2023

Informal Learning as Opportunity for Competency Development and Broadened Engagement in Engineering

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1 Introduction

Engineering for the 21st century requires graduates to have a broad range of competencies and experiences that enable them to work in a technology-dependent and globalized workforce within a complex sociotechnical landscape (National Academy of Engineering, 2004; SEFI, 2016). Fueled by both economic (National Academies of Sciences, Engineering, and Medicine, 2018) and equity (Baber, 2015) arguments, the engineering profession also needs a diverse and inclusive workforce that represents the communities it serves and that protects the welfare of all (Chubin et al., 2005; National Academy of Engineering, 2002). However, it is increasingly recognized that the engineering curriculum alone cannot fulfill these aims (National Academies of Sciences, Engineering, and Medicine, 2018).

Throughout the world, the engineering curriculum is densely packed with content that is focused on engineering science and has evolved little over the past few decades (Froyd & Lohmann, 2014). Learning outside of the classroom provides opportunities for students to develop key competencies that are needed for employability (Fisher et al., 2017; Mtawa et al., 2019; Polmear et al., 2021a; Tan et al., 2021) and skills that help them persist through the degree program (Kuh et al., 2008). Learning outside of formal class time also supports the engagement of students who have been traditionally underrepresented in engineering (Espinosa, 2011). Given the role of informal learning in supporting competency development and the engagement of diverse students, it is crucial for engineering programs to integrate these learning opportunities and to recognize their value.

Learning occurs in myriad ways and settings that contribute to students' personal, academic, and professional development (Shulman, 2005). Formal learning provides structured and intentional opportunities in classrooms and lecture halls through which students acquire knowledge and learn what it means to be an engineer (Ainsworth et al., 2010). However, only a small portion of the educational experience occurs within the formal curriculum and class time (Bell et al., 2009; Lee & Matusovich, 2016). Learning is not confined to these formal settings but rather continues informally and sometimes implicitly throughout the daily lives and activities of students (Ainsworth et al., 2010; Denson et al., 2015; Kotys-Schwartz et al., 2011).

DOI: 10.4324/9781003287483-18

Informal learning occurs outside of the instructional and institutional setting in which individuals participate, often without being part of the academic program or any requirement for graduation (Trinder et al., 2008). The definition of *informal learning* is intentionally broad to capture the range of activities, organizations, and settings through which students learn informally. Across these contexts, informal learning is defined along the dimensions of being (1) non-didactive, (2) collaborative, (3) within a meaningful context, (4) driven by the learner's interest, and (5) without external assessment (Callanan et al., 2011).

One aim of this chapter is to introduce informal learning by synthesizing the various definitions and disciplinary perspectives that have contributed to the piecemeal development of literature on informal learning. A second aim is to demonstrate the benefits and outcomes of informal learning that transcend the various settings, contexts, and activities in which it takes place. Pulling these pieces together, the chapter shows that the potential of informal learning is still being realized in education and research. More engagement from administrators, educators, and institutions is needed to provide opportunities for informal learning and recognition for the students who are participating and gaining engineering skills and experiences. More research is needed to understand the various ways in which students engage in informal learning, the different experiences of students from diverse backgrounds, and ways to assess the outcomes of informal learning.

The chapter begins with an overview of informal learning, including established definitions, a history of informal learning in engineering, a description of activities and settings relevant to engineering education in the university context, and a profile of student participation in informal learning. The chapter focuses on two key benefits related to informal learning: (1) competency development within the university experience and for engineering practice and (2) broadened engagement for learners with considerations for diversity, equity, and inclusion (DEI) in an international context.

To realize these benefits, the chapter identifies implications and provides suggestions for engineering education and research. The chapter is intended to serve as a guide for educators, administrators, researchers, and graduate students interested in studying or implementing informal learning. Informal learning is an opportunity for engineering programs to broaden the skill set and holistic experiences of their students. Yet to fully leverage this potential, there is a need for more research on outcomes accrued by students who engaged in the range of informal learning activities and settings. Also needed are better mechanisms to recognize the outcomes that students gain.

2 Overview of Informal Learning

2.1 Definitions

Since informal learning occurs throughout an individual's life, there are varying definitions and disciplinary perspectives based on context. Formalizing the vocabulary surrounding informal learning in engineering education is needed to help the engineering education community readily identify studies on the topic and work across disciplinary and national boundaries (Kotys-Schwartz et al., 2011).

In addition to being lifelong, informal learning is conceptualized as life-wide since it occurs in activities and settings outside of the classroom (Meyers et al., 2013). It is characterized as being iterative and open-ended, often collaborative, and embedded in local context (Bell et al., 2009; Falk & Dierking, 2016; Griffin, 1998). Informal learning is immersive and spontaneous (Ainsworth et al., 2010). It can be structured or unstructured – particularly regarding the objectives, availability of support, and length of time spent – but it is almost always motivated and guided by the interests of the learner. Informal learning is generally not formally or externally assessed (Rogoff et al., 2016). Informal learning stands in contrast to formal learning, which occurs in classrooms, lecture halls, and laboratories, where every student is expected to achieve specific learning outcomes and performance indicators.

In educational research, there is a longer history of examining informal learning in the context of K–12 and science education. One foundational reference in this space is "Learning Science in Informal Environments: People, Places, and Pursuits" published by the National Research Council of the National Academies (Bell et al., 2009). This work provides a helpful starting place to understanding informal learning and identifies six "stands of learning" that typify informal environments. Learning in informal settings is characterized by (1) excitement, interest, and motivation to learn about science phenomena; (2) remembering, understanding, using, and generating science concepts, explanations, arguments, models, and facts; (3) observing, exploring, questioning, predicting, manipulating, testing, and making sense of the natural and physical world; (4) reflecting on science as a way of knowing and on one's own process of learning about phenomena; (5) participating in activities and learning practices with others, using science language and tools; and (6) thinking about oneself as a science learner and developing an identity as someone who knows about, uses, and sometimes contributes to science and technology (adapted from Bell et al., 2009, p. 4).

