AC 2008-1296: THE ENGINEERING LEARNING ENVIRONMENT: A PROPOSED MODEL

Nadia Kellam, University of Georgia

Nadia Kellam is an Assistant Professor in the Faculty of Engineering at the University of Georgia. Her research involves an integration of systems and engineering ecology with engineering education, resulting in a deeper understanding of student learning through a complexity lens. In particular, she is developing the Ecological Inspiration for Engineering Education research program, which involves an innovative approach of borrowing concepts from healthy, ecological systems and applying these to engineering education systems. Ecological concepts such as distributed cognition, systems, networks, riparian zones, and niche construction promise to help develop a deeper understanding of how students learn. She also teaches at the undergraduate level within the Biological and Agricultural Engineering department, is a Lilly Teaching Fellow, and is a key faculty appointed to design a culturally inclusive Environmental Engineering program of study that will begin in the Spring of 2009.

Ashley Babcock, University of Georgia

Ashley Babcock is a pre-med student at the University of Georgia majoring in Biological Engineering and Romance Languages. Her research interests are in gender and diversity issues within engineering education with an emphasis on using the ecological concept of niche construction as a useful analog for diversity in engineering education. As the student president of the local American Society of Agricultural and Biological Engineers she has organized community outreach and professional development opportunities for engineering students.

David Gattie, University of Georgia-Athens

The Engineering Learning Environment: A Proposed Model

Abstract

While 30% of all students entering college major in science and engineering, less than half graduate in these fields. These students are typically the most qualified entrants into college and are disproportionately under-represented minorities. Previous studies have indicated that the engineering environment strongly influences the lack of diversity within engineering education. The engineering learning environment has a focus on individual achievement, competition, task orientation, and limited involvement with peers and professors, which leads to a narrow spectrum of students surviving in that environment.[1,2] Furthermore the social fields of students within engineering do not overlap, as antecedents or stream of life events are deemed irrelevant. This simplistic learning environment may provide a deeper understanding of why women account for only 21% of engineering students.[3]

A contextual model of the learning environment was developed and will be presented. This model promises to provide a lens to view the issue of diversity in engineering educational systems and eventually lead to transformational changes that address this marginization of subsets of people. This lens will provide a way to view diversity and provide tools to infuse systemic change in the higher educational system. Instead of simply blaming the student or the perceptions of the student, this approach looks at the engineering environment as the root of the problem so that we do not provide a shallow, local solution to a much deeper, pervasive issue.

"If a plant fails to flourish, to grow or even to survive in our human-constructed garden, we do not blame the plant.... We accept that it is we who have created an inappropriate ecological environment and that we must adjust that environment if plants, other than indigenous hardy ones, are to survive and flourish."[4]

Background

Rather than focus on underrepresented minorities as the issue, this study is developing a deeper understanding of the engineering learning environment to gain insight as to why there is such an underrepresentation of women and minorities within engineering. Previous engineering education studies have indicated that the culture or environment within engineering strongly influences attraction and retention within engineering programs.[1,2,4,5,6] Although some people learn in spite of the current learning environment, it cannot be assumed that the learning environment is acceptable.[7] "Male-normed classrooms, often dubbed "chilly" climates for women, have generally been described in the literature as competitive, weed-out systems that are hierarchically structured with impersonal professors."[1] This description of the engineering classroom is representative of the engineering learning environment that many engineering students experience and that often lead to females having less self confidence or self-efficacy.[8,9] Additionally, within the learning environment research, the quality of the learning environment influences the learning that takes place in that environment.[10] The authors propose to take the first steps in developing a systemic understanding of the engineering learning environment and to study the effects that altering the engineering learning environment has on the retention of underrepresented minorities in engineering. This research will be the beginning of a series of studies that aim to not only understand the learning environment, but how to take a systemic approach to initiate change within the engineering education system.

