Informal Learning in Engineering

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Abstract
With new technological developments and non-curricular resources and opportunities, sites of engineering work and learning have expanded. There is now a greater need to better understand how students learn engineering across different contexts, both formally designed and informal opportunities. In this paper we present a review of current literature on informal learning in engineering and outline a framework, drawn from the situated learning paradigm, for better understanding informal learning within engineering. We present findings from preliminary empirical research we have undertaken. Our review and preliminary studies provide evidence for the efficacy of informal opportunities for improving engineering learning. Finally, we discuss directions for future theoretical and empirical work.

Introduction

Successful education and training of engineers is essential for the long term growth of the economy and continuous improvement of our quality of life. Experts agree that we need to produce an innovative and creative workforce, one that is able to "work smarter," lead, engage with new domains and new group configurations, and utilize technology-mediated learning environments in innovative ways [36, 37]. Even professional engineers agree that if they want to be successful in the 21st century, they need to acquire technical excellence, innovative thinking, and the ability to work in fast changing dynamic environments [7, 36]. To provide engineering students the opportunity to gain these skills, there is a call for a fundamental retooling of how we educate engineers [38]. Scholars and practitioners engaged with these efforts agree that several barriers to change exist at the institutional level but are increasingly optimistic about reform [2, 36, 37]. The optimism comes from the recognition that advances can be made in engineering education by changing not just access to content and data but also the manner in which education is *organized* [36, 37]. One alternate mechanism that is now accepted as central to revising the current model of education is emphasizing and improving learning that occurs in informal settings [3, 15]. Researchers have found that through their lifetime people only spend about 14% of their time in formal learning environments and even when people are part of formal environments they undertake significant learning through informal activities [3, 20].

Although efforts to understand learning in informal environments have a significant lineage in science education, with a few exceptions, they have not yet made their way into engineering education. Therefore, improving and increasing informal learning opportunities to advance engineering education is an untapped opportunity. The lack of research on informal learning within engineering education was highlighted in the *EE2020* report, which raised the question, "How can formal education be better integrated with informal and lifelong learning by engineering graduates?" [37, p. 177]. The recently released report on Discipline-based Educational Research (DBER) [44] further argues that it is "important to augment current understanding of which field activities generate different kinds of learning and which teaching methods are most effective for different audiences, settings, expected learning outcomes, or types of field experiences. DBER scholars also should explore K-12, graduate, and **informal education**, as appropriate." Similarly, a recent workshop report on Lifelong Learning released by the NAE also accepted that what was missing from the workshop discussion "but necessary to consider" are "the implications of communities of interest in lifelong learning and also semi- and informal communities of practice [17, pg. 15].” This report further stated that “When considering whether non-traditional learning processes; e.g., informal learning, can achieve credibility, the key is certification [17, pg. 13]”. Therefore, though there is significant interest and momentum in understanding, improving, and assessing informal engineering learning, student learning in informal settings has received limited attention from engineering educators [11, 43].

Engineering Education Research Related to Informal Learning

The term “informal” within the scholarly literature has had a checkered history and the idea captured by the term “informal learning” [3, 13] is shared by many other terms that have emerged as a contrast against didactic teaching in formal environments [6, 10, 18, 22]. These include – “lifelong learning” [1, 10, 19], “non-formal learning” [18], and “self-directed learning” [29, 34]. Scholars who have studied informal learning see it in different ways. In the domain of science education research is directed towards investigation of interest-driven learning of science in out-of-school settings museums or out-of-school groups, science camp and enrichment programs [3, 20, 25]. We are aware of these debates surrounding informal learning and are cognizant that one of the goals of our studies will be to investigate students’ understanding of out-of-class and non-coursework related learning. In other words, how do students’ conceive of their experiences?

In the past decade the engineering education community has undertaken substantial research projects, as evident in articles published in engineering education journals, to develop a knowledge base about persistence, retention, identity, and cognitive issues such as misconceptions. Several strands from this work have implications for examining informal engineering learning. One strand in particular, professional engineering work, for instance, has looked extensively at informal learning in the workplace. [23] have shown conclusively that learning on the job is a more critical than all the technical knowledge engineers bring with them to their jobs. They investigated engineers’ knowledge use through a field study of structural engineers where they isolated 1072 episodes of knowledge use. They then constructed a “knowledge profile” that revealed temporal patterns in the frequency with which the engineers used each knowledge type. <u>Two-thirds of the knowledge engineers used was practice-generated i.e. generated and acquired on their job through informal means.</u> The development of identity is also shaped by the opportunities for activities and participation available to students. Many non-formal activities shape student identity. However, the overall “climate” of engineering programs often does not support diverse identities. Research on retention and persistence makes clear that diverse opportunities and diverse supports are needed for successful engineering education.