Although this chapter focuses on informal learning for university students, K–12 education provides insight into the historical development of informal learning, a larger body of scholarship, and a pathway into university engineering education.

2.2 History of Informal Learning in Engineering Rooted in K–12 Education

Informal learning has always existed in cultures and communities, and discussions of informal learning in educational theory emerged in the early 20th century through the work of Dewey and Vygotsky (Callanan et al., 2011). Informal education was explicitly distinguished from formal education in the work of Scribner and Cole in the 1970s, which ushered in a greater focus on informal learning inside and outside schools (Callanan et al., 2011). In the decades since, programming and research related to informal learning have focused on pre-university (i.e., K–12, also known as primary and secondary school; Callanan et al., 2011; Ehsan et al., 2018; Jagušt et al., 2018).

Informal learning in K–12 has long served as an opportunity to interest younger students in going to university and pursuing a STEM degree. A meta-analysis of research on out-of-class STEM programs on K–12 students indicated a positive effect on interest in STEM (Young et al., 2016). Evidence shows the importance of reaching students younger than secondary/high school and having multiple informal learning opportunities to expand pathways into STEM (Demetry & Sontgerath, 2020). Outreach programs offered through universities also benefit the university by providing a recruiting mechanism. In addition to the value of informal learning in students' STEM interest, participation in out-of-class activities is considered valuable for university admission in the USA (Clinedinst & Koranteng, 2017).

As university engineering education has evolved, from its roots in the Industrial Revolution and a practical focus then to a more theoretical approach (Seely, 1999), informal learning has served as an important entry point into engineering education, an opportunity to complement the curriculum, and support workforce development (Kovalchuk et al., 2017). Over time, the activities and settings in which students informally learn about engineering have also grown, as detailed in the following section.

2.3 Types of Informal Learning: Activities and Settings

Informal learning can happen in a range of settings and through a variety of activities. *Settings* describe the environment in which people learn informally, and *activities* describe the actions they are doing as part of their learning. Given this breadth, different typologies have been developed to categorize informal learning. Science education once again provides a starting point where scholars (Bell et al., 2009) have identified three main types of settings where people learn science: programmed settings, designed environments, and everyday environments. These three categories are also recognized in the literature on engineering education (Denson et al., 2015; Kotys-Schwartz et al., 2011).

The first type, programmed settings, tends to "emulate or complement formal school settings" (Denson et al., 2015, p. 11). Programmed settings frequently involve facilitators, a fixed group of participants for multiple sessions, and a plan with goals and learning objectives (Kotys-Schwartz et al., 2011). Programmed settings may intentionally complement a formal curriculum to extend benefits and reinforce the learning. At a general level, they include programs that are connected to schools and community organizations (Bell et al., 2009).

The second categorical environment for informal learning, designed settings, involves places that are deliberately curated to facilitate learning. Designed settings include science and technology museums, civic and community learning centers, and world fairs. With the rise of community maker spaces and maker fairs, this type of environment, designed to facilitate informal learning of engineering, is becoming more prevalent (Martin & Betser, 2020; Wilczynski, 2015).

The third category, everyday settings, is the most fluid and accessible. Individuals encounter science content throughout their lives and learn about the natural world through everyday encounters, cultural practices, Internet, and media (Bell et al., 2009). The distinguishing feature of this setting is that it often does not have the explicit goal of teaching or learning. Although everyday learning can be unexpected and opportunistic, it can also take shape through more deliberate activities, such as pursuing a science-related hobby.

Another prevalent scheme for categorizing informal learning settings in engineering education is organized into co-curricular and extracurricular (Simmons et al., 2018; Simmons et al., 2017). Co-curricular activities often extend the formal curriculum and may be explicitly tied to formal academic learning. Co-curricular activities can include co-ops, internships, service projects, and some activity in clubs and organizations. They are connected to (and reinforce or mirror) the formal academic curriculum, and they may even accrue credit towards graduation, but they are not a required component of the student's selected degree program. Usually, they are separated from academic coursework, ungraded, and occurring outside of class hours.

Extracurricular activities are less explicitly tied to the curriculum than co-curricular activities, even when they are provided by the academic institution. *Extracurricular activities* are consistently defined as engagement outside academics – and, more specifically, outside required coursework. Thus, extracurricular activities could include sports, jobs, community service, student governance, politics, arts, religion, hobbies, clubs, and other personal development or personal interest organizations.

In engineering, programmed settings for informal learning frequently include the types of co-curricular and extracurricular activities described previously (Fisher et al., 2017). This categorization mirrors the K–12 approach, which Kotys-Schwartz et al. (2011) recommend adapting in engineering education, and distinguishes (1) the "associated model," which is closely tied to and aligned with weekly objectives of the formal curriculum (curricular); (2) the "coordinated model," which relates to the general curriculum but is not tied to weekly outcomes (co-curricular); and (3) the "integrated model," which runs completely separate from the curriculum (extracurricular).

Within these typologies and broader categories, there is a wide range of activities and settings relevant to engineering education. Examples are displayed in Table 15.1. These informal learning opportunities are highlighted because they are commonly associated with universities and engineering programs (Kotys-Schwartz et al., 2011; Simmons et al., 2018). Due to their proximity to engineering education and practice, these activities and settings also provide opportunities for researchers

