UNDERSTANDING LEARNING ENVIRONMENTS AT THE GRADUATE LEVEL: A THEORETICAL ANALYSIS OF DOCTORAL ENGINEERING EDUCATION PROGRAMS

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Abstract

Educational efforts that are centered on understanding the development of a holistic style engineering professional, via the transformation of engineering programs at the doctoral level, are vital for the successful generation of future engineers able to meet increasingly complex societal needs. Using a primarily theoretical approach, we analyzed how nine engineering education doctoral programs addressed characteristics of a transformative learning environment using the Four Attributes of Learning Environments from the *How People Learn* model as the basis of comparison (Bransford et al., 1999). The nine, American university programs analyzed are unique in that they are the only doctoral programs for engineering education supported within a college of engineering identified in a national search. This analysis provides a comparative understanding of how these engineering education doctoral programs have transitioned from the traditional lecture-based culture into an environment that exists to cultivate the four interrelated attributes of successful, active learning.

Keywords: Engineering education, *How People Learn*, doctoral programs, student-centered learning, knowledge-centered, assessment-centered, community-centered

1 INTRODUCTION

At the start of the century, efforts by the American Board of Engineering and Technology (ABET) ([1]) proposed a new series of criteria for the accreditation of engineering programs across the country entitled Criteria for Accrediting Engineering Programs (herein EC 2000). The criteria compelled the call for the transformation of traditional engineering education programs, providing more holistic and socially impactful professionals, embodied by the twelve competencies that engineering students need by the end of graduation ([1], [2]). This effort was reinforced by the National Academy of Engineering ([3]) 2020 model for engineering professionals which called for the integration of various non-technical competencies (e.g., communication, collaboration, creative thinking, lifelong learning, etc.) into the core curriculum of all engineering programs. The establishment of such learning environments is dependent upon a paradigm shift, wherein the learning environment is primarily student-centered and the focus is on knowledge acquisition and knowledge transfer ([4], [5], [6]). Such elements, as discussed, have become principle tenets that are embodied in the *How People Learn* framework ([5]).

This pedagogical transformation inherently necessitated the creation of engineering programs that focused on the teaching aspects that would lead to the creation of such student-centered environments to engineering students. In accordance, across the nation the number of engineering graduate programs that offer doctoral degrees in engineering education have continuously increased since the first official program was established in 2003 ([7], [8]). In order to effectively develop the type of engineering professionals detailed above, these programs should align with pedagogical efforts that aim to promote student-centered learning environments and holistic style engineering training. However, with the number of graduate engineering education programs on the rise, only a few studies have been published that examine a program's conceptual framework to the principle learning theories that have been recognized as part of the transformation of these learning environments (e.g., key principles encompassed in *How People Learn*) ([5], [9], [10]).

The purpose of this contribution is thus to offer insight on the ways in which universities that have led the efforts within this transformative context have incorporated tenets of the *How People Learn* model into the conceptual framework of their doctoral-level, graduate programs. Utilizing a primarily theoretical approach, the authors of this work analyzed several documents (e.g., departmental goals and statements, research focus areas, and funded grants) pertaining to select doctoral-level, graduate programs against the Four Attributes of Learning Environments (i.e., Student-Centered, Knowledge-Centered, Assessment-Centered, and Community-Centered) that are central to the *How People Learn* model ([5]). We begin by offering an overview of the theoretical components of the *How People Learn* model which will anchor our analysis of the doctoral programs encompassed in this study. This is followed by the analysis of nine leading programs in engineering education against the Four Attributes of Learning ([5]). Implications and concluding remarks are offered in a separate section following this analysis.

1.1 Learning Environments: Three Core Learning Principles

Prior to outlining the Four Attributes of Learning Environments which will drive the analysis for this study, the theoretical background in which these attributes are anchored need to be developed. In accordance, this section presents an overview of the theoretical underpinnings of Bransford and colleagues' ([5]) contribution, *How People Learn: Brain, Mind, Experience, and School*. This seminal work outlines the key findings from a collaborative study (between the Commission on Behavioral and Social Sciences and Education of the National Research Council) on how people learn which resulted in the formation of key teaching and learning strategies about learners and learning and also teachers and teaching ([5]). Collectively, the researchers impressed throughout the report the need for an overhaul on the traditional methods of instruction and the need for teachers and educational professionals to engage students at the level of understanding with which the student enters the classroom ([5]). The researchers encapsulated the study by identifying three core learning principles and explained how to integrate both the development and application of four types of learning environments in order to produce the types of active learning scenarios which result in maximum transfer of knowledge.