The relationship between the socio-cultural environment and student attraction and retention to engineering fields is a critical one that promises to lead to a better understanding of the engineering education system and ways to change that system so that its participants are more diverse in their backgrounds and ways of thinking. The type of students that graduate from engineering school have similar outward appearances in addition to similar ways of thinking and learning. Interventions to attract a more diverse set of students have been implemented with successes at a small, local scale, but little change to the larger, overall system (in 2002 21% of bachelor degrees were awarded to women in engineering).[3] Experts agree that the homogeneity of engineering graduates in the US is a major issue that will hinder the US from being an innovative leader of the coming years. How can the system be changed so that a more diverse set of students will strive to be engineers? While 30% of all students entering college major in science and engineering, less than half graduate in these fields. The students that leave are typically the most qualified entrants into college and are disproportionately under-represented minorities. Some explain that the problem is not that the students are unable to handle the engineering school workload, but that it is not their choice to major in engineering.[11] How can the engineering education system be changed so that students choose to major in engineering? Jacobs et al. conducted a longitudinal study (children n=864, parents n=550, and teachers n=80) from 1987 to 2000 and found that the gendered home environment was to blame for the difference in interest in math-related endeavors. This paper attempts to develop an understanding of the larger engineering learning environment so that future studies can explore how a more complex learning environment will lead to a less gendered environment that empowers underrepresented minorities to pursue degrees in engineering.

Theoretical Background

The environment's influence on a person's behavior has been recognized since the 1930's when Lewin developed field theory (see Table 1).[12] Field theory postulates that behavior is not only a function of the individual person, but is also a function of their environment. Years later, Murray developed the needs-press theory, which extended field theory by discussing the individual's needs and the environment's press.[13] The environment's press is the pressure that the environment exerts on the individual. These theories provide a useful framework to build an engineering learning environment model in which the needs-press theory is extended further to include the people exerting pressure on the environment and becoming agents of change. However, this work recognizes the need to avoid a mechanistic or linear approach to understanding systems of people and their environments, and to take an organic, holistic approach.[14] The boundaries that are developed are open, not closed, which is critical to the concept of learning environment expressed here as well as the model that will be presented. Open systems theory extends the needs-press theory to study the system and environment exerting pressures on each other.[15] Open systems theory is socioecological; it does not study people and environments separately, rather people in environments. This ecological perspective allows us to compare learning environments across different social fields, for example those of school, work, family, and community.[7]

Theory	*Description*
Field theory[12]	Defines behavior as a function of the person and their environment
Need-press theory[13]	Behavior is dependent on the person's needs and the environment's press. The press refers to the pressure that the environment exerts on the individual.
Systems theory[14]	The focus is on organic, holistic constructions instead of mechanistic/ linear constructions. The system boundaries are open (not closed).
Open systems theory[15]	This theory is socioecological, which integrates people in their environments. The system acts upon the environment and the environment acts on the system.

Table 1. Theoretical background and brief descriptions

Learning Environment

Before continuing to the proposed engineering learning environment model, there is a need to define the learning environment as the meaning varies across different disciplines. The learning environment is socioecological, including people and their multiple social fields. It is appropriately situated within a psychosocial context as student learning occurs within a person, not simply within the built environment.

In learning environment research the meaning of learning environment is based on Moo's three dimensions of human environments: Relationship, Personal Development, and System Maintenance and Change.[7,10] Learning environments include the "atmosphere, ambience, tone, or climate that pervades the particular setting."[16] The learning environment is the environment as perceived by the individual; therefore it is different for each person with their specific antecedents[17] or stream of life events.[18] Learning environments include the people and the relationships among the people, and they are dynamic and always changing. The people within a system have the ability to change the learning environment and the learning environment has the ability to change the relationships of the people. Different types of people thrive and deteriorate in different learning environments, and different people can tolerate certain learning environments. [7] If people can learn in spite of a learning environment that does not mean that the learning environment is acceptable.[7] Decision making skills and learning outcomes are different for different learning environments. [10,19] Research conducted in School Psychology indicates that students with positive emotion have better coping styles than those with negative emotion. Emotion is a product of the learning environment, which suggests that the learning environment can affect a student's coping or decision making skills.[20]

Simple/ Complex Learning Environment

An extension of the current understanding of the learning environment is proposed here and it is presented as a range spanning from simple to complex learning environments.