Table 15.1 Examples of Informal Learning Opportunities in Engineering Education

Type	*Definition within Informal Learning*	*Example Reference(s)*
Disciplinary professional society	Student chapters affiliated with engineering professional organizations that provide access to design competitions, networking events, and career resources.	Evans et al. (2001)
Design competition teams	Student teams that design and build a vehicle or device or develop a solution to an engineering challenge and compete against teams at other universities. The competitions are typically organized by professional societies, government agencies, and nonprofit organizations.	Wolfinbarger et al. (2021)
Service learning and community engagement	Community-based projects at a scale ranging from local to global that are not situated in a course.	Swan et al. (2013), Litchfield et al. (2016)
Research	Undergraduate research experience outside of class time or course credit.	Carter et al. (2016)
Identity-based organization (can be related to engineering or not)	Activity or society associated with a particular personal or group identity (e.g., race, ethnicity, national origin, religion, gender, sexual orientation).	Revelo Alonso (2015), Ross and McGrade (2016)
Living learning community	Program in which students live together in a campus residence hall and participate in curricular and co-curricular activities.	Maltby et al. (2016)
Study abroad	Educational program or opportunity (usually as a collaboration between universities) outside the country where the student is completing a degree.	Parkinson (2007), Berger and Bailey (2013), Klahr and Ratti (2000)
Internship, work placement	The learning environment is an authentic workplace setting that usually forms part of the curricular activities with associated learning objectives. The student is expected to observe, participate in, and complete tasks usually with supervision and/or mentorship.	Winberg et al. (2011)
Sports	Sports and athletic activities within or outside the higher education institution.	Muñoz-Bullón et al. (2017), Miller and Hoffman (2009)

and practitioners to study and leverage their potential for competency development and broadened engagement.

2.4 Informal Learning in the Workplace

The transition of engineering graduates into the workplace requires the recontextualization of the knowledge, skills, competencies, and practices that students acquire. Graduates are often described as underprepared for the demands and expectations of the workplace, particularly in recent research on the employability of graduates (for example, Trevelyan, 2019). Although many attempts have been made to close the gap between university undergraduate engineering curricula and practice, these efforts have had limited success (Trevelyan, 2019).

Work placement programs are a strategy for helping prepare engineering students to transition into the workplace after graduation. While such programs are offered by many universities around the world, Eraut (2004) makes the point that "it is usually the work that is structured and not the learning" (p. 247). Despite the complexities of the workplace aligning with outcomes of the formal curriculum, there are many studies (e.g., Jackson, 2013) reporting the value of work-integrated learning for development of the competencies and skills appropriate for the employability.

The "messy, complex, everyday complexities of work" (Dean et al., 2012, p. 11) provide valuable opportunities for informal learning. Such learning, according to Eraut (2004), can include *deliberative learning*, which is planned and intentional; *reactive learning*, which, "although . . . is intentional, occurs in the middle of the action, when there is little time to think" (Eraut, p. 250); and *implicit learning*, which occurs independently of conscious efforts to learn. Ngonda et al. (2022) identify factors that could facilitate or constrain student learning in an authentic work environment, which include the student's organizational environment, the type and scope of work allocated to the student, the availability of industry mentors, and self-efficacy and agency.

Although what is learned and how it is learned may be less predictive than in the formal curriculum, the workplace has the potential to provide unparalleled opportunities for the development of knowledge, competencies, and skills appropriate for engineering practice.

2.5 Student Participation in Informal Learning

During the higher education experience, formal learning comprises a small portion of students' time. In the USA, the National Survey of Student Engagement (NSSE) collects annual data at hundreds of universities regarding how first-year and senior (final-year) students participate in activities and spend their time (NSSE, 2020). Engineering students spend on average 19 hours per week preparing for class, with 42% of seniors reporting spending more than 20 hours per week, which is higher than students in other majors (NSSE, 2011). Outside of academic activities, engineering students spend an average of 6 hours per week on co-curricular activities (NSSE, 2011). The NSSE provides some data on the specific activities in which students are participating. Table 15.2 displays data from 281,136 first-year and senior (final-year) students from 491 universities in the USA in 2019. Large-scale quantitative research on engineering undergraduate student engagement in informal learning is limited, but additional data on engineering student participation in informal learning activities can be found in work by Wilson and colleagues (2014) and Simmons and colleagues (Simmons et al., 2018; Simmons, Ye, et al., 2018).

Table 15.2 is provided to show engineering student participation within out-of-class activities that are commonly offered at higher education institutions in the USA. A similar survey was conducted in Europe through the European Student Engagement Project (STEP), which examined how students engage inside and outside higher education curricula, with a focus on the development of transversal skills (European STEP, 2019). The survey included sports, peer mentoring, law clinics,

Table 15.2 Engineering Student Participation in Co-Curricular Activities

Activity	*Student Participation (%)*	
	First-Year	*Senior (Final-Year)*
Internship/co-op	-	48
Study abroad	-	14
Service learning	53	60
Research	5	22
Living learning community	13	22

artistic/cultural activities, student unions, and student associations as activities within the higher education institution that are considered part of student engagement.

South Africa similarly conducts a national survey, the South African Survey of Student Engagement (SASSE), adapted from the NSSE (SASSE, 2021). Survey data is collected from first-year and senior (final-year) students to measure engagement based on four themes, namely, academic challenge, learning with peers, experiences with staff, and the campus environment. In addition, students report their participation in 15 co-curricular activities that are seen to have high impact for learning (Kuh, 2008). In this survey, engineering is included in a category with science and technology, and this overall group reports the highest rates of participation in service learning, peer learning support, and working with students (e.g., group work) of all student categories.

2.6 Cultural and National Context

Opportunities for informal learning are not uniform across institutional contexts. Whereas higher education institutions in the USA leave room for student choice within the formal curriculum (providing several open electives in a student's graduation requirements, as well as general education requirements that allow for free choice within specified themes such as history, humanities, or languages), the curricula in other parts of the world may not leave much, or indeed any, free choice of modules for students.

In Europe, for instance, the Bologna process standardized the first (ordinary bachelor's) engineering degree into a three-year program, which is technically focused and affords the student little to no room for self-selection in the curriculum. Europe did, however, implement a wide-scale Erasmus program that facilitates credit transfer across European universities, thus enabling some students to study outside their home countries. Efforts are underway to align university curricula across the continent, through university alliances and a European universities initiative, which "will enable students to obtain a degree by combining studies in several EU countries and contribute to the international competitiveness of European universities" (O'Malley, 2021, para. 10). These programs provide a somewhat-higher level of flexibility for students, at the formal level.

