Chapter 12
The Toolkit: Pedagogies, Curricular Models, and Cases for Engineering Academics and Schools Implementing Industry-Integrated Engineering Education

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Introduction

In this chapter, we highlight a number of pedagogies and curricular frameworks and models as toolkit for engineering education academics and schools for facilitation of the implementation of industry-integrated engineering education. In particular, we provide further details on competency-based education (Frank et al. 2010; Kenkel and Peterson 2010; Morcke et al. 2013; Johnstone and Soares 2014) and a number of learner-centric, constructivist, and experiential pedagogies (Abdulwahed et al. 2008) such as service-based learning (Bringle and Hatcher 1996; Waterman 2014), high-impact practices (Brownell and Swaner 2009; Kuh 2008), problem-/project-based learning (Mills and Treagust 2003; Abdulwahed et al. 2009), engineering design (Dym et al. 2005; Abdulwahed and Hasna 2017), etc. The learner-centric approaches are in particular useful for executing on competency-based education models in practice in the classroom and curricular delivery. Competency-based education is in particular a suitable framework for implementing industry-integrated engineering education because CBE emphasizes the combination of the following triangulation in situation, context, or professional activity:

1. Knowledge
2. Attitude or value
3. Skill or ability

These three components can be an optimal setup to systematically design an effective industry-integrated engineering education for the following rationales:

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- The context to be chosen will be a professional industry context in which the competency in the engineering education is designed around.
- Knowledge of theory and information of this context need to be taught in engineering education (e.g., engineering theory and content knowledge for industrial context).
- The proper professional attitude and value for this professional context need to highlighted and potentially practiced (e.g., professional ethics, professional behaviors, etc.).
- The skill or ability to perform and execute on the professional context needs to be trained in engineering education (e.g., lab, practicum, internships, etc.).

In the next section, further details on competency-based education are provided.

Competency-Based Education: A Holistic Framework for Implementing Workplace Competencies in Engineering Education

Competency (Mastery)-Based Education

Competency-based education (CBE) ensures graduates are produced with necessary levels of mastery for their next station (career or further studies), they are flexible systems that admit learners with demonstrated competency at the proper level and allows time variants for mastery attainments.

Competency-based education (CBE) is a paradigm shift in which it distinguishes itself from traditional education models with the following:

1. The central focus of the education system is on students' competency development and mastery.
2. These competencies are defined in close alignment with workplace and contextual needs.
3. Learning outcomes (outcome-based education (OBE)) is central, and the time for achieving it is variant (not fixed by completion of a number of credit hours).
4. Provides flexibility in the way that credit can be earned or awarded and offers students personalized learning opportunities.
5. Ensure that more students who succeed in academia build career readiness.
6. CBE is highly learner-centric and experiential based.

Transformation from traditional into competency-based education has implications on the following:

1. *Delivery*: mainly using learner-centric and experiential approach, as well as digital-based learning

2. *Curriculum design*: mainly comprehensive integration of competencies of workplace and context in curriculum
3. *Competency framework, learning outcomes, and competency assessment*: a need to develop a systematic competency framework and moving from traditional exam-based assessment toward competency-based assessment that focuses more on mastery and process development

Definition of a Competency There are several definitions of competency, and in many times, the term competency is interchangeably utilized by other terms. In this chapter, we are utilizing the following definition of competences: "A competence is the **INTEGRATION** of **KNOWLEDGE**, **SKILLS/ABILITIES**, and **ATTITUDES** (or values) which **SITUATIONALLY** allow a person to **DEVELOP** effectively in different contexts and **PERFORM** a **FUNCTION**, **ACTIVITY** or **TASK** in proper way." The model we are adopting for competency definition is represented in Fig. 12.1.

Approaches to Develop Competency (Mastery)-Based Education

Competency-based education is rather a generic framework that several approaches can be considered under its umbrella. We highlight below some of these approaches:

Workplace Competency Development in the Curriculum: This should come as the first stage of transformation of engineering school curricula into CBE. The main aim of this phase is to develop comprehensive set of competencies and curricular programs based on workplace and contextual needs that Qatar University aims to serve. There are several models and frameworks for this, and one of the widely utilized methods is called DACUM (Developing A CurriculUM).