The first core learning principle highlights the necessity of teachers (facilitators of learning) to draw out, extrapolate, or challenge the pre-existing understandings that students have at the onset of learning new material ([5]). This principle is essentially founded on the epistemological elements of constructivist approaches to learning and necessitates that the teacher becomes a facilitator of learning wherein their role is central to helping students construct their own meanings in the learning process ([4], [11]). The next learning principle emphasizes the need for the facilitator of learning to be well-versed in the material which they are trying to convey understanding, through both experience and in-depth studies ([4], [5], [11]). The third and final learning principle incorporates the development of students' metacognitive skills in order to produce learners that recognize the difference between when they are understanding the concepts and when they are lacking information, in order to create meaning ([5]). The holistic-style engineering professional are better developed within environments that are guided by the core principles encompassed in *How People Learn* ([3], [6], [12], [13]). The following will provide descriptions of these principles and their relation to holistic-style engineers.

1.1.1 Level of Pre-existing Understanding

The initial concepts that students possess, regarding their understanding of certain topics, will provide the foundation on which more formal understanding may be built ([14]). Understanding that students enter the classroom with preconceived notions and ideas from their own, individual backgrounds and experiences, which is important in regards to the facilitation of learning at a level that is appropriate for the student ([4], [12]). If the student is presented with the initial concepts of the class at a level that is above or below the student's level of knowledge, then the engagement may cause the student to fail at grasping future concepts or be unable to connect relevant principles of knowledge within the curriculum ([4]).

1.1.2 Teacher Expertise

In the setting of a classroom learning environment, the teacher is generally considered as the prime source of intelligence and understanding for students. However, in order for such an individual to be able to effectively facilitate the learning process, the teacher must possess a firm grasp of the subject knowledge and on the relationship between the information and the concepts that help organize that framework of knowledge ([4], [12]). The exchange of current teaching methods, which results in a superficial coverage of topics throughout a course without attaining a deep understanding of the topics, with more in-depth methods that focus on discussing fewer topics overall, but allow for students to identify key principles of knowledge within the curriculum. This ability to identify key principles will create the potential for students to be able to apply and connect such principles within the proper bodies of knowledge ([15]).

1.1.3 Metacognitive Ability

The third core principle of learning centers around the incorporation of techniques to develop a student's metacognitive abilities. As metacognitive skills increase, so does a student's ability to provide an internal dialogue with oneself regarding their current levels of mastery and understanding in order to identify, process, and organize information being presented within the classroom ([16]). This type of ability leads to learning that focuses on sense making, self-assessment, and reflection on what is working and what needs improving to lead to self-directed and lifelong learning.

1.2 Learning Environments: Four Attributes of Learning Environments

As part of these core principles within the *How People Learn* model, Bransford and colleagues ([5]) highlight Four Attributes of Learning Environments which must be present in order to achieve efficient student-centered approaches to learning. These four attributes, as shown in Fig. 1, are effectively a system of interconnected components that mutually support the learning of the students within these dynamic environments. Moreover, these four attributes complement and support one another in the development of these types of innovative learning spaces ([5]). The following will provide details pertaining to each of these attributes.

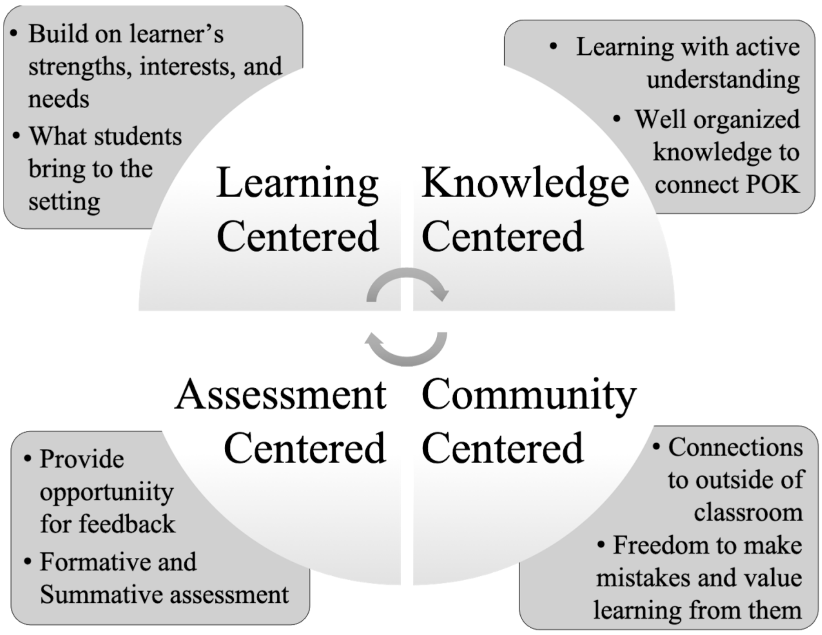

Figure 1. Four Attributes of Learning Environments and their Descriptions ([17])

