knowledge of global, cultural, and societal issues

- 4.2.1. How different people/communities perceive and experience issues
- 4.2.2. Interpersonal/social interactions, group dynamics, and relationship building
- 4.2.3. Ethics in work and community
- 4.2.4. Legal issues and human rights

4.3. Know and understand oneself

- 4.3.1. Awareness and understanding of personality and personal biases, limits, strengths, weaknesses, and emotions
- 4.3.2. Understand one's positionality and privilege in social hierarchies and how power structures affect relationships, decisions, and contexts
- 4.3.3. Understand and apply complexity and dialectics over simplistic, dualistic thinking
- 4.3.4. Develop and commit to thriving in health and well-being stakeholders

Table 4.2 Competency Taxonomy (v.7) (continued)

5. PERSONAL/PROFESSIONAL SKILLS

What you can do...

5.1. Continuously learn and explore

5.1.1. Seek new experiences and knowledge from diverse sources

5.1.2. Apply education and experiences to various industries, communities, and institutions

5.1.3. Apply critical thinking, analysis, and creativity

5.1.4. Use continuous and self-directed learning (technical, personal, professional) materials

5.1.4. Use continuous and self-directed learning (technical, personal, professional)

5.2. Lead, support, and collaborate with people

5.2.1. Recognize people for their work and service and help them succeed

5.2.2. Build high-performance teams

5.2.3. Serve as a role model to students

5.2.4. Build coalitions and gain support for ideas and projects

5.2.5. Work collaboratively to change the culture of STEM

5.3. Act in a globally inclusive manner

5.3.1. Communicate effectively across diverse disciplines and communities, including technical communication

5.3.2. Listen critically, interact, and work with diverse people and ideas

5.3.3. Focus on large problems (grand challenges)

5.3.4. Act with purpose

5.4. Work in cooperative/ collaborative ways with diverse team members, stakeholders, clients/customers

5.4.1. Work in virtual and distributed teams

5.4.2. Work in machine-assisted partnerships and teams

6. PERSONAL/PROFESSIONAL ATTRIBUTES

Who you are...

6.1. Value integrity, ethical and moral values

6.1.1. Trustworthy

6.1.2. Fair and impartial

6.1.3. Humble

6.2. Respectful, collaborative, and civically engaged

6.2.1. A leader, mentor, and colleague who is open-minded, receptive, and a good listener and team member

6.2.2. Empathetic with sense of responsibility and duty to address concerns and issues of diverse people and communities

6.2.3. Welcoming and inclusive

6.2.4. A clear communicator to various audiences

6.2.5. Prudent with resources

6.3. Committed to personal and societal development, well-being, and life-long learning

6.3.1. Inquisitive and curious with multiple interests

6.3.2. Multi-disciplinary educational background

6.3.3. A global, growth mindset with a high aptitude for literacy and awareness

6.3.4. Creative, innovative, entrepreneurial, and a risk-taker

6.3.5. Resilient and balanced with perseverance, determination, and grit

6.3.6. Passionate, confident, and courageous

6.3.7. Understand the big picture with an ability to connect various ideas, topics, and interests

6.3.8. Commitment to the common good, environmental stewardship, and human dignity

Rubric for Action

Table 4.4 Rubric for Action

INDIVIDUAL-LEVEL Indicators of HIGH PROGRESS	Moderate Progress	Low Progress
ADMINISTRATORS		
Substantial, high-level support for and actions taken to integrate competency-based educational components in curricula (including policy changes, additional resources, and recognition and rewards for faculty, students, and industry/community partners)		
FACULTY		
Faculty continuously **engage in professional development,** especially related to competency-based education and industry/professional experiences (specific competencies)		
Faculty actively c**ollaborate with each other, community members, and industry partners** to enhance the competency-based learning of students		
Faculty actively participate in competency-based education by **designing competency-based instruction** into their courses (e.g., service learning and project-based learning)		
Faculty provide students with **broad interdisciplinary experiences to enhance competency-based learning**		
Faculty serve as **coaches and mentors to students** emphasizing competency-based development		
Faculty have **real, measurable impact** on student competency development and community/ industry engagement		
STUDENTS		
Students have a **high level of support for and participation** in developing their competence		
Students have a **high sense of accomplishment and satisfaction** for competency-based learning		
Students **regularly interact with and serve** community, industry, the profession, and associations		
Students **take greater control of planning and managing their experiences** to meet their goals (individualized pathways)		
Students own, develop, and enhance their **professional identities**		
OTHERS		
Industry and community partners **engage in competency-based programs and contribute** knowledge, projects, mentoring, and advice to students and faculty related to the development of engineering competencies		

Table 4.4 Rubric for Action (continued)

PROGRAM-LEVEL Indicators of HIGH PROGRESS	Moderate Progress	Low Progress
Program-wide acceptance and implementation of modular, competence-based instructional approaches and learning outcomes across courses, curricula, and colleges		
Increase **interdisciplinary collaborations** across colleges, industries, and communities		
Offer **customizable, individualized, non-standard degree requirements, program tracks**		
Program **implements and supports robust competency and other professional development**		
Programs **include holistic criteria to assess competency and demonstrate mastery** (including portfolios, presentations, and other alternative measures)		
Programs foster a **broad abundance of resources, mentors, and industry partners engaged** in programs		
Programs focus on **hiring faculty and other professionals having competency-based experience**		
Accreditation efforts **recognize and reward competency-based learning outcomes**		
INSTITUTIONAL-LEVEL Indicators of HIGH PROGRESS	**Moderate Progress**	**Low Progress**
HIGHER EDUCATION		
Institution shows enthusiastic **commitment and support for competency-based learning** (including from university administration, trustees, etc., as well as students, faculty, community, and industry)		
Institution demonstrates **high level of transparency regarding power** relations in educational change efforts		
Significant **emphasis on, recognition of, and rewards for faculty, staff, and other personnel for development and teaching to advance competency-based education,** including in evaluation, promotion, and tenure process		
Institution has a stronger **emphasis on skills and attributes,** along with knowledge competencies in learning		
Effective increase of **vertical integration of K-16 STEM education**		
Greater emphasis on **real-world issues in education,** including interdisciplinary service learning and project-based learning		
Support for increasing **global faculty exchanges**		
Increased **student enrollments and graduation rates, including increased graduates' success and satisfaction** with engineering education and career		
Competency-based learning outcomes included in **ABET and institution evaluation metrics** (including quality of instruction)		
Complete redesign and integration of programs to **eliminate fixed 4-year/3-credit model in favor of individualized pathways** codesigned by students and faculty		
Competency-based assessment accepted as an alternative assessment instrument, including portfolios and other means of assessing success		
INDUSTRY, COMMUNITY		
Robust **collaboration with industry partners, organizations, and multiple colleges** to integrate competency-based and interdisciplinary education into curricula		
Enhanced **community and industry relations and collaborations**		
Employers support improvements in graduates' competencies for work		

Notes


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