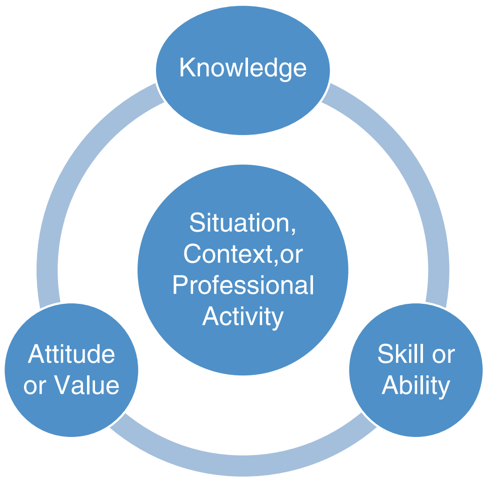

Fig. 12.1 Conceptual model of a competency which is represented by the integration of knowledge, skills/abilities, and attitude/value to handle a situation, context, or professional activity

Formal Credentials for Attained Competencies (Formal or Informal): This is one of the characterizing foundations of CBE systems, which normally allows acknowledgment of developed competencies in terms of previous experience, informal learning, or training by provisioning formal credentials upon demonstrating satisfactory mastery level via CBE assessments.

Variation of Time to Degree Completion: This is another foundational principle of CBE systems; the main target is demonstration of mastery of certain set of competencies to attain a degree. The time to complete a degree would depend on the learners' ability to reach a certain mastery level.

Engineering Graduate Attributes Framework

Engineering graduate attributes define a selected set of attributes that students of an engineering school should develop during their time in college. Engineering graduate attributes should be strongly aligned with national attributes and competency needs (e.g., attributes identified by the Ministry of Education on K–12 level, digital literacy, national visions, etc.), as well as the employer needs (e.g., technical competency, leadership, etc.). The engineering attributes are qualities that prepare graduates to succeed in their personal and professional lives. Each attribute is composed of a set of competencies; the latter are by-product of program learning outcomes. The engineering graduate attributes model defines the key competencies to be acquired by all students that will enable the development of the desired graduate attributes. These competencies represent the desired knowledge, skills/abilities, and attitudes/values (KSA) to be acquired by the engineering students during their time at the engineering school. On a high-level sketch of Engineering Competency Framework, the following dimensions should be identified:

- Contextual and National Competencies: e.g., K–12 comp., government and employer competencies, etc.
- Universal Competencies (for all): e.g., twenty-first-century, employability, KBE citizens, national, and other competencies
- Profession Specific (for professional domain-specific personnel): e.g., engineering profession
- Discipline Specific: e.g., civil engineering, mechanical engineering, etc.
- Vertical Specialization and Mastery: e.g., those careers on advanced R&D or high specializations (normally not at UG level)
- Functional, Situational, and/or Workplace Performance Competencies: e.g., welding, coding, calling, curating, etc.

Universal competencies can be classified into three dimensions:

- Cognition, thinking, and mental
- Interpersonal and professional
- Business and management

For profession, discipline, or vertical competencies, the KSA classification (described earlier and shown in Fig. 12.1) can be utilized:

- Core knowledge
- Core skill/ability/practice
- Core attitudes/traits

Pedagogical and Curricular Models for Facilitation of CBE Implementation

Constructivist Learning

Constructive learning (students construct knowledge and experience by their own) is a framework umbrella for several learner-centric and experiential approaches such as (Richardson 2003) (1) active learning, (2) flipped classroom, (3) experiential learning cycle and styles, (4) project-/problem-based learning, (5) research-based learning, (6) community- and service-based learning, (7) collaborative learning, (8) entrepreneurial learning, (9) design-based learning, (10) competency-based learning, (11) inquiry-based learning, (12) seminar-based learning, (13) internships, (14) field visits, etc. With the advancement of ICT, digital tools and learning technologies have become significant enabler of implementations of constructivist learner-centric and experiential pedagogy approaches.