A simple learning environment emerges from an overly simplistic worldview, a positivistic one (see Table 2). This worldview results in a focus on objects and information (presented as facts). This learning environment focuses on details and individuals instead of relationships and groups of people. The decision making is linear with a focus on steps instead of processes. Students are severed from other social fields and their previous experiences (stream of life events and antecedents) are deemed irrelevant. In a simple learning environment, the student is isolated from much of their environment as there are no connections between the student and other students, and competition prevails. All of these characteristics of a simple learning environment are likely to marginalize people and subsets of people. In the educational learning environment the information flows from the expert to the student and it is unidirectional. There is no feedback within this system because students are not supposed to fail; therefore the students cannot learn from their mistakes, i.e. it is an unforgiving environment. The student's social field outside of class and inside of class are disjointed. The primary relationship exists between the teacher and the student with the teacher controlling the relationship (see figure 1). In a simple learning environment all of the parts of the learning environment are disparate or disjointed, with the different parts of the environment being linear and sequential.

Simple Learning Environment	***Complex Learning Environment***
Information	Information cycling
Textbook exercises	Decisions (equifinality)
No feedback	Feedback
Unidirectional	Bidirectional
Social fields are disparate	Social fields overlap
Overly simplified worldview	Complex worldview
Straightforward decision making	Complex decision making
Marginalizes people	Empowers people
Competition	Cooperation

Table 2. Characteristics of a simple and complex learning environment

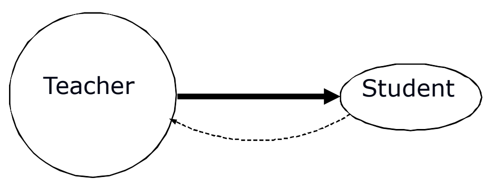

Figure 1. Primary relationship in an educational simple learning environment

A complex learning environment emerges from a complex worldview (see table 2). It emerges from an interpretivist theoretical perspective. The information cycles throughout the system in a complex learning environment. It cycles throughout the people in the classroom and outside of the classroom. Knowledge is built on prior experiences (constructivist), and these stream of life and antecedents are crucial in this environment. The social fields (family, community, school, and work) within each student overlap. There is feedback within this system, which leads to students taking chances and occasionally failing. This open environment that allows for students to make mistakes and learn from them generates needed feedback within the system. Learning is multilateral, as it is shared among the people within the learning environment. The teacher is a facilitator or a guide, not an uncontested expert. This complex learning environment leads to complex decision making, which is more representative of genuine decision making. All of the characteristics of a complex learning environment are likely to empower people as the learning environment is not disjointed from all other aspects of their life, but an integral part of their life within and beyond the classroom. The primary relationship between students in this complex learning environment is one of cooperation. A complex learning environment consists of a more connected system, which results in a more robust psychosocial environment (see figure 2). In a complex learning environment all of the parts are connected directly or indirectly and there are many relationships throughout the system. Antecedents and stream of life events are critical to the complex learning environment, as these allow for the social fields to overlap.