In the USA, residential campuses (where most students live on or near campus) typically provide a range of informal, extracurricular, and co-curricular activities. This is also true of residential campuses in South Africa. Likewise, in the UK, "three quarters of students are classified as 'movers' or students who study away from their parental/guardian home, with the average student choosing to travel 91 miles for their university education" (Chipperfield, 2019, para. 1). To continue attracting students to make this commitment of time and money, Chipperfield (2019) explains, universities in the UK and elsewhere "are looking at their offer more holistically – ensuring a structured academic curriculum alongside an informal education program with a focus on developing skills, social events and a large range of sports activities." Residence life activities seek to build a sense of community and learning outside the formal classroom and have been an important part of universities' move toward informal learning in the UK, USA, and beyond.

In places where students do not reside on or near their campuses but rather continue living with their families or commuting from elsewhere, they may engage in paid employment or in community activities more than in university-sanctioned clubs and societies. Moreover, in non-Western parts of the world, informal learning may take forms not defined in this chapter. The format and type of learning may fall outside Anglicized or American perspectives and definitions. Even in Western places, opportunities to engage in "living learning communities" and professional "sororities and fraternities" may be limited. Yet individuals may still learn and develop engineering-related competencies by participating in other activities. In such scenarios, work placements, competitions, and service projects may be integrated into the required curriculum rather than offered as elective modules or optional activities.

In South Africa, elective modules and work placements are classified as part of the formal engineering curricula (ECSA, 2022), with a range of optional opportunities provided by both the university and external organizations. Available options include service-learning, competitions, and mentoring programs. Work placements are also integrated in some universities in Australia (Blicblau et al., 2016), the UK (Tennant et al., 2018), Ireland (GTI Futures Ltd., 2022), and elsewhere.

Across these activities and settings, project-based learning (PBL) can be employed. In engineering education today, much attention is paid to studying the process and outcomes of PBL. A systematic review conducted in Denmark by Chen et al. (2021) analyzed 108 empirical research papers on PBL implementation that were published between 2000 and 2019. Chen et al. found that this active learning format was being used and reported in the literature at four different levels. The authors called one of these the "project level," explaining that it is conducted outside the required curriculum. This level could also be labelled "co-curricular" or "extracurricular," as these characteristics distinguish it from PBL provided at the other levels (individual course, set of courses, or program curriculum). This example illustrates that scholars outside the USA may be using terms besides "informal learning" to describe similar or related concepts.

Although the systematic review by Chen et al. (2021) did not mention "informal learning" (Chen, 2022), it stated that "during the professional socialization process [for engineers], students could have opportunities to interact with peers, including in-team collaboration, after-class communication, and other formal or informal interactions" (p. 18). This highlights that the term *informal learning* may not be as prevalent outside the USA, and that scholars in other places may be studying associated issues but using other keywords (like PBL). Apparently, PBL research may be more common outside the USA than inside it, considering that the systematic review of PBL implementation conducted by Chen et al. (2021) identified 27 relevant publications from inside the USA, with 81 originating elsewhere. Researchers elsewhere may be more concerned with the group-based and hands-on aspects of learning than with considering if the activities accrue credit or not.

It is also worth considering that, because important informal learning may be happening completely outside the academic environment, educators may not notice the many ways they might harness the power of, or connect to, these nonacademic environments in ways that support students' informal learning of engineering. It is crucial, therefore, to broaden our understanding of what counts as learning, since these opportunities outside of the classroom can be formative in students' engineering knowledge and socialization.

3 Benefits and Outcomes of Informal Learning

Research on education has historically focused on formal learning. However, empirical and theoretical work in the past few decades has illuminated the important interplay between formal and informal learning in achieving desired outcomes. Informal learning via out-of-class activities supports a range of outcomes, which Kuh (1993) organized into five factors, based on a qualitative study of 149 seniors from 12 USA institutions. These five factors involve (1) **practical competence**, which includes self-management and contribution to society; (2) **personal competence**, which includes self-awareness, autonomy, confidence, social competence, and purpose; (3) **cognitive complexity**, which describes reflective thought and knowledge application; (4) **knowledge and academic skills**, which relate to the acquisition and valuation of skills; and (5) **altruism and estheticism**, which entail awareness of others and the ability to collaborate.

Notably, such benefits are not uniform or universal. In fact, Wilson and colleagues (2014) pointed out that evidence is mixed regarding the impact of co-curricular participation on academic outcomes. It is thus important to consider the type of informal learning, the targeted outcome, and the disciplinary and demographic characteristics of the students. In engineering education, learning outside of the classroom has emerged as an opportunity to develop nontechnical and professional competencies that are desired by employers but afforded limited space in the curriculum.

3.1 Persistence

Learning occurs within and beyond class time as students are involved inside and outside the classroom. Astin's (1984) theory of student involvement posits that the more energy a student puts into learning, the higher the learning gains will be – and that gains are in direct proportion to the quality of the effort expended. One implication of this theory is that participation in extracurricular activities contributes to the decision to persist through university (Astin, 1984). A systematic literature review on persistence of transfer students found student integration, including learning communities and campus involvement, was a key factor (Smith & Van Aken, 2020). Although the effects of informal learning in engineering often center on competency development and workforce preparation, as detailed in the following, it is important to note the benefits are also being realized during the undergraduate experience in helping students progress toward degree attainment.

3.2 Development of Nontechnical and Professional Competencies

Engineering practice is constantly evolving in response to technological, environmental, and societal changes. To keep pace with these changes and to anticipate future needs, engineers are expected to demonstrate a broad range of competencies. The past few decades have ushered in growing recognition that engineers need to develop professional, interpersonal, and intrapersonal skills to work effectively on international and interdisciplinary teams, account for the societal context of engineering solutions, design for a range of stakeholders, communicate with various audiences, and make ethical decisions (ABET, 2018; International Engineering Alliance, 2013; National Academy of Engineering, 2004).

