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Studying the Formation of Engineers in the Learning Ecologies of Energy Engineering Education and Energy Engineering Practice

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Studying the Formation of Engineers in the Learning Ecologies of Energy Engineering Education and Energy Engineering Practice

Over the past century of engineering education there has been a persistent debate about and critique of the outcomes of engineering education regarding the preparation of engineers for practice [1], [2], [3]. The focus of this critique largely centers on the tendency of engineering education to emphasize the technical, rational science of engineering, while overlooking the complex practical, social, and behavioral interactions that comprise most of the practices of employed engineers [4], [5]. As the importance of the human systems of work has increased, there is increased attention paid to the practical and social practices of scientific, technology, and engineering work [6]. In addition, there are calls to develop more holistic, interdisciplinary capabilities in future scientists, engineers, and technicians to grapple with the increasingly complex problems facing society today [7], [8], [9], [10]. In general, there has been increasing pressure on higher education to better prepare students for employment after graduation [11].

Developing students into competent graduates for work and society has been a long-standing goal of education, including engineering education. To this end, ABET identified 11 criteria as guidelines for educating competent engineering graduates [2], [3]. Others, for example Passow and Passow [12] and Trevelyan [13] have conducted extensive studies of competencies in engineering practice and identified a wide range of competencies contributing to competent engineering work.

There have been few studies that look at the connections and disconnections of what students learn in school compared to what graduates learn in the workplace. Based on previous studies by the authors [14], [15], [16] we have found evidence of school learning that is useful in the workplace and learning that is not. While there have been studies focused on what competencies practicing engineers claim to be important, we are not aware of more direct links between what is learned in school and what is learned in the workplace.

In this paper we present a qualitative study about the learning experiences of two related groups of engineers: 1) engineering students in an energy engineering program in higher education and 2) newly hired engineering practitioners beginning new jobs in an energy utility company. The purpose of the study is to investigate the learning experiences of engineering students and the learning experiences of newly hired engineers in a workplace to better understand the similarities, differences, connections, and disconnections between these two learning contexts. This study focused on developing a better understanding of learning in school and the workplace by studying *what* engineering students learn and *how* they learn in school. The second focus was understanding *what* practicing engineers learn and *how* they learn in the workplace. This understanding can enhance our development of engineers in the educational and workplace contexts.

This paper begins with a brief review the conceptual and theoretical framing of the research that guided the study to answer the question of what and how do engineering students learn in comparison to what and how practicing engineers learn. We then report the analysis of the learning experiences of engineering students in an energy engineering program and the learning experiences of newly hired practicing engineers in a renewable energy division of a power utility company. A discussion and conclusion follow the analyses of both groups.

Conceptual and Theoretical Framing: Learning Ecologies

To explore the perceptions of learning experienced by engineering students and practicing engineers, we conceptually framed the university setting and the workplace setting as learning ecosystems (ecologies). Bronfenbrenner [17] introduced an ecological model of learning to emphasize the importance of context and that human development is intimately intertwined with the multiple environments in which people exist. Furthermore, he emphasized that the environmental effect was not so much the influence of the "objective" characteristics of the setting, but rather the *perceptions* by learners of the environment. What environmental factors that people believed (perceived) affected their development, in fact were what affected their development [18]. The ecological approach emphasized the complex interplay between people, others, and their environments. The unit of analysis was not just the individual, but rather the relationships between people in the ecosystem.

Over the past few decades, the ecological perspective can be found in the work of many authors for different purposes—even if they did not call their models ecosystems [19], [20], [21], [22]. Taking a broader and more holistic view of learning recognizes the many ways that people learn and develop, and the importance of the interactional, social, relational, and environmental aspects of learning that contribute to the meaning people make of their experiences. Human agency and action are crucial for learning and development—both for developing one's own capabilities and for developing the capabilities of the environments in which they live, learn, and work. Jackson [23] identified several key elements of social ecologies (that included learning, development, and work systems). These elements involved **contexts** (the physical and social environments, cf. Bronfenbrenner's microsystems); **spaces** for inquiry and learning; **resources** for learning; **relationships** with people and materials; **processes** that enable learning; **whole-person** capabilities; and **affordances** in the ecosystem that provide possibilities for action and learning. In addition, there is the dimension of time including what one learned from **past** experiences, what one is learning in the **present** (current learning ecologies), and **future** experiences and learning—all designed more or less to achieve one's goals.