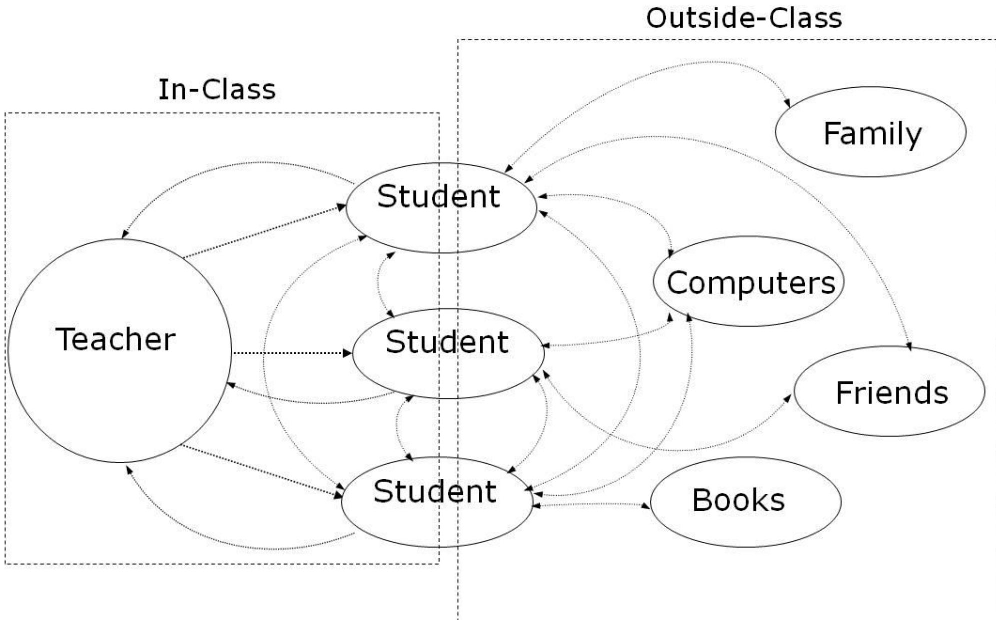

Figure 2. Relationships found in a complex learning environment

The learning environment can empower or marginalize people and subsets of people. In severing the relationships within the engineering learning environment (making it a simple learning environment) and not allowing social fields to overlap, there is a higher likelihood of marginalizing subsets of people.

Proposed Learning Environment Model

This model attempts to further understand the correlation between the learning environment and problem solving approach of students. The learning environment spans from simple to complex and the problem solving approach spans from reductive to holistic.

In this proposed systems diversity model, the problem solving approach of the students span the spectrum from a reductive approach to holistic approach. The reductive/holistic approach dichotomy is a useful metaphor to divide different types of people, although any professional real-world problem would require both reductive and holistic approaches. When one takes a purely reductive approach to solving problems, they are focusing on the analytical, sequential, and textual ways of thinking which are traditionally ways in which engineers and accountants are encouraged to approach problems.[21] This analytical approach to solving problems is very mechanistic and object-oriented. Conversely, people that take a holistic or global approach to solving problems are creative, intuitive, nonlinear reasoning, and contextual and tend to become counselors, inventors, and entertainers.[22] A good fit naturally exists between students that tend to take a reductive approach to solving problems and a simple learning environment, and between students that tend to take a holistic approach to problem solving and a complex learning environment (bottom, left and upper, right corners of figure 3 respectively) and those in between (blue oval). Ideally, students would be capable of using a holistic and reductive approach by the time they reach graduation. The blue oval area is a good fit region and would prepare students for the professional, real-world environment. This would be an ideal region for students to remain in order to best prepare them for their professional careers so that they can transition seamlessly between reductive and holistic problem solving approaches. This is an example of natural selection in an ecological system; the environment selects the students with innate characteristics that are in alignment with the environment.

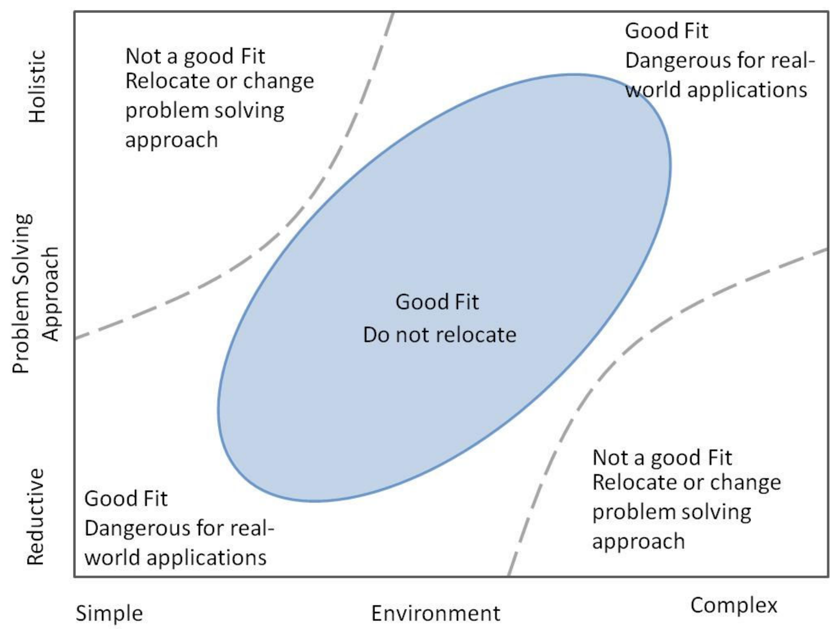

Figure 3. The proposed engineering learning environment model

Students with a complex problem solving approach that find themselves in a simple learning environment and students with a reductive problem solving approach that find themselves in a complex learning environment are faced with a dilemma, because the environment is not aligned with the student attributes. The students could do a number of things to better match their learning environment:

1. Change their problem solving approach to better match their environment (perturbation, see the blue, vertical arrows in figure 4),
2. Move to a different environment that is better suited for them (change majors),
3. Change the environment to better suit their interests and abilities (perturbation, see the purple, horizontal arrows in figure 4), or
4. A combination of the above options (see the red, diagonal arrows in figure 4).
5. Cope with the bad fit and just 'tough it out.'

The students that decide (possibly subconsciously) to change themselves to match their environment are the most likely to change to a different learning environment, while those that can change their environment will be likely to stay in the learning environment. Moos explains that just because students can survive in an unfavorable environment, that does not mean that the environment is a good one.[7] If students relocate they would move to another environment that better matches their problem solving approach. For example, they could transfer to a social science major where a holistic approach is needed for the complex learning environment.

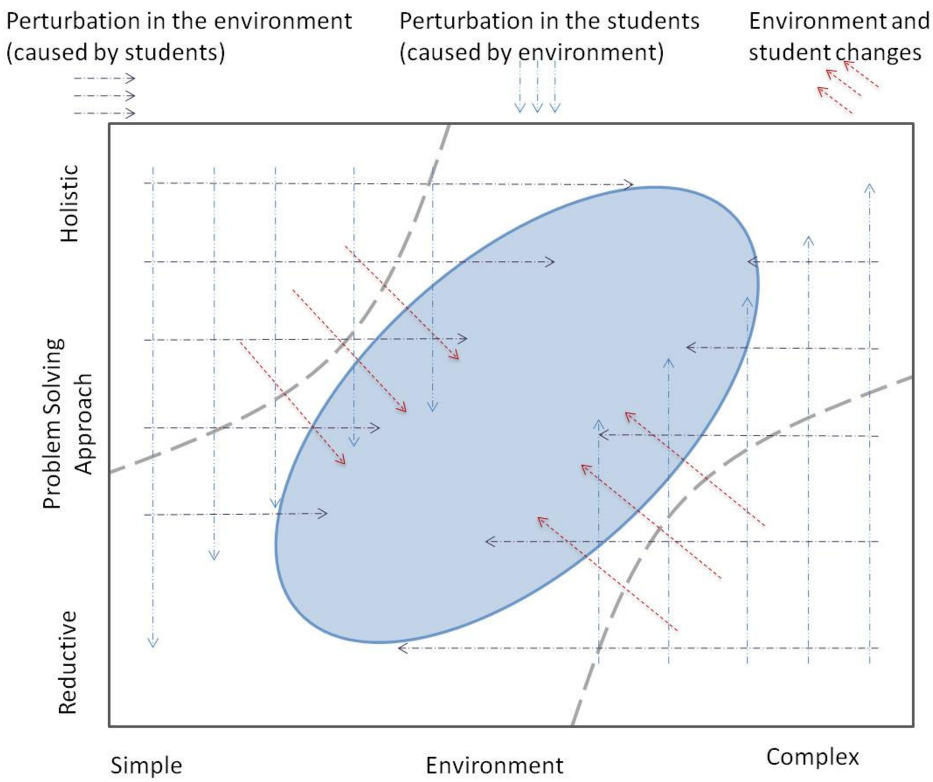

Figure 4. The proposed engineering learning environment model with perturbation field lines. The purple, horizontal lines represent perturbation in the environment caused by the students. The blue, vertical lines represent perturbation in the students caused by the environment. The red, diagonal lines represent a combination of environment and student changes.