One of the major research programs that has shaped our thinking and research study is the *Academic Pathways Study (APS)* undertaken by scholars from multiple institutions under the aegis of the *Center for the Advancement of Engineering Education (CAEE)* [9]. Although not exclusively, APS has examined and reported on many informal activities in which engineering students participate and discusses students’ self-report of their participation. The study found that students, classified as, “High Involvement” and “Low Involvement” were opposite on measures related to engaging in engineering and non-engineering activities, formal as well as informal [9, p. 45]. Students in the Low Involvement Group were far less involved with engineering and non-engineering activities and were less motivated, less confident, and less satisfied with the overall college experience; the groups were the same on course-related measures such as GPA, academic involvement in engineering classes, and sense of curricular overload. The study also found that students in the Engineering-focused Group dedicated more of their extracurricular involvement on engineering activities as compared to those in Non-Engineering-focused Group. Furthermore, the students in the Engineering-focused Group were highly motivated to study engineering to contribute to the greater social good (in addition to psychological motivation), whereas those in the Non-Engineering-focused Group indicated far less social good motivation. Several other important findings of relevance can be synthesized from the APS study. The study reports that student involvement and engineering knowledge gains is related to participation in extracurricular activities; women tend to participate more in extracurricular activities (both engineering and non-engineering). Throughout their college careers, women tend to be more involved in extracurricular activities (both engineering and non-engineering) and ascribe more importance to these activities than do men. Women are also more likely than men to report taking administrative leadership positions in student organizations.

Another study within engineering education that relates to informal learning is the National Engineering Students' Learning Outcomes Survey (NESLOS) survey. This survey was used to collect data for three experiences: undergraduate research (N=250), capstone design (N=120), and industry internships (N=60), and comparative analysis revealed that statistically significant differences in many of the outcomes existed when comparing the three experiences as well as gender differences [40, 41]. A comparison of undergraduate research and industry experiences found that most students participated in these learning experiences as rising juniors and seniors but the majority of the participants (about 70%) only participated in either industry internships or undergraduate research. Once students selected to participate in undergraduate research or industry internships, most of them also continued participating in the same type of experience. Students participating in industry experiences are more likely to stay in industry after graduation (72%), while most students participating in undergraduate research are more likely to attend graduate school (75%). These findings suggest that early on (probably during freshman and sophomore years), most students (about 70%) identify with being the engineer practitioner (thus following an industry career path) or the engineer researcher (thus following the graduate school career path).

The insight provided by engineering education literature is that non-curricular design experiences, and other non-curricular learning activities, should strive to enhance existing curricular opportunities, filling in academic gaps that traditional curricular activities do not have the time or resources to address. This is particularly pertinent in large research-focused universities, where undergraduate curricular experiences might be limited with large class sizes and limited resources, but where copious non-curricular design and research experiences are available to students. It is known that many students engage in non-curricular learning experiences, and that these experiences have a significantly positive influence on students' educational and professional development.

Situative Framework for Informal Learning in Engineering

Even though the idea of informal learning is surrounded by debates from an empirical perspective, theoretically, especially from a Learning Sciences perspective, one theoretical frame can serve us well in its investigation – "situated learning"; alternately referred to as the "situative perspective" or just "situativity" [24]. Greeno [24] argues, as do others [33], that all action, cognition, and learning is situated – happens at a specific time and place – whether in informal settings or formal school settings. The situative perspective views human knowledge as arising conceptually through dynamic construction and/or reinterpretation within a specific social context [12] and in this perspective knowledge is socially reproduced and learning occurs through participation in meaningful activities that are part of a community of practice [33]. The core commitment of the situative perspective is, "to analyze performance and transformation of activity systems that usually comprise multiple people and a variety of technological artifacts [42]." In other words, a central aim of the situated perspective is to understand learning as situated in a complex web of social organization rather than as a shift in mental structures of a learner.

In order to leverage both the situated perspective from the learning science and current findings from engineering education, we present a framework first articulated in [28], and revised in [27]. This framework (see Table 1) synthesizes three key analytical features of the situated theory paradigm to help frame investigations of engineering learning: (1) the social and material context on learning, (2) the role of activities and interactions, and (3) the ideas of participation and identity in relation to situativity. This framework will specifically guide the development of the research instruments – interview and observation protocols for the qualitative portion of the study and their subsequent use for designing the survey. Informal learning can be understood as a situated activity that takes place in a specific setting, a setting different than a formal classroom, and often involves students becoming a part of a community of practice over time. The situated perspective also helps shed light on the different identities that students take on as they work on different projects, for instance, as part of collaborative teams. Therefore, although we believe that the debates and frameworks around informal learning are important to review, a lot more can be gained by using them in conjunction with a situative lens. A situated perspective, through a qualitative approach, has also allowed us to examine why, given the crowded undergraduate curriculum, and limited opportunities for informal learning, do students seek out these experiences? How does their context shape this decision? Furthermore, scholars have argued for its importance in supporting formal learning – it works in conjunction and improves both – how does it do this?