High-Impact Practices (HIPs) in Undergraduate Education

This is a new trend gaining momentum in the USA. HIPs are practical implementations of several pillars of constructivist pedagogy that are clustered into ten themes, which was forumalted based on a comprehensive scan of evidence-based research in learning and teaching. The ten practices are (Kuh 2008):

- First Year Seminars and Experiences
- Common Intellectual Experiences
- Learning Communities
- Writing Intensive Courses
- Collaborative Assignments and Projects
- Undergraduate Research
- Diversity/Global Learning
- Service-Based Learning and Community-Based Learning
- Internships
- Capstone Courses and Projects

Flipped Classroom

Flipped classroom (Tucker 2012; Bishop and Verleger 2013) is a "fancy" name of a pretty much learner-centric experiential constructivist pedagogy, which is normally digitally enriched via videos and other learning technologies. The core of "flipped classroom" philosophy is rearrangement of time spent on learning in and out of classroom in which it shifts learning responsibilities toward students for a significant extent. In the "flipped classroom" approach, the expertise of the instructor is utilized more effectively in the valuable time of the classroom on guiding higher cognitive and more active and problem-/project-/experiential-based learning activities. Flipped classroom is normally characterized with pre-, in-, and post-classroom learning experiences. In recent study, 29% of faculty in the USA reported utilizing flipped classroom approaches. Emerging research and impact evaluation of the approach suggest significant improvement in learning outcomes and retention as compared to traditional teaching.

Research-Based Learning

Research-informed/research-based learning (Shaban and Abdulwahed 2012) and/or undergraduate research (UR) in the curriculum is increasingly an embraced trend. The central focus of research-based learning is on the development of the learners as independent researchers. This teaching approach is designed to promote, among the learners, a commitment to making a difference in the world through intellectual inquiry and creative expression leading to useful and innovative solutions for real-life problems. RBL assists the learners in exploring how to develop their research skills and to conduct research activities under the supervision of faculty members. Learners are encouraged to engage in real-life problem-solving, liberate their thinking, develop their writing and presentation skills, and gain confidence in their intellectual abilities.

Many benefits of RBL/UR have been enumerated in the literature. Utilizing RBL/UR may lead to enhance students' perception and interest in STEM careers, as well as to increase confidence and self-capacity to learn; learning outcomes; management, communication, and organizational skills; motivation and enthusiasm; likelihood to pursue graduate studies and development of leadership skills; and academic GPA (Bahr et al. 2006). Students who participate actively in rigorous research experience, which may involve authoring research papers, attending a conference, and/or mentoring other students, are the most likely to experience positive outcomes.

Service-Based Learning

Service-based learning is a teaching method that combines academic coursework with the application of institutional resources (e.g., knowledge and expertise of students, faculty, and staff, political position, buildings, and land) to address challenges facing communities through collaboration with these communities. This pedagogy focuses on critical, reflective thinking to develop students' academic skills, sense of civic responsibility, and commitment to the community (Definition by Centre for Civic Engagement, Michigan State University); this definition is shown in Fig. 12.2.

Service-based learning engages students in a three-part process: classroom preparation through explanation and analysis of theories and ideas; service activity that emerges from and informs classroom context; and structured reflection tying service experience back to specific learning goals. Service-based learning is a mutually beneficial endeavor in which course learning objectives are met by addressing community-identified needs "through linking academics to the community…(and) develop(ing) the skills, sensitivities and commitments necessary for effective citizenship in a democracy."

Other Pedagogies and Models

There are quite few other pedagogies and models that enable learner-centric education and can serve as a framework for developing and executing industry-integrated engineering education; we enumerate some of these below:

- Design-Based Education (Abdulwahed and Hasna 2017)
- CDIO Approach from MIT (Conceive, Design, Implement, Operate) (Berggren et al. 2003)
- DACUM Framework for Workplace Competencies Implementation (DeOnna 2002)
- Engineering Executive Education and Professional Development Courses (Berkeley 2019)
- Problem-/Project-Based Learning (Abdulwahed et al. 2009)
- Entrepreneurial Learning (Abdulwahed et al. 2013)

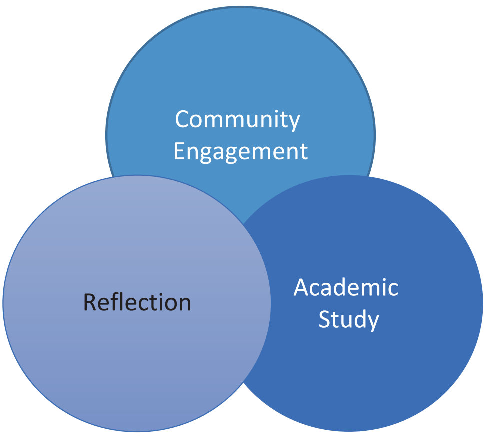

Fig. 12.2 Conceptual model of a service-based learning, which combines community engagement, academic study, and reflections