Traditionally in engineering education, students are taught to take a reductive approach to solving problems and the corresponding learning environment is simple. While this is appropriate for constrained, single solution problems, it is not adequately preparing students for professional practice. This is a forced fit, which does not prepare students to be engineers of the 21st century. The orange, lower trajectory with circles on figure 5 is a typical movement of a student through the four years of their engineering educational experience. When students graduate and begin working in a professional environment that is complex, this can result in a dangerous situation—engineers taking a reductive approach in a complex environment. If the students take the approach of changing their problem solving approach to meet the needs of the simple environment, their trajectory would align better with the upper, green trajectory with squares on figure 5. The student begins engineering school with a holistic approach to solving problems. When they recognize that this does not match the simple environment, they change their approach to better meet the needs of the simple learning environment (green, upper trajectory, square #2, Figure 5). This may explain why students become less innovative and creative to their problem solving approach, because by the time they reach the senior, capstone design experience they are entrenched in the reductive problem solving approach. They may revert slightly to a more holistic approach. As long as the students do not become discouraged with engineering school and decide to stay despite the needed reductive problem solving approach, these may become the best prepared engineers for professional life and the 21st century.

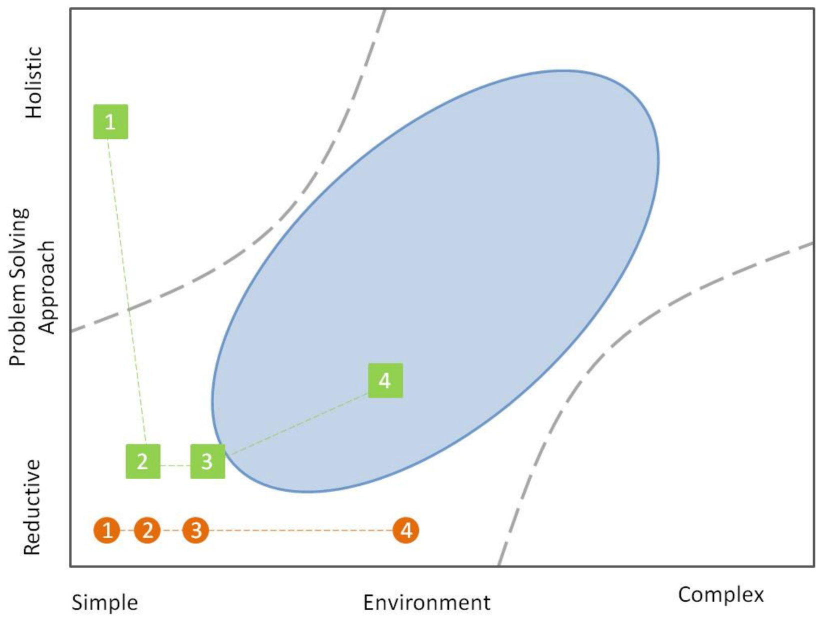

Figure 5. The proposed engineering learning environment model with an orange trajectory (lower one with circles) that represents the typical transition of an engineering student with a reductive problem solving approach and a green trajectory (upper one with squares) that represents the typical transition of an engineering student with a holistic problem solving approach who must change themselves to match the environment.

Ideally, learning environments need to be designed so that they encourage students to use both a reductive and holistic problem solving approach. In most career work, the learning environment will cycle between a simple one to a complex one depending on the situation. It is critical that engineering graduates are capable of mapping back and forth easily. Any major that caters to only one type of student, and only one type of learning environment is arguably not preparing students to flourish in today's society.

Implementation of the Model

This theoretical model has been integrated into the design of new curricula for the Faculty of Engineering's undergraduate program programs. This is a unique opportunity to apply this theoretical engineering learning environment research to emerging engineering education programs in the Faculty of Engineering, including Environmental Engineering, Biochemical Engineering, and Computer Systems Engineering. This exciting new Faculty of Engineering promises to be a different way of educating engineers in a truly cross-disciplinary environment. This program will begin in the Spring of 2009, with an expected enrollment of 200 students within five years. One aspect of the proposed Environmental Engineering undergraduate program that demonstrates a transition towards a more complex engineering learning environment is a series of Synthesis and Design courses that all students take throughout their education. These courses will involve engineering and non-engineering students and teachers (art history, studio art, engineering, and creativity experts from educational psychology) integrating concepts that are learned in general education and engineering science courses and concepts from each student's antecedents and stream of life events. This will allow social fields to overlap, thus harboring a more complex learning environment. The issues that students will address will be culturally inclusive and socially relevant to allow for a more connected and robust learning environment. Moreover, I will have the unique opportunity to compare the complex engineering learning environments to more simple, disconnected learning environments within the traditional Biological and Agricultural Engineering undergraduate programs. Rigorous research will be conducted on these undergraduate programs to determine the degree of complexity of the engineering learning environment and to assess how this relates to student attraction and retention. Lessons learned from these experiences can be applied to new engineering departments and can be used to tweak existing engineering programs. After these courses are underway, the theoretical model presented within this paper will be revised so that it is informed not only by research (see Future Work section below) but also by practice.