Table 1: Analytical Features of the Situative Perspective and Implications for Informal Learning in Engineering

Analytical Feature	Implications for Examining Informal Engineering Learning
Social and Material Context Engineering depends highly on representations that are shared among people and also uses different kinds and amounts of materials.	Informal activities take place in different contexts and availability of materials varies across spaces and events changing the availability of representations, as well as, mediation of learning by tools. It is important to the unique attributes of each context and to identify variations across contexts. What attributes of the context contribute to learning? How does variation in context contribute to different types of learning events and outcomes?

Activities and Interactions Engineering work is problem and project based; accomplished by teams through highly collaborative activities.	How do teams and groups form in informal settings? How do the activities they are engaged in shape team formation? Is there sharing of expertise and peer learning? Are all informal activities on campus? What about online informal activities? How does the nature of the project or the nature of the problem shape the learning processes, events, or outcomes in which they engage?
Participation and Identity Engineers have a strong community of practice – which varies across disciplines. They develop distinct identities as a result of their opportunity for participation, or lack thereof.	What is the role of participation in informal activities on identity formation? Does it affect diverse students differently? Is there a common trajectory for all newcomers or does trajectory, and consequently the identity, vary? Is there conflict between identities and how do formal and informal activities compare? How do learners organize themselves to engage in informal activities?

Empirical Findings: Informal Engineering Learning through Design

Findings from initial field studies of this work have focused on better understanding informal experiences related to design [30, 31, 32]. With regard to where engineering design learning occurs, the literature points to various educational contexts that effectively deliver engineering design education. The most common settings include capstone design courses, first-year engineering courses, and other non-traditional classroom experiences (e.g. Virtual laboratories). Strategies that involve authentic and longer-term engineering design experiences tend to be the most impactful in terms of student outcomes and perceptions, however those experiences are not always implementable at larger scale. More traditional educational approaches to engineering design learning, though less impactful, are still effective delivery methods for introducing key aspects of engineering design education (e.g. modeling, global/societal/economic/environmental factors, communication skills). We used ethnographically-informed qualitative observations and interviews to collect in-depth and interpretive data on students' informal engineering learning and then use that data, in conjunction with pre-existing survey instruments.

Table 2: Summary of Current Findings from Empirical Field Studies

How do students describe their experience with engineering-related non-curricular activities?	Autonomy/Agency over work Practical experiences that influence persistence in engineering
What are salient features of engineering-related non-curricular activities?	Strong self-directed learning skills exhibited by students Environments of extracurricular activities cultivate self-directed learning attributes by providing students a space to be exposed to an engineering community, authentic engineering work, and accessible resources Influence on students' self-efficacy

	Community and peer networks within extracurricular engineering environments facilitate students' validation of their perceived experience
What role do non-curricular activities play in providing engineering students navigational flexibility?	Space for students to express engineering identities Opportunities for personalized, meaningful learning within extracurricular experience By providing a space for students to express their engineering selves in primarily self-directed ways, non-curricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experience Institutional constraints (time and merits) are the most salient barriers to students taking full advantage of seeking navigational flexibility through non-curricular participation

We found that the earlier in their career that students are exposed to engineering design, and the more consistently they participate, the better the learning outcomes (i.e. communication skills, teamwork skills, innovative and critical thinking). With the exception of service-learning experiences, there was limited literature considering other non-curricular educational settings where engineering design learning might occur. This presents a significant gap in the existing engineering education literature with regard to more non-curricular learning experiences, such as learning in designed settings, outreach learning, learning media, and everyday informal learning. As an approach to address this gap in the engineering education literature, in this research we investigated five non-curricular engineering learning sites for undergraduate engineering students at a large research-driven state institution. Informed by the findings of a pilot study that investigated how students describe their experience with engineering-related non-curricular activities, we investigated the salient features of engineering-related non-curricular activities from the students' perspectives using a self-directed learner autonomy framework to guide the study. Students participating in extracurricular engineering environments exhibited strong attributes of self-directed learners, particularly a willingness and ability to be challenged and to learn. The educational environments of the extracurricular opportunities cultivated these self-directed learning attributes by providing students a space to be exposed to an engineering community, authentic engineering work, and accessible resources. By providing a space for students to express their engineering selves in primarily self-directed ways, students have the opportunity to develop as even stronger self-directed learners, which in turn helps students develop a strong sense of self-efficacy in engineering. Also, the community and peer network that students inherently join by participating in extracurricular engineering environments further facilitates individual students' validation of their perceived experiences. We also investigated the role non-curricular activities play in providing engineering students navigational flexibility through engineering curricula. Students demonstrated multiple ways in which they were able to personalize their curricular and non-curricular experiences to achieve their self-defined goals and interests. However, institutional barriers, particularly time constraints and institutionally recognized achievements, stifle students' flexibility and willingness to pursue personally meaningful experiences. Extracurricular engineering environments afford navigational flexibility by offering students opportunities to work on motivating challenges with and among supportive communities. By providing a space for students to express their engineering selves in primarily self-directed ways, extracurricular engineering experiences cultivate students' drive to find and pursue personally meaningful curricular and non-curricular educational experiences. We recommend that university and program level structures be reevaluated to encourage and provide students with more flexibility to find personalized learning experiences in and out of the classroom. To summarize, this study aimed to better the understanding of engineering students' holistic educational experiences by identifying where engineering design learning is occurring, and how participation in non-curricular engineering-related activities influence students' educational experiences. We found that engineering design learning can effectively occur in a variety of educational settings, but specific curricular contexts (I.e. Capstone design, first-year engineering courses) are much more heavily studied than non-curricular learning contexts. Through ethnographically-inspired investigations of non-curricular student groups, I was able to bring to surface a sampling of engineering students' perceptions and experiences. By taking account of students' experiences, our study was able to begin to shed some light on the valuable features of non-curricular experiences that influence engineering students' educational experience, as well as to identify the prevalent barriers that students encounter while pursuing non-curricular activities.

