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Studying the Formation of Engineers: A Case Study of a Higher-education Learning Ecology

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Studying the Formation of Engineers: A Case Study of a Higher Education Learning Ecology

This paper reports on a **work-in-progress**—a study about the learning experiences of engineering students exploring possible careers in the energy industry. It is a follow-up to a previous study of the learning experiences of practicing engineers beginning new jobs in an energy company [1]. The overall objective of the two studies is to map the learning ecology of engineering students in a higher education program to the learning ecology of practicing engineers in a workplace. This paper also reports on the perspectives of engineering faculty educating engineering students—specifically in an energy engineering program at a university. Our objective is to better understand the similarities and differences between the two learning ecologies of an engineering program in higher education and a related workplace setting. This particular paper is focused on the higher education learning ecology.

The following sections briefly review the educational aims of engineering education. We then report the initial findings about the educational objectives and practices of faculty and the learning experiences of students in an energy engineering program in a School of Engineering.

Educational Aims of Engineering Education

For decades, there has been a persistent gap between the outcomes of engineering education and what counts as expert engineering practice [2], [3], [4], [5]. A commonly cited cause of this gap is the tendency of engineering education to narrowly focus on the technical, rational subject matter (e.g., engineering science) while largely ignoring the practical, social and behavioral interactions that make up a significant part of engineering practice [6], [7], [8], [9], [10], [11]. There is an increasing sense that science and engineering need to develop broader, more interdisciplinary perspectives to address the complex social problems facing the world today [12], [13], [14]. To become competent professionals, engineering graduates need to work across disciplinary boundaries and engage more meaningfully and holistically with the social world and social systems that embed engineering such as the diverse international, societal, and community interests, as well as the various political, economic, legal, ethical and commercial interests in which engineers work [15].

Engineering education aims to educate students on what is important to know and do (e.g., competencies) leading to competent professional engineers. ABET identified 11 criteria, or technical and professional skills, as educational outcomes that make up engineering student competence. This general list of criteria was intended to guide faculty to better prepare students for engineering practice [4]. More recently, Trevelyan [10] and Passow and Passow [16] conducted a broad review of work across education and practice identifying a wide range of competencies required for engineering practice. Many of these discussions on educating students for engineering competence are linked to the aim of employability, an aim that is controversial in higher education. While arguments for and against attending to what employers expect and need from engineering graduates are not new, the goals of higher education in general have come under increasing pressure to educate students for employability, at least as one of the important goals of higher education [17], [18], [19].

From this perspective, this study was designed to better understand the nature of learning in engineering education to better prepare for an engineering career. We begin with a brief review of the theoretical concepts of learning ecologies as a guiding framework for this study.

The Learning Ecologies of Engineering Education and Engineering Practice

The purpose of the overall study was to examine the nature of the learning ecology in a particular energy engineering educational program in a U.S. university (this study) and engineering practice in a particular energy utility company (previous study [1]). Recognizing the complex, systemic nature of both settings, we drew upon the theory of learning ecologies developed by Urie Bronfenbrenner in the 1970s [20].

Bronfenbrenner [20] proposed an ecological structure of education composed of nested, interrelated systems: the **micro-system** focuses on a learner in a particular environment where she/he engages in particular activities for specific periods of time. The **meso-system** includes interrelations among particular environments (micro-systems) that include the learner. The **exo-system** extends the meso-system to include higher level formal and informal social structures that enable or constrain the particular environments of the learner. The **macro-system** includes overall institutions of the societal culture/subcultures in which the learner is a member.

Current views of learning ecologies are broader and more holistic than in the past and include a greater emphasis on experience from formal and informal learning, as well as experiential learning, training, education, and development [21]. The learning ecology view recognizes the dynamics of learning across time and space, within and across different settings [22]. The ecological approach provided us a systematic way to examine the learning affordances of education and industry related to the professional formation of engineers.

Learning to become a competent engineer is a complex socio-technical process drawing from a broad and diverse learning ecology encompassing multiple experiences in various contexts [23]. There are numerous configurations of learning ecologies from simple blended learning models of face-to-face and online delivery to more complex models incorporating distributed learning models drawing upon multiple resources, networks, activities, delivery methods, and so on [21]. For this study we conceptualize the learning experiences of engineering students and faculty as a learning ecology or ecosystem that draws upon various content, activities, and resources in multiple contexts, informed by theories of Experiential Learning [24] and Development Networks [25], [26], [27] (see Figure 1). The following describes the research design, initial findings, and a discussion of this work-in-progress.