In line with this work, we conceptualized the environments in which engineering students and newly hired engineers learned and developed professionally as learning ecologies attending to many of the key elements noted by Jackson above [23]. We explored participants' learning experiences in these two ecologies for the purposes of better understanding the complexity of students' and newly hired professionals' learning. We mapped the two learning ecosystems as a network model [24] to compare and contrast the ecological elements between school and work. The focus on the transition of engineering students from higher education to the workplace is an area that offered the opportunity to investigate the learning in two related ecosystems and look for connections and disconnections. We intended this study to contribute to understanding more about the different kinds of learning experienced in two different ecosystems to inform educators and managers of the complexities of learning within and between these ecosystems.

Research Methodology and Design

This study followed a basic qualitative design using semi-structured interviews following approved IRB protocols. We gathered data on the learning experiences and perceptions of engineering students and practitioners. The guiding research questions for the **engineering students** were, 1) ***What*** *do energy engineering students learn about energy engineering work*—and 2) ***How*** *do they learn what they learn?* The data gathered from this group related to the learning and experiences of the educational ecosystem. Data from the workplace ecosystem were gathered from newly hired engineers in a renewable energy utility company and focused on their learning experiences while starting their new jobs as engineers in the organization. The guiding research questions for the **practicing engineers** were, 1) ***What*** *do newly hired engineers learn about their work as they begin their new jobs in an energy company*—and 2) ***How*** *do they learn what they learn?* Learning is often conceived of as both content, the *what*, and process, the *how*.

Participant Samples

The student participants were students in an energy engineering program at the university. The students were mostly senior undergraduates who identified as Mechanical (12), Electrical (1), International Business (2), International Affairs (1), Economics majors (1); females (5), males (12) along with two master's graduate students who identified as Engineering Management (1), Mechanical (1); males (2). 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). Additional data were collected from individual semi-structured interviews with six students (some of them also participated in the focus groups). Note that in the middle of our data gathering from students, the COVID pandemic shut down in-person classes and student residence, which hindered our recruitment of individual students for interview. Interviews were recorded and transcribed for a total of 202 pages of transcripts.

The **newly hired engineers** were recently hired into a renewables subsidiary of an electric power company. Four participants were *new graduates* (beginning their first engineering jobs after graduation), and their time with this company ranged from one month to eighteen months. Eight participants reported coming from previous jobs with other organizations (*experienced hires*), and their time with this company ranged from seven months to three years. Seven reported their education as Electrical Engineers, two as Mechanical Engineers, one in Civil Engineering, one in Physics, and one Technician (ten males, two females). All worked as engineers in various engineering groups in the organization. Interviews were recorded and transcribed for a total of 1802 pages of transcripts.

Data Analysis

We analyzed the data (transcriptions) using an iterative thematic analysis and constant-comparative process according to qualitative data analysis techniques specified by Braun and Clarke [25], Miles, Huberman, and Saldaña [26], and Strauss and Corbin [27]. Thematic analysis is commonly used in qualitative research as a flexible method enhancing researchers' interpretations of meaning in the data [25]. The analysis was done with the aid of a qualitative analysis software called *Atlas.ti* and proceeded through the following steps:

- **Reading the data:** Each transcript was carefully read by the first author, who also conducted the interviews.
- **Coding the data:** The first author used a two-part coding process wherein the first set of codes applied (pre-determined codes) broadly categorized the data based on social learning and social interaction theories. The second part of the coding used the 'open coding' process recommended by Strauss and Corbin [27] to label the particular content of a section of the texts while also staying close to the participants' language. We identified and labeled 429 codes for the student dataset and 657 codes for the practitioner dataset.
- **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 and categorizing were done for codes collected from the practitioner dataset.
- **Cluster-analyzing the data:** The results of the sorting yielded several categories, which were subsequently analyzed and labeled as thematic learning processes [25] (see Tables 1 and 2 in the Appendices).
- **Developing memos:** We created memos to further analyze and describe the themes and begin answering the research questions of what the participants learned and how they learned. These memos were the basis for the presentation of the findings in the next section.

Findings 1: Student Learning Experiences in the Educational Ecosystem

From the analysis of the students' interviews, we identified five main themes characterizing the learning processes in their university engineering studies: (a) Learning the science and application of engineering; (b) Learning beyond engineering; (c) Learning the importance of non-technical, professional skills; (d) Learning to manage one's education; and (e) Reflecting on one's passions that include becoming an engineer. Each learning process is described in more detail below (also see Table 1 in the appendix).