These findings also provide a strong motivation for studying learning trajectories of students. Learning trajectories are a well-recognized theoretical and empirical method with the Learning Sciences and engineering education, and as the APS and NESLOS studies show, significant incidents throughout the student experience shapes outcomes. Sometimes these occur at the start and sometimes later on and it is important to study if early exposure makes a qualitative difference. Therefore, a rich, descriptive, and in-depth study of students' trajectories is of immense value in creating, testing, and validating quantitative data. In our research for uncovering learning trajectories we are biased towards a sample of students who are engaged and "successful". We recognize this bias and this by design as we believe that to improve our understanding of informal learning and to design an instrument that capture reliable and valid data we have to document the experience and participation of engaged students. We believe with others that the current focus of social science research on the problems rather than what works is not always theoretically and empirically useful and needs to be balanced through a focus on students who persist and are engaged.

Directions for Future Work

Many questions are raised by these findings that necessitate a more in-depth study. Future work related to this area should investigate the decision making behaviors engineering students exhibit when considering extracurricular participation. Participating students represented by this study are a small portion of the general student body in the engineering program, and it is possible that findings from this study are only pertinent to the types of students who choose to participate in extracurricular engineering activities. Future work should consider uncovering the demographic characteristics of students who choose to participate in extracurricular engineering activities, as well as of students who do *not*. By better understanding participation in non-curricular opportunities, engineering programs and non-curricular programs can be better informed when making recruitment and administrative decisions. Identifying the decision making behaviors of participating and non-participating students can also help uncover barriers to entry of extracurricular engineering activities, particularly any barriers affecting underrepresented groups of engineering students.

Another topic for investigation is self-efficacy trends as they relate to extracurricular participation. Self-efficacy development was an emerging construct of this study, however since self-efficacy was not intentionally investigated for this study, a sufficient understanding of self-efficacy as it relates to extracurricular participation was limited by the research design of this study. Future work should focus primarily on self-efficacy theory and measurement. A possible direction of this work would be to employ a mixed-methods study of students participating in extracurricular activities. A longitudinal study can then measure the extent of students' self-efficacy development due to participation in extracurricular engineering environments. A more intentionally comparative study could also be done to identify various curricular and non-curricular influences on students' self-efficacy development. Qualitative and quantitative data can be used to investigate whether self-efficacy develops as a result of extracurricular participation, or if students with pre-existing high self-efficacy are more likely to participate in extracurricular activities.

Finally, future work should consider a comparative analysis and assessment of various extracurricular opportunities available to engineering students. In addition to the opportunities represented in this study, other engineering-related opportunities such as summer internships, co-ops, professional societies, and informal engineering clubs should also be considered. Research also needs to delve more deeply into the role of faculty or professional advisors that mentor and facilitate students in these extracurricular activities – why do faculty members choose to facilitate extracurricular student groups? What kind of experiences do they get? What institutional affordances and barriers faculty face when choosing to advise or facilitate a student organization? Answers to these questions can help shed light on what faculty might consider to be a valuable use of time and resources, as well as how faculty translate their expertise to manageable application-based opportunities for students, and could help inform how to best shape recommendations for faculty interested in participating in extracurricular student groups.

Conclusion

There is increased attention being paid to informal learning within engineering and empirical work is not beginning to address how engineering students learn through their participation in non-curricular experiences. Findings suggest that informal experience provide students with a more holistic understanding of engineering and assists them with their formal learning as well. Future work should look more closely at different informal experiences and provide a more comparative analysis of what experiences are the most beneficial.

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