However, the broadening of engineering competence has been accompanied by the tightening of curricular space. Engineering programs around the USA are reducing their credit hours to make the engineering degree more manageable in four years (Williamson & Fridley, 2017), and as we have noted, in some parts of the world, the engineering bachelor's is condensed into just three years. This has created a squeeze for programs to offer the requisite courses and to achieve and document the student outcomes mandated by accrediting agencies. With a finite number of hours in the curriculum, informal learning has emerged as a more flexible opportunity for developing the competencies and experiences that engineering students need to be workforce-ready. Informal learning can provide forms of engagement and cultivate competencies that are otherwise limited in the curriculum (Garrett et al., 2021).

The following subsections focus on three competencies (leadership, ethics, and communication) that are highly demanded in the engineering workforce but have been found to receive insufficient attention in the engineering curriculum (Bodmer et al., 2002; Grant & Dickson, 2006).

3.2.1 Leadership

Within engineering, leadership is recognized as a crucial competency for individual advancement, organizational innovation, and societal problem-solving (Klassen et al., 2020). Recent scholarship has highlighted informal learning as a way for students to develop and practice leadership skills. Activities outside of the classroom provide different forms of engagement that can support leadership development through experience (Knight & Novoselich, 2017). For example, participation in design competition teams can support students' identity development as engineering leaders, by providing them experience with shared decision-making, peer coaching, and task management on complex projects (Wolfinbarger et al., 2021).

A survey of engineering faculty members and administrators revealed consensus among respondents that leadership is most effectively developed in extracurricular activities (Novoselich & Knight, 2014). Civil engineering students similarly reported attaining leadership through out-of-class activities, especially female and first-generation students when compared to male and continuing generation students, respectively (Polmear et al., 2021a). With a focus on situated and self-driven learning, context, and application, informal settings provide opportunities for students to engage in the process and development of leadership skills while supplementing formal leadership instruction in the classroom.

3.2.2 Ethics

Engineers are expected to protect public welfare and demonstrate professional responsibility (National Society of Professional Engineers, 2019). The undergraduate experience is instrumental to professional ethical development, as future engineers are equipped with the skills and values of the profession. On a global scale, accreditation has served as a powerful lever for the integration of ethics in the formal engineering curriculum (ABET, 2018; International Engineering Alliance, 2013).

Despite significant growth in ethics education and research over the past few decades, research with engineering faculty members (Polmear et al., 2019), industry employers, and alumni (McGinn, 2003) has indicated that instruction in ethics is insufficient. Structural factors, such as limited curricular space, the assumed dichotomy of social and technical realms (i.e., sociotechnical dualism), and cultural norms, which include the marginalization of nontechnical skills and the educators who teach them, have challenged the integration of ethics in the curriculum (Martin & Polmear, 2022; Newberry, 2004; Polmear et al., 2018).

Most instruction and research have focused on the formal curriculum (Hess & Fore, 2018), but the quantity and quality of engineering students' participation in co-curricular activities also contribute to their ethical development (Finelli et al., 2012), and ethics can be an outcome of out-of-class engagement (Polmear et al., 2021b). Undergraduate engineering students reported exposure to ethical decision-making through co-curricular activities (Burt et al., 2011), and project-based, informal learning in Engineers Without Borders helped students develop ethical responsibility (Lee et al., 2017). Engineering educators have also reported that students in their program learn about ethics via co-curricular activities (Bielefeldt et al., 2020).

3.2.3 Communication

Communication is another learning outcome expected by accreditation agencies and a professional skill desired by employers. Engineering students have attributed communication skill development to co-curricular activities (Kovalchuk et al., 2017). Engineering students who participated in undergraduate research grants and projects reported higher communication skills compared to students with similar backgrounds and experiences who did not participate in these types of research activities (Carter et al., 2016). The social context of informal learning facilitates communication through opportunities to work with others and articulate ideas.

3.3 Broaden Engagement of Diverse Learners

Calls to increase the number of engineering graduates and diversify the engineering profession are often accompanied by recognition of the need to attract and retain students from demographic groups that have been traditionally underrepresented in engineering (Chubin et al., 2005; National Academy of Sciences, 2002). Participation in informal learning is one strategy to support engagement, persistence, and competence for all engineering students and can be particularly impactful for underrepresented students (Simmons, Van Mullekom, et al., 2018; Polmear et al., 2021a). However, the outcomes and benefits are not evenly distributed due to challenges with access and equity in informal learning (Bell et al., 2009).

There can be structural and cultural barriers to participation in informal learning. "Learning begets learning" (Noy et al., 2016, p. 56); thus, inequities in access to informal learning starting in pre-K to fifth-grade informal learning (Bell et al., 2009) can continue to be compounded through higher education. Lack of time as well as schedule and cost were the reasons most selected by undergraduate engineering students for not participating in out-of-class activities (Simmons, Ye, et al., 2018).

The broad view of participation described in the overview section does not, therefore, capture the variations and nuances across the population of engineering students. Prior research has shown that demographics influence students' involvement in co-curricular activities, and that there are differences across the type of activity and level of involvement. Among engineering students, women have reported higher engagement in out-of-class activities relative to men (Millunchick et al., 2021) and greater participation in living learning communities, fraternities/sororities related to their engineering field of study, service, international experiences, identity-based organizations, and engineering outreach support (Simmons, Van Mullekom, et al., 2018).

Research has shown that female students may find engineering more appealing when it has clear or explicit social or environmental relevance (Du & Kolmos, 2009; Kolmos et al., 2013), and the interest in social and environmental relevance is likely to influence a student's motivations to engage with informal learning as well. For example, engagement by women in Engineers Without Borders is twice as high as in engineering education as a whole (Amadei & Sandekian, 2010).

Students from low-income families are less involved in activities outside of class than their peers (Simmons, Ye, et al., 2018), and first-generation college students are less likely to be involved than continuing generation students (Simmons & Chau, 2021). However, recent work by Millunchick and colleagues (2021) indicates that demographic factors may be only part of the story. Participation in co-curricular activities can be predicted by a combination of utilizing proactive behaviors (including general socializing behavior and feedback-seeking behavior) and of knowledge of higher education systems (e.g., having university preparatory experience, family ties to the university, or relatives who studied at university and understand how to identify, name, and navigate university systems, opportunities, and support structures). In the study by Millunchick and colleagues, participation in design competition teams and professional societies was best predicted by proactive behavior – while participation in research was best predicted by a combination of demographics and knowledge of higher education.