Learning the science and application of engineering. Generally, students were aware of and expecting to learn technical knowledge and skills. Their learning and experiences ranged from broader abstract knowledge of engineering fundamentals (e.g., engineering science) to specifics focused on their personal interests (see Table 1 in the appendix). Even those with more exposure to the nature of engineering practice, meaning they realized there were differences between "book" knowledge and "practical" knowledge, believed that knowing the fundamentals of engineering would be needed later in practice. It was a necessary foundation for engineering work. For example, one student reported that it was important,

> just to learn the basics really well because they come back a lot. . . And so, I think getting across at least to like maybe freshmen or the sophomores [*sic*] that it's really important to understand just the basics, because that's what really propels you and really helps you solve problems moving forward. (*Student-01*)

Other students described their expectations and interests in learning various technical competencies, such as calculus, fluid dynamics, using various software, coding and computational work, and one student described it would depend on the industry you wanted to work in, but a generic list of foundational knowledge would be force diagrams, including the statics and dynamics behind it, math basics, linear system dynamics, algebra and differential equations, conservation of mass, conservation of energy. These are the things one keeps coming back to.

Students also discussed the importance of problem-solving in engineering. The engineering way of thinking included the capability to solve problems by using math, theories, pragmatics, and the steps to decompose a problem into smaller more manageable problems.

> I feel like what I've most learned is that it's about problem solving and that there are all these fancy techniques that we use and . . . there's a lot of theory behind everything but really . . . it's mostly about thinking practically and thinking your way around and through problems (*Student-03*)

Another view of the engineering way of thinking, related to problem solving focused on increasing efficiency and/or optimizing some parameter, such as cost, time, output, etc. In addition, one described the ability of fitting abstract ideas and variables into the world. In addition, the ability to solve problems was linked to being able to explain your thinking to others and convincingly answering, *how did you do that*? And *why does it matter?* "You need to be able to solve problems and you need to be able to explain how you solve problems. . . like those two go hand in hand." (*Student-04*)

Overall, students emphasized the importance of having a broader view of energy engineering, and the engineering way of thinking helps one to have a deeper understanding of the world. Both perspectives perceive the connections of engineering to the world—it is an ecological view of engineering.

Learning beyond engineering. Many students mentioned the importance of learning about business and developing business skills. One described engineering as the combination of science and business mentioning that many engineering graduates go into business jobs. One student described what they learned from the industry practitioners speaking to students in the program: "there's this whole other side . . ., which is more I guess the business-political-managerial side of things" [*Student in focus group 1*].

Some students remarked that they wish their professors did a better job of relating their classwork to the bigger picture—especially in the first- and second-year classes. It was a desire to know how engineering fit into the larger industrial and societal landscape. Students learned more about the nature of engineering work in energy from guest speakers invited into their program who worked in various energy related companies and agencies of the industry. From the business and governmental sectors, students learned of the major dominance of financial feasibility, politics, and policy in decisions made about energy.

Learning the importance of non-technical, professional skills. The most common non-technical skills described were communication and teamworking. There were thoughtful nuances reported for these two skillsets, such as, "I think the main thing that needs to be emphasized when talking about communication is 'willingness' to communicate." (*Student-03*). Teamworking required "accountability and responsibility. I think they go hand in hand with – when you're working in a team it’s other people [*that*] are reliant on you and you should be relying on other people . . .” (*Student-04*). The importance of working with others was something to be learned, “[A] Necessity, in terms of working with other people. It just – you just have to do it, and then suddenly you realize that it’s not the worst thing in the world . . .” (*Student-05*).

Other non-technical skills mentioned included attributes of, “The ability to learn a new skill fairly quickly.” (*Student-05*). Being organized as in “staying on top of your tasks” (*Student-03*), along with having “a positive, upbeat attitude” (*Student-03*), and being empathetic, patient, collaborative, self-aware and ethical were also important attributes mentioned by students.

Learning to manage one’s education. Students responded to the question about what they would do differently if they could start over in their engineering education. Most emphasized the importance of joining organizations, clubs, and making better use of the resources offered by the school and university (e.g., Career Services and advising). Some described the importance of having an open mind and being more proactive about having a variety of experiences.