- Engineering Leadership Learning (Abdulwahed and Hasna 2016)
- Cooperative Education (Linn et al. 2004)
- EngD (Engineering Doctorate) Conducted in Industry (Kerr and Ivey 2003)

Pedagogical and Curricular Models from the Book Chapters Global Cases

One of the major aims of this book has been to provide engineering academics and schools with global perspectives on advances and cases of implementing industry-integrated engineering education from different parts of the world; in this section, we provide a brief summary for some of the pedagogical and curricular models presented in various chapters throughout the book:

Engineering MSc for Engineering Professionals (Denmark): Bente (Chap. 4, this volume) provided a case of implementation of a part-time MSc program in Denmark for professional engineers to upgrade their skills. The program is designed using project-based learning for problems in the professional context as a core component.

Integrated Model for IT Workforce-Ready Graduates (Thailand): Siddo et al. (Chap. 9, this volume) provided a study on the development of an integrated model for preparing IT graduates in Thailand for the workplace needs. The model takes into consideration influencing factors, development activities, and the IT worker's learning stages and can be implemented in IT education.

Onboarding Programs for Early-Career Engineers in Practice (USA): Babajide and Al Yagoub (Chap. 6, this volume) provided analysis of onboarding programs in the USA and provided key factor requirement of structure; these programs are utilized also as leadership development platform.

Professional Ethics for Engineering Education (USA): Winn et al. (Chap. 8, this volume) provided a well-rounded professional ethics model development in engineering education in the USA that integrates theory, philosophy, behavioral value, experiential learning, and professional ethics frameworks.

Industry-Integrated Introductory Engineering Course with Sustainability Theme (Malaysia): Yusof et al. (Chap. 3, this volume) provided collaborative design and delivery models for implementing industry in introductory engineering course through focus on sustainability.

Reverse Engineering Design for Industry-Integrated Engineering Course (Mexico): Lopez et al. (Chap. 7, this volume) provided models for implementing reverse engineering design in engineering course in Mexico together with model and procedures for delivery of the course; project-based learning (PBL) was a core component in the pedagogy delivery.

Theoretical and Empirical Framework for Design of Industry-Integrated Program (France and Qatar): Veillard et al. (Chap. 10, this volume) provided theoretical framework derived from the sociology of curriculum theory for development of industry-integrated programs, with overview models for proposed MSc program in Qatar and also overview model of existing undergraduate program in France.

Industry-Integrated Cybersecurity Needs in Graduate Certificate in Building Information Modelling (Qatar): Hammi and Bouras (Chap. 5, this volume) provided model for implementing graduate certificate in BIM with cybersecurity component based on industry needs.

Holistic Model for Industry-Integrated Cybersecurity Curriculum (France): El Melhem et al. (Chap. 11, this volume) provided a holistic approach for designing interdisciplinary cybersecurity curriculum in France in line with global and EU frameworks and best practice models.

Conclusions

Industry-integrated engineering education is an ever-emerging field and is increasingly becoming of high priority and demand by the industry. There are several advantages of effective integration of engineering education with industry needs, such as better employability of graduates, enhanced motivation of engineering students, better linkage between academic professors and industry, reduced expenditure on training in onboarding programs for early career engineers and recent engineering graduates, etc. In this chapter, we provided a toolkit of pedagogies, models, and frameworks for engineering academics to implement industry-integrated engineering education. In particular, we focused on competency-based education as one of the most suitable frameworks for holistic integration of industry in engineering education for its triangulation approach of knowledge, value/behavior, and skills/abilities. Furthermore, we demonstrated some of the learner-centric pedagogies that can be utilized for delivery and execution of industry-integrated engineering education, and finally we summarized the different models and conceptual frameworks of industry-integrated engineering education detailed in the various chapters of the book from different parts of the world.

References

Abdulwahed, M., & Hasna, M. O. (2016). *Engineering and technology talent for innovation and knowledge-based economies: Competencies, leadership, and a roadmap for implementation*. Cham: Springer.

Abdulwahed, M. and Hasna, N. O. (2017). *Engineering and technology, talent for innovation and knowledge-based economies*. Springer International Publishing AG, Cham, Switzerland.

Abdulwahed, M., Nagy, Z. K., & Blanchard, R. E. (2008). Beyond the engineering pedagogy: engineering the pedagogy, modelling Kolb's learning cycle, AaeE Conference held at Yeppoon, Australia.