Another consideration related to access and equity is the climate within the informal learning setting, which can support or impede inclusion. For example, design competition teams are one of the most common co-curricular activities among engineering students in the USA (Wilson et al., 2014). However, design competition teams can represent homogenous environments dominated by White males in which cultural and structural factors contribute to systematic exclusion (Walden et al., 2015). Women have felt discouraged from participating due to perceiving gendered stereotypes and disregard for their contributions (Foor et al., 2013).

The culture is also exclusionary for students who must work or commute and thus cannot fulfill the "pervasive ethos of commitment" within these teams (Foor et al., 2013, p. 18). On the other hand, informal learning in out-of-class settings can contribute to the academic success and persistence of groups traditionally underrepresented in engineering. For example, participation in the Society of Hispanic Professional Engineers provided a sense of community, family-like connection, and mentorship that supported Latino/a/x students' engineering identity development (Revelo Alonso, 2015). Inconclusive research findings regarding the benefits of informal learning in different environments and for different groups suggest the need for further research to understand these contextual variations and increase access and inclusion for all students.

4 Considerations for Practice

This section provides considerations and recommendations for practitioners to facilitate informal learning in ways that realize its value related to competency development and broadened engagement.

4.1 Designing Informal Learning Opportunities

Regardless of the specific setting or activity, there are guiding recommendations for informal learning (Bell et al., 2009). The environment should be developed for specific learning objectives, be interactive, provide different ways to engage, encourage learners to draw on their past knowledge and experience, and stimulate lifelong learning. More purposeful and effective use of informal learning environments can support the shift in engineering education away from traditional delivery-focused transmission-of-content models toward constructivist approaches, which focus on the student, rather than content, and leverage how students learn through social interactions and past experiences (Hein, 1991).

These more innovative constructivist approaches use active, collaborative, and increasingly informal learning to help improve the analytical, problem-solving, technical, and collaboration skills needed to solve contemporary engineering challenges (Chang et al., 2009). Moreover, engaging with engineering outside formal curricula allows students to "'experience engineering' in an authentic environment" (Kotys-Schwartz et al., 2011, p. 1) and to develop crucial competencies.

4.2 Designing Informal Learning Spaces

Built environments can also support various types of learning and serve as "third teachers" for immersive and experiential learning. Campos Calvo-Sotelo (2010) asserts that universities must be designed to support the social and psychological development of students as well as their intellectual growth. The author's principles for planning an educational campus include helping people bond with the place and with each other – thus fostering a community of learning by stimulating personal contact – with spaces and buildings serving multiple functions, to bring disparate factors together.

Such places also should promote the psychological well-being of community members by providing spatial, emotional, and intellectual harmony (Campos Calvo-Sotelo, 2010). Campus spaces can expose people to nature and art and provide lessons in sustainability, having to do with geography, climate, and biodiversity (Chance, 2010, 2012; Fox, 2007). Moreover, campus designs can help

Table 15.3 Learning Modes vs. Categories of Spaces Matrix

	Presentation	*Seminar*	*Brainstorm*	*Study*	*Simulation*	*Contemplative*	*Social*
Amphitheater	✓✓	X	✓	-	XX	-	✓
Library	XX	XX	X	✓✓	X	✓	-
Learning space	-	-	✓✓	✓✓	✓✓	-	✓✓
Simulation space	✓	✓	✓	✓✓	✓✓	✓✓	-
Green spaces	XX	XX	✓✓	✓✓	XX	✓✓	✓✓
Reflection space	XX	XX	X	XX	XX	✓✓	X
Café and cafeteria	XX	XX	✓✓	✓	XX	✓✓	✓✓
Atrium	-	-	✓✓	✓	-	✓✓	✓✓
Circulation	XX	XX	✓	X	X	✓✓	✓✓
Iconic place	X	X	✓✓	✓	X	✓✓	✓✓

Legend: *XX*, not recommended; *X*, unsuitable; –, suitable; ✓, recommended; ✓✓, highly recommended.
Source: Content adapted from Carreira and Heitor (2014).

tie members to larger social, cultural, and political contexts, and they can encourage increasingly innovative modes of learning and teaching.

In a follow-up to the work by Campos Calvo-Sotelo (2010), Carreira and Heitor (2014) investigated how the design of spaces on university campuses affects learning. They focused specifically on how spaces influence social interactions related to acquiring, transmitting, generating, and sharing knowledge. Carreira and Heitor developed a matrix for evaluating the learning supported by various types of spaces (see Table 15.3). Informal learning that involves a mix of contemplation and social interaction, these researchers found, can be best supported in the purposeful design of green spaces, cafés and cafeterias, atriums, circulation spaces, and iconic places on campus.

From the field of engineering education research, Chang et al. (2009) reported a preliminary study regarding the use and benefits of campus spaces at the University of Melbourne. The spaces under investigation were designed to support the learning of information by enabling student-centered and small-group learning. One of the ways that planners achieved this was by providing casual-feeling bar- or café-style seating. Communal spaces were arranged for small groups rather than individual learners and designed with attention to light, color, density of activity, provision of electric sockets, pervasive Wi-Fi, and the like. These communal spaces were placed close to the students' formal classrooms, and they were made available for students' use around the clock via swipe-card access.

In similar fashion, Chance and Cole (2014, 2019) provide a case study of techniques used in one K–12 school district in the USA to build, teach, and operate with environmental sustainability at the core. Readers interested in learning more about designing learning spaces are further directed to Fraser (2014) and Strange and Banning (2001). Fraser provides a reference book on the next generation of learning spaces. Strange and Banning consider the role of design and space (physical environments) as well as humans and organizational environments to foster success, promote safety and inclusion, and build a community of learners.