Reflecting on one’s passions that include becoming an engineer. Two topics were related to students’ passions for becoming engineers: 1) The desire for learning and understanding more about the world and 2) the realization that engineering was important to many different areas of life and work. Students perceived the engineering skills learned are applicable to a broad range of work and life. One student described the skillset learned that could be applied to their personal interests, rather than searching for a particular job that matched their skillset, “there is just a lot more uses and applications for an engineer than what I had originally thought, and I didn’t realize how important that was” (*Student-04*)

Summary of Student Learning Experiences

From the analysis of students’ learning experiences, we found that they described what they learned (knowledge, skills, content) and how they learned from various activities, and resources. What students learned was clustered into five categories labeled as: (a) Learning the science and application of engineering; (b) Learning beyond engineering; (c) Learning the importance of non-technical, professional skills; (d) Learning to manage one’s education; and (e) Reflecting on one’s passions that include becoming an engineer (see Table 1).

Although the learning was largely grounded in a higher education setting of coursework and labs (the microsystem), these students were able to experience and access information from beyond the traditional boundaries of higher education. The resources that expanded their learning (guest speakers, community projects, and internships) were mostly brought into the higher education setting by their instructors, and these “outside” resources were often linked to their expanding views of engineering work is in the workplace. Also, some students learned that they could align their engineering education with their life passions that were beyond what they originally thought was engineering. For these students, engineering education was more than a path to an engineering career, it was a strong foundation to potentially many different careers in the future.

Findings 2: Newly Hired Engineers Learning Experiences in the Workplace Ecosystem

Beginning their career was a major goal for many students described in the previous section. This section presents findings of the learning experiences of newly hired engineers in an energy company. As with the students, we were interested in finding out *what* (content) and *how* (process) learning occurred—focused on newly hired engineers "learning the ropes" of their new jobs in a commercial energy company. For four of them this was their first job out of school and for eight this was a new job moving from a previous job. From the analysis of the interviews with these newly hired engineers, we identified four categories of experiences related to learning: (a) Learning about the role and work (b) Learning to work with others; (c) Learning to manage projects; and (d) Learning about the culture of the organization (see Table 2 in the appendix).

Learning about their role and work. A common comment about what was learned referred to surprise at the variety of things learned—from a variety of different technologies to the number of things beyond just technical things, such as business things. For new grads, there was this sense that they were starting over, from the beginning. For experienced hires, this sense of starting from the beginning was based on the understanding that things are done differently in different companies and there is always a new learning curve at the beginning of a new job.

Two methods of learning stood out in the descriptions of their learning their new roles and job tasks: 1) Trial-and-error learning and 2) Self-directed learning. Trial-and-error learning was described by one participant as the knowledge that was more informally developed from experience, rather than from data or theories. Although another newcomer included developing theoretical knowledge in the process of trial-and-error as well. "we'll apply theoretical knowledge, it doesn't work, and then we're causing bad things to happen and then we're learning from it, but that's the biggest thing is learning from your mistakes . . ." (*Newcomer-12-new grad*)

Self-directed learning was also a common experience with participants. There was a common perception that there was less explicit direction about what and how to learn—especially compared to their experiences in school. There was one newcomer who was hired into a new position in the company that was not completed specified. This required the newcomer to figure it out on their own—and justify it at the same time. Self-directed learning was described by all participants in this study.

Learning to work with others. The most common process of learning in work was from interacting with and observing other people in the organization. For these participants, this meant coworkers and one's supervisor or manager within their work groups. Another important process was interacting with others in the field, such as technicians, site managers, and suppliers. Learning to work with others was generally done informally, unplanned, and on-the-job. One participant remarked that there were two ways of learning—from the field and from documents, and you get richer information from the field.

There was also risk with self-directed learning, as one participant stated, a lot of the errors in trial-and-error actions come from moving ahead without asking someone with more experience if the solution is viable. This related to a comment that there were often many solutions to a problem and those solutions depended on the views of different stakeholders, however not all were viable. An important thing learned was that everyone has their own view of the problem and solution. Finding out the requirements and views of various stakeholders was an important source of learning required for solving problems.

Participants mentioned it was essential to deliberately build good working relationships based on the personal interests and needs of others. A common objective of working with others was the need to learn something. Additionally, one expressed that, "if you've got good relationships with your techs and your site managers and your boss and your peers it's a lot easier to get stuff done and I think a lot more enjoyable to get stuff done" (*Newcomer-06-experienced hire*).