Most engineering faculty do not have an opportunity to develop a new engineering program; however there are ways that individual faculty can change the learning environment in their classrooms. The following intervention approaches can be used in a single classroom, a department, or even the larger engineering community:

1. Provide a supportive educational environment[23]

Educators can encourage a supportive educational environment for the students by incorporating cohorts or networks among peers and near peers in individual courses, across multiple courses, in undergraduate research projects, and across disciplines. Additionally, students can initiate cohorts through extracurricular activities related to engineering. By encouraging and supporting students in developing and maintaining peer cohorts, a more complex learning environment will easily be realized. One way to support these cohorts is to develop a cooperative classroom climate instead of the more traditional, competitive climate.

2. Encourage a supportive environment—out of education[23]

Additionally, educators can encourage a supportive environment outside of students' formal education. One way to accomplish this is to encourage students to be well-rounded and lead rich, full lives through example, i.e. showing that they themselves are well-rounded. Moreover, through encouragement and support of extracurricular activities outside of engineering students can find a supportive environment outside of their educational experience.

3. Instructional approaches[23]

Through a constructivist pedagogy, faculty can bring antecedents and stream of life events into class discussions. This will integrate the varying social fields of the students, thus harboring a more complex learning environment. Additionally, engineering faculty can incorporate humanistic attributes of engineers into the classroom. An example of this is using examples and case studies that are not purely technical in nature, but that have a humanistic component as well. These connected, relevant examples in engineering science courses will encourage a more connected, complex learning environment. Moreover, by making connections among courses (engineering and non-engineering) explicit, students will begin to understand how their coursework is not simply a series of individual, unrelated courses, but actually a part of an integrated, organic, holistic educational program. Finally, by incorporating active and collaborative learning into the engineering classroom, students will begin to identify themselves as belonging to a group of students, instead of as an individual competing for success in engineering school.

4. Redefine the discipline[23]

By changing the learning environment and subsequently the makeup of the students, eventually the profession of engineering will change. This is a recursive process in which changing the environment will result in a change in the makeup of the students, which in turn changes the environment.

Continued intervention efforts of community building, cognitive ability development, and occupational choice development[24] are not getting to the root of the problem, they are at best providing temporary, local scale changes and do not promise to change the system of engineering education. This research has the potential to change engineering education and the engineering profession over time if it shows that the engineering learning environment is simple and that this simple learning environment is marginalizing women and underrepresented minorities. These intervention approaches and programmatic approaches promise to move engineering towards a more complex learning environment.

Future Work

The purpose of research that is currently in progress to validate this engineering learning environment model is to explore how the retention and attraction of women and underrepresented minorities is affected by their perceptions of the engineering learning environment. More specifically, this research seeks to determine whether students are more likely to continue in an environment if its complexity matches their approach to understanding the world. This multi-institutional research study takes a mixed methods approach that attempts to understand the engineering learning environment at different scales and different grain sizes.[25] The methods will include surveys, interviews, narratives, and observations and will explore the following research questions:

1. How do students perceive the engineering learning environment?
2. How simple or complex are engineering learning environments?
3. How do engineering learning environments support differences between men and women?

While this learning environment model is based on learning environment, diversity, and engineering education literature it must be used to inform practice in order to move the field forward. Additional validation of the learning environment model must be done through rigorous research. The model proposed here based on current literature and the suggested interventions are aligned with Clewell's intervention approaches. In other words, the theory and resulting models from this research need to be integrated with pedagogies that can be integrated into the classroom to better prepare engineering students to be engineers. Without this link to practice, this research will not help move the field forward.