4.3 Recognizing Student Participation in Informal Learning

As described in the section "Benefits and Outcomes of Informal Learning," engineering students develop a range of competencies via out-of-class learning that contribute to their undergraduate experience and workforce preparation. However, since this learning is outside the curriculum, it is often not recognized or assessed. Although students can include activities, organizations, and jobs on their résumés and curriculum vitae, specific skills they acquire are typically not reflected in formal documents or academic transcripts. As a result, it can be difficult for employers to evaluate applicants' competencies. One approach that has emerged to address this challenge is a co-curricular or experiential transcript, an electronic documentation of student participation in learning outside the curriculum (Parks & Taylor, 2016).

Another system that has gained traction is microcredentialing, the validation of skills gained through learning activities that are linked to workforce demands (European Commission, 2022). Microcredentials can be earned by students and practitioners alike; they provide evidence of learning and/or achieving specified outcomes by way of short courses or modules that are transparently assessed (Ruddy & Ponte, 2019). Typically, a certification or digital "badge" is conferred on those who successfully complete the course. The certificates that one can earn via LinkedIn Learning and subsequently post to one's LinkedIn profile illustrate the popularity of relatively new microcredentialing programs (Du, 2021). Readers are referred to Chapter 16 within this handbook on non-degree credentials for a detailed account of how such credentials can shape education, employment, and equity within engineering.

Practitioners and programs should consider how to recognize competencies gained through informal learning to leverage the value of these learning opportunities and support students in their employability.

5 Considerations for Research

This section provides considerations and recommendations for researchers to examine informal learning in ways that realize its value related to competency development and broadened engagement. The section begins with theoretical perspectives that have been historically employed to understand students' outcomes and experiences and framework that may aid future investigations. The section also offers areas for future research. Research on assessment in informal learning has been highlighted as scarce (Kotys-Schwartz et al., 2011) and is important to understand students' competency development. Mental health is also highlighted since it is a growing area of focus in engineering education generally, and more work is needed to understand the effect of informal learning on mental health.

5.1 Theoretical Perspectives

Various theoretical perspectives have been developed and applied to understand students' experiences and outcomes in university education, both inside (formal) and outside (informal) the classroom. Research on students in university often follows development or impact approaches (Kuh, 1993).

Development approaches describe discrete, and somewhat-linear, developmental stages during which changes in the cognitive, affective, and behavioral domains are examined. They are rooted in psychology and emphasize intrapersonal, rather than environmental, influences. Kuh (1993) cites Baxter Magolda's (1992) study of co-curricular influences on cognitive development as an example of this approach.

On the other hand, impact approaches emphasize the interaction between the individual and the environment to explain outcomes associated with the university experience. Foundational research using this approach includes Astin's (1984, 1993) input-environment-output (I-E-O) model, with a focus on student involvement. In addition, Tinto (1987) applied the impact approach with a focus on social and academic integration to develop a framework for understanding students' decisions to depart from university. Weidman (1989) extended the I-E-O model to conceptualize undergraduate student socialization.

These models, and more recent work that has employed and revised them (e.g., Terenzini & Reason, 2005), share four basic elements: student characteristics, institutional characteristics, student interactions with faculty members and peers, and interactions with the academic environment (Pascarella, 1985). Within the impact approach, informal learning is conceptualized as part of the academic environment or organizational context and peer environment. Recent scholarship in engineering education has employed this approach to understand the impact of informal learning. Millunchick and colleagues (2021) used Weidman's (1989) model of socialization to examine undergraduate engineering students' participation in co-curricular activities based on their pre-university preparation and knowledge of how higher education systems work, proactive behavior, and demographics. As another example, Lee and Matusovich (2016) employed Tinto's model of departure to develop a conceptual model of co-curricular support for undergraduate engineering students. Knight and Novoselich oriented their study of curricular and co-curricular influences on undergraduate engineering students' leadership in Terenzini and Reason's (2005) I-E-O model.

Engagement is another theoretical lens for examining informal learning; it draws in part on Astin's theory of involvement (1984) and Tinto's theory of integration (1987). Engagement broadly links activities and experiences within higher education to their outcomes. Engagement research, and the work from which it builds, demonstrates that the impact of higher education is dependent on students' efforts and involvement in formal/curricular and informal/co-curricular opportunities (Pascarella & Terenzini, 2005).

Engagement serves as the conceptual framework for the National Survey of Student Engagement (NSSE) (National Survey of Student Engagement, 2013) used in the USA and replicated elsewhere. The resulting student survey, the College Student Report, collects data from first-year (freshman) and final-year (senior) students in the USA and Canada on how they spend their time and what they gain during their undergraduate experience. Since 2000, six million students from 1,650 institutions have participated in the survey, providing a profile of student engagement inside and outside the classroom.

Applications of this theory in the context of engineering education research have demonstrated the contribution of faculty members to student engagement via experiences in-class and out-of-class (Chen et al., 2008), the link between co-curricular participation and academic engagement (Wilson et al., 2014), the role of communities outside the classroom in shaping student engagement and outcomes (Allendoerfer et al., 2012), the development of ethics as an outcome of out-of-class engagement (Polmear et al., 2021b), and the attainment of outcomes across a range of out-of-class activities and student demographic groups (Simmons, Van Mullekom, et al., 2018). Research on informal learning through the lens of engagement indicates the importance of students' efforts and involvement associated with their outcomes, while also accounting for the different types of activities and characteristics of students, thus providing more granularity.

Another theoretical perspective relevant to informal learning in engineering education is "situative learning." The foundation of this theory is that all learning happens in a particular place, at a given time, and thus, knowledge develops through a social context (Johri & Olds, 2011). The situative perspective is applied to informal learning because it emphasizes active participation, community membership, and student self-direction (Newstetter & Svinicki, 2013). Johri and colleagues (2016) detailed three analytical features of situative learning and their implications for informal learning: (1) **the social and material context** accounts for the tools and representations in a setting and their contribution to learning; (2) **activities and interactions** describe the teamwork and modality of informal learning that shape students' engagement; and (3) **participation and identity** examine the role of community and participation in identity formation. Situative learning has been used to frame community and service-learning, design competitions, and internships (Newstetter & Svinicki, 2013).