There were also comments indicating that having empathy for others was important to their work. The comment of 'being in another's shoes' or 'knowing what it is like on their side' expressed the idea that a deeper understanding of another person's situation was an important requirement for work. One participant described that, "each site is almost like a different personality—some are receptive, and some are resistant" and "you have to deal with different sites differently" (*Newcomer-11-experienced hire*). There is a definite informal and perceived hierarchy between the corporate office personnel and the field sites.

Several comments referred to the importance of communicating effectively with others. There were also some comments of advice specific to new engineers (new grads). For example: "a young engineer needs to communicate with confidence, don't emphasize how young and naïve you might be", (*Newcomer-13-new grad*); "I think building trust within the team, especially for the new guy is crucial" (*Newcomer-09-new grad*), and "try to be useful not only for yourself but for the team also" (*Newcomer-05-experienced hire*). Many of the ideas discussed around this topic of learning to work with others indicated the need to learn and integrate effectively into the work group.

Learning to manage projects. At the basic level, ideas of project management were described rather simply as the mechanics of getting something done. Participants spoke of a linear progression of tasks or building a puzzle of the project. These sorts of descriptions were quickly followed by comments about the more complex factors of managing a project regarding the unique personal and cultural aspects characteristic of managing projects in this company. In cases where participants had experience in other companies some commented on differences between this company and others.

Participants talked about the complexity of the projects they worked on, and this complexity was amplified because it went beyond the technical aspects of their work. An important area of learning for participants, whether or not they had project management experience prior to this job, was learning the idiosyncrasies of managing projects in this company. "to do well out in industry . . . there's a lot more to offer if you can do the technical side and understand how the business side of it works as well." (*Newcomer-13-new grad*)

Another complicating factor was knowing who to contact and recruit for a project. Getting the right people together was easier when the project was a responsibility of the group. It was more difficult to get the "right" people together when the project required participation beyond the group. It was more difficult to get others involved—especially when one didn't know who the "right" people were.

Learning the culture of the organization. We also asked participants what they learned about the culture of this organization, commonly described as "the way we do things here." What they learned about the culture was sorted into two categories: 1) What is the culture here? and 2) How does this compare to other organizational cultures? Comments about the culture of their new organization, were nearly all positive. One described the company as, "it's a laidback environment—you know, just get-your-work-done type of environment." (*Newcomer-08-experienced hire*).

Everyone reported learning that safety is a core commitment of the organization and participants emphasized that it was not a vague corporate commitment, but a deeply held concern for everyone's safety. Other elements of the culture reportedly learned by participants were that there were high expectations for performance and development. One mentioned that key elements of the work ethic here were time management and working together (teamwork). Other descriptions of the company supported participants' impressions that the company was supportive and collaborative, and everyone was helpful.

Comparisons to other organizational cultures were made by experienced hires who came from other organizations and noted differences. Also, a comparison was made between a former job that was 'old school' requiring one's regular presence in the office and this one where people were often out of the office visiting field sites. One of the new grads compared their new job to school, and stated they enjoyed the job and brought their work ethic learned in their engineering program to the new job.

Summary of Learning Experiences of Newly Hired Engineers

The analysis of participants' learning on the job identified four learning processes important to their success in their new jobs: (a) Learning their role from work; (b) Learning to work with others; (c) Learning to manage projects; and (d) Learning the culture of the organization (see Table 2). Along with the influences of their past schooling and/or previous jobs, their first experiences were significant experiences of the company and the work they were expected to do. These early experiences answered the question of what and how individuals learned. Through these experiences participants learned how to learn from and work with others, how to better do the job and navigate the culture of their workgroups and the company. Developing these important competencies was necessary to become a competent and valued member of the organization.

Comparing School & the Workplace

The transition from school to work was an important process connecting these learning ecologies. Additional findings from participants in the workplace compared their experiences at work with their experiences in school (see Table 3 in the appendix). Differences ranged from the benefits of developing a strong work ethic and learning fundamental knowledge and skills in STEM to the differences in the way things work (i.e., culture) and the kinds of knowledge useful on the job.

Generally, the school ecosystem is structured for learning by individual study and the work ecosystem is structured for learning through/with others. Most of the comments comparing the educational ecology with the workplace ecology focused on differences (see Table 3). Efforts to enhance learning in school and work might be found in creating more opportunities for high-quality interactions between students and practitioners beyond the limitations of internships.