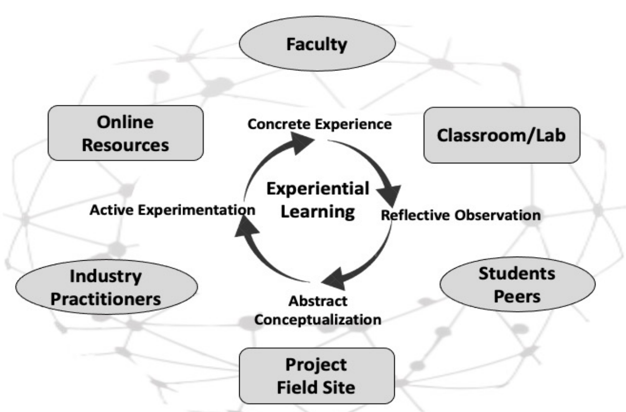

Figure 1:
Learning Ecology based on Experiential Learning and Developmental Networks

Research Methodology and Design

In this paper we report on the learning experiences of engineering students in an energy engineering program at a U.S. university. This study was a basic qualitative design to examine the learning content, activities, and resources of courses taught by energy engineering faculty and the learning experiences of students in an energy engineering program, including relevant content, activities, resources, and contexts. The ***general research question for engineering faculty*** was, "What is important for students to learn as they prepare for careers in the energy industry?" We asked ***engineering students***, "What did you learn about engineering and work in the energy sector?" Following IRB protocol, we **gathered data** from semi-structured interviews conducted via two student focus groups and 5 individual faculty interviews. Additional interviews are planned in the coming year. Interviews were recorded and transcribed (total of 180 pp.). We are currently **analyzing the data** (transcriptions) using an iterative, constant-comparative process according to qualitative data analysis techniques specified by Miles, Huberman, and Saldaña [28] and Strauss and Corbin [29]. The analysis is done using a software analysis program called Atlas.ti and entails the following procedures:

- **Reading the data:** Each interview transcript was carefully read by the first author, who also conducted the interviews.
- **Coding the data:** We used a two-part coding process wherein the first set of codes applied were broadly based on categories/concepts drawn from relevant theories (experiential learning, developmental networks, and distributed learning) and related research in the literature (pre-determined codes). The second part of the coding uses the 'open-coding' process recommended by Strauss and Corbin [29] to label relatively singular and focused ideas in the texts while also staying close to the participants' language. At this point we have identified and labeled 113 open codes for students and 176 open codes for the faculty datasets.
- **Categorizing the data:** The pre-determined codes and open codes related to learning were extracted from the student dataset. These codes were then categorized by similarity using an affinity sorting process. The same sorting was done for codes collected from the faculty dataset based on teaching and learning.
- **Cluster-analyzing the data:** The categories from the sorting in the previous step were analyzed as clusters and initial themes identified. For students, three initial themes emerged based on the source of learning: *learning from project experiences*, *learning from industry practitioners*, and *learning from coursework*. For faculty, four initial teaching and learning themes emerged roughly based on course content: *environmental and contextual characteristics [of energy and engineering], career-related competencies, individual and professional competencies,* and *teaching & learning experiences.*
- **Developing memos:** We created memos during the analyses to further understand and describe the emergent themes and begin answering the research questions.

Further analyses of the data are forthcoming, along with more interviews and analyses of syllabi, pre-, post-surveys of student learning, and curricula documents.

As of this point, **the participants** in this continuing study are students and engineering faculty in an energy-engineering program at the university. The students (19) were mostly senior undergraduates (12 Mechanical, 1 Electrical, 2 International Business, 1 International Affairs, 1 Economics majors; 5 females, 12 males) along with two Master's graduate students (1

Engineering Management, 1 Mechanical; 2 males) We interviewed the students in two focus groups—one for the first year of the program (10 students) and one for the second year (9 students). From the perspective of a learning ecology, students learned different *content* about the energy industry, engaging in different *activities (e.g., experiential learning)*, from different *resources* in different *contexts*. Five faculty (1 Electrical, 2 Mechanical, and 2 Systems Engineering) were individually interviewed about their objectives and experiences in teaching energy courses to engineering students—especially what they believed students should learn about the topic of energy engineering and the energy industry. Four had previous experience in industry.

Initial findings

Overall, both students and faculty emphasized the importance of having a broader, ecologically oriented view of energy engineering. For example, one student described what they learned from the industry practitioners speaking to the students in the program: *"there's this whole other side . . ., which is more I guess the business-political-managerial side of things [student, focus group 1]*. All of the faculty emphasized the broader view of (energy) engineering that went beyond the technology to include the interpersonal and macro-social dynamics of society in which energy is a major component of the economy. One professor reported: *"in my course I emphasize . . . the three pillars of energy . . . the technology, the economics and the politics" [faculty 03].*

An emphasis on technology in engineering was regularly challenged by some of the faculty as limited in the realm of energy engineering. These faculty often took a 'systems engineering' approach that they described as having an emphasis more on the social context of engineering rather than on the technical context. As one professor said, "*That right there [an example] is a human component of trying to address a problem that you think just the point of technology will solve" [faculty 04]*. Students engaged with industry employers and practitioners as part of the cases and as resources in the program. Faculty engaged with industry employers at the program level who advised faculty about what students need to be prepared for the workplace.