Abdulwahed, M., Nagy, Z. K., & Blanchard, R. (2009). Constructivist project based learning design, a cybernetics approach. *Journal of Education, Informatics and Cybernetics, 1*(2), 1–8.

Abdulwahed, M. A., Hamad, J. A., Hasanain, M. A., & Hasna, M. O. (2013). Entrepreneurship education in engineering: A literature review and an integrated embedment proposal. *World, 12*, 5.

Bahr, M. W., Walker, K., Hampton, E. M., Buddle, B. S., Freeman, T., Ruschman, N., Sears, J., Mckinney, A., Miller, M. & Littlejohn, W. (2006). Creative problem solving for general education intervention teams: A two-year evaluation study. *Remedial and Special Education, 27*(1), 27–41.

Berggren, K. F., Brodeur, D., Crawley, E. F., Ingemarsson, I., Litant, W. T., Malmqvist, J., & Östlund, S. (2003). CDIO: An international initiative for reforming engineering education. *World Transactions on Engineering and Technology Education, 2*(1), 49–52.

Bishop, J. L., & Verleger, M. A. (2013, June). The flipped classroom: A survey of the research. In *ASEE national conference proceedings* (Vol. 30, No. 9, pp. 1–18). Atlanta.

Bringle, R. G., & Hatcher, J. A. (1996). Implementing service learning in higher education. *The Journal of Higher Education, 67*(2), 221–239.

Brownell, J. E., & Swaner, L. E. (2009). High-impact practices: Applying the learning outcomes literature to the development of successful campus programs. *Peer Review, 11*(2), 26.

DeOnna, J. (2002). DACUM: A versatile competency-based framework for staff development. *Journal for Nurses in Professional Development, 18*(1), 5–11.

Dym, C. L., Agogino, A. M., Eris, O., Frey, D. D., & Leifer, L. J. (2005). Engineering design thinking, teaching, and learning. *Journal of Engineering Education, 94*(1), 103–120.

Frank, J. R., Snell, L. S., Cate, O. T., Holmboe, E. S., Carraccio, C., Swing, S. R., Harris, P., Glasgow, N. J., Campbell, C., Dath, D., & Harden, R. M. (2010). Competency-based medical education: Theory to practice. *Medical Teacher, 32*(8), 638–645.

Johnstone, S. M., & Soares, L. (2014). Principles for developing competency-based education programs. *Change: The Magazine of Higher Learning, 46*(2), 12–19.

Kenkel, M. B. E., & Peterson, R. L. (2010). *Competency-based education for professional psychology*. Washington, DC: American Psychological Association.

Kerr, C. I., & Ivey, P. C. (2003). The Engineering Doctorate model of consultant/researcher/innovator/entrepreneur for new product development—a gas turbine instrumentation case study. *Technovation, 23*(2), 95–102.

Kuh, G. D. (2008). *Excerpt from high-impact educational practices: What they are, who has access to them, and why they matter*. Washington, DC: Association of American Colleges and Universities.

Linn, P. L., Howard, A., & Miller, E. (Eds.). (2004). *Handbook for research in cooperative education and internships*. New York: Routledge.

Mills, J. E., & Treagust, D. F. (2003). Engineering education—Is problem-based or project-based learning the answer. *Australasian Journal of Engineering Education, 3*(2), 2–16.

Morcke, A. M., Dornan, T., & Eika, B. (2013). Outcome (competency) based education: An exploration of its origins, theoretical basis, and empirical evidence. *Advances in Health Sciences Education, 18*(4), 851–863.

Richardson, V. (2003). Constructivist pedagogy. *Teachers College Record, 105*(9), 1623–1640.

Shaban, K. B., & Abdulwahed, M. (2012, August). Research-based learning in computing courses for senior engineering students. In *Proceedings of the 2012 IEEE international conference on teaching, assessment and learning for engineering (TALE)* (pp. 20–23). Hong Kong.

Tucker, B. (2012). The flipped classroom. *Education Next, 12*(1), 82–83.

UC Berkeley Engineering Executive and Professional Education, Leadership for Engineers by Engineers. (2019). [Online] Available from http://exec-ed.berkeley.edu/

Waterman, A. S. (Ed.). (2014). *Service-learning: Applications from the research*. New York: Routledge.