This brief overview of theoretical perspectives relevant to informal learning captures the various ways in which the higher education experience has been conceptualized in terms of how students navigate the university experience and what they gain as a result. Broadening the lens to outside the classroom puts into focus the myriad ways students learn and develop during the undergraduate experience and the outcomes they attain.

5.2 Areas for Future Research

Given the piecemeal development of literature in informal learning (Bell et al., 2009), the number of activities and settings that fall within informal learning, and the range of outcomes that can be developed, there are many directions for future research. To continue realizing the potential of informal learning for competency development and broadened engagement, the following sections highlight assessment and mental health.

5.2.1 Assessment

Despite the growing visibility and popularity of informal engineering settings, "little research has been conducted to actually define what constitutes appropriate content for informal learning models or to assess the degree to which these informal experiences impact students" (Kotys-Schwartz et al., 2011, p. 1). There is evidence that informal learning activities provide skills and experiences that support engineering students' competency development and their transitions into the workforce (Kovalchuk et al., 2017). However, research in this space often relies either upon students' self-reported skills and gains or upon internal evaluations of program objectives.

Based on an extensive review of informal learning in engineering, Kotys-Schwartz and colleagues (2011) concluded there is a dearth of validated tools for assessing gains and benefits. Furthermore, informal learning can be tacit and unintentional, and it can occur in settings out of the reach of traditional assessment. Competency development in engineering happens in a complex social system, which contributes to "accidental competency," in which this wider context, including informal learning outside of the classroom, affects students' professional formation (Walther et al., 2011).

Assessment thus remains a challenge, and there is a need for instruments and methods to capture the short- and long-term impacts of informal learning across a range of settings (Noy et al., 2016). Given both the existing evidence on the benefits of informal learning and the broad range of activities that fall within informal learning, assessment is a promising future direction of research. Scholars should consider the interpersonal, intrapersonal, and professional competencies that students gain by participating, while accounting for the context in which these competencies are being developed, and for which groups of students.

Assessment and evaluation are critical components in broadening the participation of students who have been historically underrepresented and marginalized in engineering (Holloman et al., 2021). Such assessment can determine the effectiveness of informal learning programs and interventions and their impact on aims, such as recruiting and retaining diverse students or improving the experience of diverse undergraduates. A literature review on assessment in engineering education related to broadening participation indicated a focus on K–12 programs while identifying a need to plan outcomes, collect data, and implement change (Holloman et al., 2021).

Another question in assessing informal learning is what constitutes informal learning and what activities and settings are valued within academia and the workforce. It is important to consider how the value of informal learning opportunities is being weighted, both formally through evaluation and informally through messaging students receive. The latter connects to the hidden curriculum: the tacit lessons and attitudes that students learn related to what they should value and how they should behave (Hafferty, 1998; Villanueva et al., 2018); the hidden curriculum is further discussed in Chapter 18 of this handbook. Future research could explore the messages that students receive related to if and how they should participate in informal learning, as this could help illuminate the role of informal learning in engineering education and identify what is enabling or impeding students' engagement.

5.2.2 Mental Health

Mental health is a growing area of attention and scholarship in engineering education. For example, Jensen and Cross (2021) found high self-reported levels of stress, anxiety, and depression among engineering students in the USA and noted the relationship between inclusion, engineering identity, and mental health. A review of literature on engineering graduate students' mental health found the important role that social support, faculty member interaction, and belonging play in mental health; the authors called for additional research in this area (Bork & Mondisa, 2022).

Participation in co-curricular activities has been associated with subjective well-being, which describes individuals' general satisfaction and emotional state (Hossan et al., 2021). Extracurricular engagement has also been found to support well-being and belonging (Winstone et al., 2022). Although the studies by Hossan et al. and Winstone et al. examined to what extent students participated in such activities, future work could untangle the multiple informal learning environments to understand their potential effect on mental health while also accounting for access and impact for students from diverse backgrounds.

6 Conclusions and Future Directions

Engineering education scholars are constantly examining how to better prepare graduates for workforce demands and societal needs. Challenges related to sustainability, technological development, and employability (Hadgraft & Kolmos, 2020) and calls for DEI have highlighted the importance of developing competencies to address these challenges and to provide pathways for diverse learners, which have resulted in needing to look outside the formal curriculum to educate future engineers. Informal learning offers non-didactive, collaborative, and contextual opportunities for students to learn – opportunities that are driven by students' interest (Callanan et al., 2011). Most research on informal learning has focused on science and K–12 education, but the interplay between undergraduate engineering education and informal learning is critical.

Research in higher education demonstrates the need to examine the impact of the undergraduate experience holistically by accounting for learning in both formal and informal settings. By better understanding the diversity of informal learning environments, the ways they are experienced by students, and the outcomes students gain, educators can design better, more effective ties between formal and informal learning. The heterogeneity of informal learning activities and settings available today is a strength that can be built upon, but students do not have equal access to these opportunities. There is a need to broaden participation in informal learning among those who have already joined engineering – and to use informal learning to help attract more, and increasingly diverse, participants to join engineering.

There is also a clear need to build awareness and understanding of the many structural and cultural barriers that prevent access and to recognize the compounding effect that existing inequities cause. Students with the highest levels of social and economic capital are also those who can afford the time away from family obligations and paid employment, which will let them spend time and money in clubs and other optional learning activities.

Looking at issues of equity and inclusion and recognizing that much of the research on informal learning comes from the USA and other English-speaking countries, there is a need to expand our definitions and understandings of informal learning. Engineering education can benefit from research that asks students in a diversity of national locations, cultural contexts, and demographic groups about out-of-class activities they engage in, where they apply, build, gain, or develop their engineering skills, knowledge, and values. It is likely educators and researchers are not identifying or recognizing the full range of settings.

Informal learning represents an opportunity to prepare current and future generations of engineers for 21st-century challenges by cultivating the requisite competencies and engaging students with a range of backgrounds and experiences. Research and practice can leverage the benefits of informal learning, helping design effective and inclusive learning activities, examining outcomes across settings and learners, and extending our understanding of what counts as learning.

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