From coursework, projects, and information from engineers practicing in the field, students expanded and enriched their understanding of energy engineering. We found that students were surprised by the strong emphasis on business in energy engineering—everything had to be financially feasible and the focus on the 'bottom line' dominated most decision making in the energy industry. One student recalled, "*like before coming in I didn't really know too much about energy. However that one workshop . . ., that is when it like hit me and I remember getting [angry] and just like feeling very passionate . . ., like what's wrong with the world…it's all about money, right?" [student in focus group 1].* Another surprise for students was the dominance of politics and policies in shaping the nature of the industry. Discussing the contribution of renewables to the total U.S. energy portfolio, students were surprised at how little impact renewable technologies made across the energy industry. One commented that despite how successful and efficient these technologies were, they were under the heavy influence of politics (e.g., fossil fuel lobbyists, government policies and funding).

Faculty were instrumental in expanding students' understanding of energy engineering beyond the technology and the science of energy. One described energy engineering as composed of macro-level dynamics of 1) technology, 2) economics, 3) politics, and 4) the environment, and at the micro-level, faculty emphasized the essential skills and qualities of interpersonal relationships among peers, coworkers, stakeholders, and constituents. Regarding professional skills, *"There's probably a lot of other competencies [students need] having to do with personal relationships, working on teams – things like that." [faculty 01].*

Initial Discussion

Faculty emphasized the importance of the social, commercial, and political influences on energy engineering in their coursework, and students reported developing a greater appreciation of the socio-political context of energy beyond the technology. Some of the faculty drew upon their prior experiences in the energy industry and others emphasized the influences of non-technical factors on technology. All faculty in this sample focused on developing students' competence for teamwork and communication, along with other social competencies needed in the workplace.

Faculty described their efforts to design courses affording students a variety of experiences and the opportunities to reflect on these experiences. Students reported that guest speakers and company-based projects afforded them opportunities to develop their professional networks. An important resource for experiential learning comes from others via development networks, which explain the learning and development acquired from 'constellations' of developmentally oriented relationships experienced in various social contexts [27]. Rich developmental networks in learning ecologies enrich students' experiences and facilitate more holistic learning—especially in complex, multidisciplinary socio-technical contexts such as energy engineering.

Scholarship on learning ecologies emphasizes the need to develop 21st century capabilities that require students to push beyond traditional boundaries of disciplines and higher education. For students to contribute to and lead society forward, they need to become "expert generalists" who can adapt and synthesize across disciplines and create new ideas, practices, and communities [21]. One goal of a learning ecology approach is to develop intentionally generative "distributed learning environments that attract and sustain participation" [22] of students, faculty, and practitioners alike.

Next Steps: Linking to the workplace

In a previous study, we analyzed what newly hired engineers learned on the job and how they learned these things [1]. The general framework of energy engineering being embedded in a commercial, industrial, and socio-political context was a reality of the work experienced by these practicing engineers—their learning ecology. This study, reported here as a work-in-progress, will eventually link to the learning ecology of the workplace. We plan to map out the synergies and disconnects that affect the professional formation of engineers as they develop in school and continue developing competence as they transition into the workplace.

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References

[1] R. Korte and S. LeBlanc, “Work-in-progress: Investigating the experiences that develop competence for newly hired engineers in an electric power company,” in *Proceedings of the American Society for Engineering Education Virtual Conference*, 2020.

[2] National Academy of Engineering, “Educating the Engineer of 2020: Adapting Engineering Education to the New Century,” The National Academies Press, Washington, DC, 2005.

[3] J. W. Prados, “The editor’s page: Engineering criteria 2000—A change agent for engineering education,” *Journal of Engineering Education,* vol. 86, no. 2, pp. 69-70, 1997.

[4] L. J. Shuman, M. Besterfield-Sacre and J. McGourty, J. “The ABET “Professional Skills” – Can they be taught? Can they be assessed?” *Journal of Engineering Education,* vol. 94, no. 1, 41-55, January 2005.

[5] R. Stevens, A. Johri and K. O’Connor. “Professional engineering work,” in *Cambridge Handbook of Engineering Education Research,* A. Johri, B. M. Olds, Eds. Cambridge: Cambridge University Press, pp. 119-138, 2014.

[6] R. F. Korte, S. Sheppard and W. C. Jordan. “A study of the early work experiences of recent graduates in engineering,” in *Proceedings of the American Society for Engineering Education Conference, Pittsburgh, Pennsylvania*, 2008.