Discussion

Using an ecological perspective to investigate learning and development in educational and work settings provides two benefits: first it helps to capture more of the complexity of learning embedded in particular contexts, and the influences of those contexts on one's learning and development [18], [19]. Second, it provides a framework for individual learners to better understand their own learning in context (self-diagnosis) and to enhance their learning in different contexts (enhanced learning agency; self-directed learning) Each person has their own learning ecology and understanding it helps one better manage it [22], [28].

In the school ecosystem, the traditional didactic experiences of learning science and engineering were enhanced by a rich ecological context of people outside the classroom, near-peers, industry practitioners, members of professional associations, cross-disciplinary experiences, and advisors who provided additional contexts and relationships for students' learning [17], [18], [23]. Students in this study valued the processes that offered opportunities to learn beyond engineering (especially about business) and valued their ability to manage their education more directly (their learning agency), including their reflections on their learning and development within and beyond their school program.

In the workplace, the typical focus for beginning a new job, learning one's role and job tasks, was only part of the experience recounted by participants in this study. Arguably, the ecosystem that was their workplace depended more on relational and sociocultural processes among coworkers, managers, and others in the contexts of their workgroups, other departments, and the larger organization. Building relationships by learning how to work with others in the organization was an essential process that participants learned on the job.

The analysis of the participants' learning experiences also included reflections on their transitions from school to work. These reflections largely focused on the transferability of what they learned in school (and life) to the workplace. Participants in the workplace described some kinds of learning in school that they found relatively easy to transfer into the workplace, such as developing a strong work ethic, learning how to prioritize work, a way of problem solving, some of the foundational knowledge in engineering science, and importantly, their co-op and intern experiences. They also noted that these were general levels of competence that in turn had to be further operationalized and applied to work in a particular time and place. The details of working in a particular job context would be impossible to learn about in a different context, such as school, however becoming aware of contextual influences is possible in school.

Although most of the students' learning experiences occurred within a relatively traditional microsystem [17] of the university (their engineering classes and program), the experiences from systems beyond the university (e.g., guest speakers, community projects, internships) had a tremendous impact on their learning. These developmental resources provided different perspectives, values, and contexts to their learning affording them a broader perspective on their learning and future careers.

Conclusions

One goal of a learning ecology approach is to develop intentionally generative "distributed learning environments that attract and sustain participation" [22] of students and practitioners alike. Students reported that their early courses in engineering often overlooked opportunities to link engineering content to the larger world of practice and society. Exceptions to this were reported in this study of professors presenting the practical, "real world" applications of scientific concepts and methods. Students reported that in their programs, later courses did a better job of emphasizing the importance of the nature of engineering in the larger world of commercial, political, and social influences on energy, and they reported developing a strong appreciation of the political and business contexts of energy that had major influences beyond the technology. These experiences point to opportunities to reconfigure first- and second-year courses into introductions to a more holistic view of engineering work—an ecological view.

Newly hired engineers in this study described how their learning was highly dependent on their self-direction, proactivity, and their interactions (relationships) with others in the company and partners in the field. These critical processes are often marginalized in higher education. These kinds of experiences could enhance students' learning in the educational ecosystem. The general framework of an engineering ecology emphasizes its systematic connections with commercial, industrial, and socio-political contexts, which are important parts of learning ecologies.

It is one thing to reframe schools and workplaces as ecologies of learning and another to enact such a view. The idea of interconnectedness is a key concept of ecologies [17], [19]. If leaders and decision-makers in education and industry saw their roles as part of a larger learning ecology that included school and work, they would find ways to make stronger connections between them. The current gap between the ecosystems of school and work might be reframed as one larger learning ecology—an engineering learning ecology (see figure 1).