Bibliography

1. Vogt, C. M., Hocevar, D., & Hagedorn, L. S. (2007). A Social Cognitive Construct Validation: Determining Women's and Men's Success in Engineering Programs. The Journal of Higher Education, 78(3), 337-364.

2. Hall, R. M. & Sandler, B. R. The classroom climate: a chilly one for women? Project on the status and education of women, Association of American Colleges, Washington, DC 1982.
3. National Science Board. (2006). Science and Engineering Indicators Volume 1. Washington, D.C.: National Science Foundation.
4. Byrne, Eileen M. Women and Science: The Snark Syndrome. Bristol: The Falmer Press, 1993.
5. Seymour, E., & Hewitt, N. M. (1997). Talking About Leaving: Why Undergraduates Leave the Sciences. Boulder: Westview Press.
6. Litzler, Elizabeth & Sheila Edwards Lange (2006). Differences in climate for undergraduate and graduate women in engineering: the effect of context. ASEE
7. Moos, R. H. (2002). The Mystery of Human Context and Coping: An Unraveling of Clues. American Journal of Community Psychology, 30(1), 21.
8. Zeldin, A. L., & Pajares, F. (2000). Against the Odds: Self-Efficacy Beliefs of Women in Mathematics, Scientific, and Technological Careers. American Educational Research Journal, 37(1), 215-246.
9. Bandura, A. (1985). Social Foundations of Thought and Action: A Social Cognitive Theory. Alexandria, VA: Prentice Hall.
10. Dorman, J. P. (2002). Classroom environment research: Progress and possibilities. Queensland Journal of Educational Research, 18(2), 112-140.
11. Jacobs J. E. (2005) I can but I don't want to: The impact of parents, interests, and activities on gender differences in math. In Gender Differences in Mathematics: An Integrative Psychological Approach. New York: Cambridge University Press.
12. Lewin, K. (1936). Principles of topological psychology. New York: McGraw Hill.
13. Murray, H. A. (1938). Explorations in personality. New York: Oxford University Press.
14. Bertalanffy, L. (1976). General System Theory: Foundations, Development, Applications. New York: George Braziller.
15. Emery, F. E. (1959). Characteristics of socio-technical systems. In Emery, F. (ed.), The Emergence of a New Paradigm of Work. (Centre for Continuing Education, Australian National University, Canberra, 1978, pp. 38–86.)
16. Johnson, B. L. (2002). Extending the study of learning environments: connecting the field to other literatures. Queensland Journal of Educational Research, 18(2), 183-206.
17. Sergiovanni, T. J. (1986). Understanding reflective practice. Journal of Curriculum and Supervision, 1(4), 353-359.
18. Aviolo, B. J. (1999). Full leadership development: Building the vital forces in organizations. Thousand Oaks, CA: Sage Press.
19. Aldridge, J. M., & Fraser, B. J. (2000). A cross-cultural study of classroom learning environments in Australia and Taiwan. Learning Environments Research, 3(2), 101-134.
20. Fredrickson, B. L., & Branigan, C. (2005). Positive emotions broaden the scope of attention and thought-action repertoires. Cognition and Emotion, 19(3), 313-332.
21. Pink, D. (2005). A Whole New Mind: Moving from the Information Age to the Conceptual Age. Bob Land: Amazon Remainders Account.
22. Felder, R. M., & Brent, R. (2005). Understanding student differences. Journal of Engineering Education, 94(1), 57-72.
23. Clewell, B. C., & Campbell, P. B. (2002). Taking Stock: Where We've Been, Where We Are, Where We're Going. Journal of Women and Minorities in Science and Engineering, 8, 255-284.
24. Watson, K., & Froyd, J. (2007). Diversifying the U.S. Engineering Workforce: A New Model. Journal of Engineering Education, 96(1), 19-32.
25. Denzin, N. K., & Lincoln, Y. S. (2005). The SAGE Handbook of Qualitative Research (3rd ed.). Thousand Oaks: Sage Publications, Inc.