[7] R. Korte and S. Lin, “Getting on board: Organizational socialization and the contribution of social capital,” *Human Relations,* vol. 66, no. 3, pp. 407-428, 2013.

[8] R. Korte, “Learning to practice engineering in business: The experiences of newly hired engineers beginning new jobs,” in *The Engineering-Business Nexus: Symbiosis, Tension and Co-Evolution,* S. Christensen, B. Delahousse, C. Didier, M. Meganck, and M. Murphy, Eds. Cham, Switzerland: Springer Nature, pp. 341-364, 2019.

[9] J. Trevelyan. “Reconstructing engineering from practice,” *Engineering Studies,* vol. 2, no. 3, pp. 175-195, 2010.

[10] J. P. Trevelyan, *The Making of an Expert Engineer.* Boca Raton, FL: CRC Press, 2014.

[11] J. Trevelyan, “Transitioning to engineering practice,” *European Journal of Engineering Education,* vol. 44, no. 6, pp. 821-837, 2019.

[12] A. Buch, “Ideas of holistic engineering meet engineering work practices,” *Engineering Studies,* vol. 8, no. 2, pp. 1-22, 2016.

[13] S. M. Fiore, “Interdisciplinarity as teamwork: How the science of teams can inform team science,” *Small Group Research,* vol. 39, no. 3, pp. 251-277, 2008.

[14] L. R. Lattuca, D. B. Knight, H. K. Ro and B. J. Novoselich, "Supporting the development of engineers' interdisciplinary competence," *Journal of Engineering Education,* vol. 106, no. 1, pp. 71-97, 2017.

[15] S. Haase, H. L. Chen, S. Sheppard, A. Kolmos, and N. Mejlgaard, "What does it take to become a good engineer? Identifying cross-national engineering student profiles according to perceived importance of skills," *International Journal of Engineering Education,* vol. 29, no. 3, pp. 698-713, 2013.

[16] H. J. Passow, and C. H. Passow, "What competencies should undergraduate engineering programs emphasize? A systematic review," *Journal of Engineering Education,* vol. 106, no. 3, pp. 475-526, 2017.

[17] R. Barnett, *The Limits of Competence: Knowledge, Higher Education and Society.* Buckingham, UK: The Society for Research into Higher Education & Open University Press, 1994.

[18] R. Barnett, "Knowing and becoming in the higher education curriculum," *Studies in Higher Education,* vol. 34, no. 4, pp. 429-440, 2009.

[19] M. Besterfield-Sacre, L. J. Shuman, H. Wolfe, C. J. Atman, J. McGourty, R. L. Miller, B. M. Olds and G. M. Rogers, "Defining the outcomes: A framework for EC-2000," *IEEE Transactions on Education,* vol. 43, no. 2, pp. 100-110, 2000.

[20] U. Bronfenbrenner, "The experimental ecology of education," *Educational Researcher,* vol. 5, no. 9, pp. 5-15, 1976.

[21] J. J. Walcutt and S. Schatz, "Modernizing Learning," in *Modernizing Learning: Building the Future Learning Ecosystem,* J. J. Walcutt and S. Schatz, Eds. Washington, DC: Government Publishing Office, pp. 3-16, 2019.

[22] B. Barron, "Configurations of learning settings and networks: Implications of a learning ecology perspective," *Human Development,* vol. 49, pp. 229-231, 2006.

[23] J. Walther, N. Kellam, N. Sochacka and D. Radcliffe, "Engineering competence? An interpretive investigation of engineering students' professional formation," *Journal of Engineering Education,* vol. 100, no. 4, pp. 703-740, 2011.

[24] D. A. Kolb, *Experiential Learning: Experience as the Source of Learning and Development,* (2nd ed.). Upper Saddle River, NJ: Pearson Education Inc, 2015.

[25] K. E. Kram, *Mentoring at Work: Developmental Relationships in Organizational Life.* Glenview, IL: Scott, Foresman and Company, 1985.

[26] M. C. Higgins and K. E. Kram, “Reconceptualizing mentoring at work: A developmental network perspective,” *Academy of Management Review,* vol. 26, no. 2, pp. 264-288, 2001.

[27] W. Murphy and K. E. Kram, *Strategic Relationships at Work: Creating Your Circle of Mentors, Sponsors, and Peers for Success in Business and Life,* New York: McGraw-Hill Education, 2014.

[28] M. B. Miles, A. M. Huberman, and J. Saldaña, J. *Qualitative data analysis: A methods sourcebook* 3rd ed. Thousand Oaks, CA: Sage Publications, Inc., 2014.

[29] A. Strauss and J. Corbin, *Basics of qualitative research: Techniques and procedures for developing grounded theory* 2nd ed. Thousand Oaks, CA: Sage Publications, Inc., 1998.