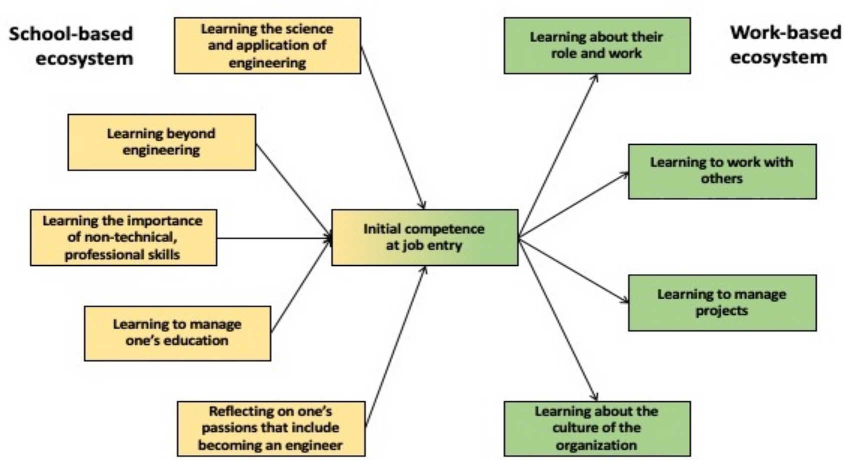

Figure 1: Map of the bilateral engineering learning ecology in this study

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References

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

[2] 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.

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

[4] J. Trevelyan and B. Williams, "Value creation in the engineering enterprise: an educational perspective," *European Journal of Engineering Education*, vol. 44, no. 4, pp. 461-483, 2019.

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

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

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

[8] 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.

[9] 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.

[10] 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.

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

[12] 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.

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

[14] R. Korte, S. Brunhaver, and S. Sheppard, "(Mis)interpretations of organizational socialization: The expectations and experiences of newcomers and managers," *Human Resource Development Quarterly,* vol. 26, no. 2, pp. 185-208, 2015.

[15] S. R. Brunhaver, R. F. Korte, S. R. Barley, and S. D. Sheppard, "Bridging the gaps between engineering education and practice," in *The Science and Engineering Workforce Project,* Cambridge, MA: National Bureau of Economic Research, 2018, pp. 129-163.

[16] R. Korte and S. LeBlanc, (2021). "Studying the Formation of Engineers: A Case Study of a Higher Education Learning Ecology," in *Proceedings of the American Society for Engineering Education Conference, 2021*, Long Beach, California USA.

[17] U. Bronfenbrenner, *The Ecology of Human Development: Experiments by Nature and Design,* Cambridge, MA: Harvard University Press, 1979.

[18] U. Bronfenbrenner and P. A. Morris, "The Ecology of Developmental Processes" in *Handbook of Child Psychology* (5^{th} ed.) Volume 1: *Theoretical Models of Human Development,* R. M. Lerner, Ed. New York: John Wiley & Sons, Inc., 1998, pp. 993-1028.

[19] N. J. Jackson, "Ecologies for learning and practice in higher education ecosystems," in *Ecologies for Learning and Practice: Emerging Ideas, Sightings, and Possibilities and Political Paradoxes,* R. Barnett and N. Jackson, Eds. London: Routledge, 2020, pp. 81-96.

[20] R. Barnett, *The Ecological University: A Feasible Utopia*. London: Routledge, 2018.

[21] K. Evans, "Learning ecologies at work," in *Ecologies for Learning and Practice: Emerging Ideas, Sightings, and Possibilities and Political Paradoxes,* R. Barnett and N. Jackson, Eds. London: Routledge, 2020, pp. 163-176.

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

[23] N. Jackson, "Developing the idea of learning ecologies & ecosystems for learning in higher education," 2017. [Online]. Available: http://www.normanjackson.co.uk/uploads/1/0/8/4/10842717/dit_handout_final.pdf [Accessed December 12, 2022].

[24] J. Watling Neal and Z. P. Neal, "Nested or networked? Future directions for ecological system theory," *Social Development,* vol. 22, no. 4, pp. 722-737, 2013.

[25] V. Braun and V. Clarke, Conceptual and design thinking for thematic analysis. *Qualitative Psychology*, vol. 9, no. 1, pp. 3-26, 2022.

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

[27] 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.

[28] A. Sangrá, J. E. Raffaghelli and M. Guitert-Catasús, "Learning ecologies through a lens: Ontological, methodological and applicative issues: A systematic review of the literature," *British Journal of Educational Technology,* vol. 50, no. 4, pp. 1619-1638, 2019.

Appendix

Table 1: Learning processes of students in energy engineering studies.

Learning Processes	Sampling of related codes
Learning the science and application of engineering	• Learning the basics because that is what is needed • Engineering way of thinking is solving a problem the most efficient way while also contending with other relevant variables • Learned that engineering is solving problems; then you have to learn to communicate how you solved the problem • Taking classes, you learn all the equations and stuff, but in the other things you get to see the application/impact of engineering
Learning beyond engineering	• Engineering is the combination of science and business • Learned to do more networking by seeing older students doing it and building community among engineers • Things I wish I had learned more about, but will have to pick up on the job • Learned from professors who advised us to do more than study course material • Learned from different sources--internship, classroom, shadowing engineers
Learning the importance of non-technical, professional skills	• Important for engineers to learn--how to learn new things quickly and how to communicate--especially with non-engineers • What makes a team is balance between collaboration and personal responsibility • Learning teamwork and communication is also about learning about different people and different perspectives from others • In an ideal world it would be good to have more time spent on communication and other non-technical skills, but our time is very limited • I consider being a project manager as one of the kinds of engineering work
Learning to manage one's education	• It took me to the end of my sophomore year to see that I should be more strategic with my electives and keep focused on my interests • Classes are only half the student experience • By taking classes with upper-class students, I saw them using and learning from other services (e.g., career services) to be better prepared • Advice for new students is to network and build your network beyond university • Advice for new students--learn to schedule your time well; join organizations/events/talks; and lastly keep an open mind
Reflecting on one's passions that include becoming an engineer	• Passion for engineering comes from learning and developing a deeper understanding of the world/universe • I came to realize that engineering is involved in many different areas, and it is a good base for many interests • Excited by the ability to make things that leaves your mark on the world • Dad was a civil engineer and was influential in me going into engineering • Things I want from my career are to pursue my passions and get my return on value for my skills • I would like my first job to be the third most important thing in my life, after living in a good place and being with people I like

Table 2: Learning processes of newly hired energy engineers

Learning Processes	Sampling of related codes
Learning about their role and work	• Work is technical, but also introduces the social dynamics • This company has more procedures for dealing with different issues • Respect for experience, not just education • Tribal knowledge developed from trial-and-error (missed ops) • Theoretical knowledge is also learning by trial-and-error (also not always written down and error gets repeated) • Taught myself about the technology in my work • Be proactive and look for more work, more experiences • Continuous learning, keep studying many things you didn't study in school
Learning to work with others	• Join conference calls and field visits to learn more about how things work • It's harder to approach guys you don't relate to (older and more experienced), but you just have to • Having situational awareness of others, situationally aware of others' struggles • Getting help from field technicians for writing/refining some procedures
Learning to manage projects	• The project is a progression of tasks-rather linear really • Not a specific team, but I had to pull some folks together • Different ways of solving a problem between former company and this company • Asking why things are done the way they are and is that the best way? • Go back in history and look at the past set up • School learning applied to the workplace
Learning about the culture of the organization	• Working in a corporate office is a little different than working at a field site • There are more resources here and I had to learn how to use them • Learning about the culture of the company and very impressed with it • Company is dedicated to safety (send everyone home at the end of the day) • I have a lot of leeway and flexibility to do my work without my manager interfering much • It's a laidback environment, very supportive, collaborate--just get your work done kind of place • Company is more structured (managed) than I am used to

Table 3: Sampling of thematic comparisons between educational and workplace ecosystems

The Educational Ecosystem	The Workplace Ecosystem
Focused on a more general learning experience	Merging the technical knowledge learned in school with the practical application needed on a specific case
More about calculation and the ideal case	More about communication than calculation, and real life was never an ideal case
Focused on standard lessons (it is more cookie-cutter)	Focus is on specific management preferences, urgency, financial outcomes, labor, resources, and getting results
School was more about numbers	Work was more about things
Problems are all preplanned	Problems come up randomly (unplanned)

Table 4: Examples of newly hired engineers' coded comments on the school-to-work transition

Initial competence at job entry	• Learning the basics in school helps you check your work--especially when learning to use new software • Learned a lot in college about various things like problem solving, communicating, and surviving • Construction site exact opposite of a classroom-more communicating than calculating • The most valuable experiences where you learn the most come from working through difficult, stressful situations • Even though you learned it in school you have to relearn it on the job • It was valuable connecting with other young interns that were aspiring to come on full time, and we still get together for lunch sometimes • Sitting down with experienced coworkers who showed me what/how to do this • Seeing things in real-life "bridged a gap" between school learning and real-world learning (in internships) • It is a good way to see reality compared to your dream • Value of internships is that people see you work (see your work ethic) • Advice, get internships, get as much experience as you can in school