1.2.1 Student-Centered

The Student-Centered attribute of the learning environment as posited by Bransford and colleagues ([5]) focuses on the attention that the facilitators of learning need to provide to the knowledge, skills, attitudes, and beliefs that learners bring to the classroom. As part of this attribute, facilitators of learning must be aware of the epistemological implications of constructivist environments wherein students' learning is based off of the construction of their own meanings ([4], [5]). This inherently entails that the facilitator of learning integrates the students' beliefs, perspectives, and cultural practices into the foundation of the content being presented in order to help facilitate the construction of relevant meanings ([4], [5]). One example of how this is accomplished is through the prompting of students to explain and develop their knowledge structures through inquiries which guide their predictions about various situations and to have them explain their perspective and rationale for these predictions ([5]).

1.2.2 Knowledge-Centered

The Knowledge-Centered attribute of the learning environment centers on building upon well-organized bodies of knowledge which then drive students' understanding of different disciplines through the planning and strategic thinking of these bodies of information ([5]). This attribute emphasizes sense-making; that is, how does the facilitator of learning help students make sense of new information when it does not necessarily adhere to their understanding or experiences ([4], [5], [12]). The conceptualization of knowledge acquisition and transfer is embodied in this attribute through the integration of activities that are designed to promote understanding and those that are designed to promote the automaticity of skills ([5]). Bransford and colleagues ([5]) suggest that this attribute intersects with the Student-Centered attribute in that the facilitator of learning through the content aims to integrate students' previously conceived notions of knowledge into the pedagogical strategies utilized to present new knowledge.

1.2.3 Assessment-Centered

The Assessment-Centered attribute of the learning environment posits that facilitators of learning should provide opportunities for feedback and revisions in the form of summative and formative assessments which, in turn, need to align with the overall learning objectives ([5]). Further, as part of this attribute, assessments must occur continuously, should not be intrusive, and should be integrated as part of the overall pedagogical strategy being used ([5]). As part of this attribute, facilitators of learning are challenged to provide a theoretical framework that helps to align the assessment practices with the learning theories ([5]). Such assessments must be tailored to the learning objectives that identify the various ways in which students interact with their learning environment ([5]).

1.2.4 Community-Centered

The Community-Centered attribute of the learning environment emphasizes the importance of students' continual interaction with all aspects of their immediate and larger learning communities ([5]). For example, students should understand their classrooms and schools as part of a community wherein they, in addition to their facilitators of learning and administrative staff, form the central social aspects of these communities ([5]). Learning is then understood to be a central part of the social norms of these communities and their ability to construct meaning and understand knowledge is linked to the norms produced within these communities ([5]). From the facilitator of learning perspective, this sense of community guides the way in which students are able to make out-of-classroom connections to society and how the pedagogical practices utilized within the classroom influence the creation of these connections ([5]). This community provides students with the opportunity to make mistakes in order to learn from them and construct meaning from these experiences ([5]).

2 METHODOLOGY

2.1 Analytical Strategy

The purpose of this work is to better understand how universities that offer engineering education programs at the graduate level have incorporated tenets of the *How People Learn* model into their doctoral programs. In this work we employ a primarily theoretical approach to answer following research question: in what ways are doctoral-level, graduate programs in the field of engineering education integrating the Four Attributes of Learning Environments into the contextual framework of their programs? To answer this question, we utilize the theoretical descriptors of the Four Attributes of Learning Environments to compare and contrast the various characteristics of these programs align with these descriptions. A thorough search, utilizing refined search criteria (detailed below), resulted in the selection of nine university programs that purveyed the material for this analysis. For data, we utilized a myriad of documents, that were publicly posted on the university websites at the beginning of 2019, in order to obtain key details about their engineering education programs. These documents included: available departmental goals and statements, reports regarding research focus areas for faculty and graduate students, and also any funded grants, inter alia. We outline the selection criteria for the nine programs of study selected for this analysis in the following section.

2.2 Selection Criteria

The search for the university programs selected for this analysis was conducted in three phases. The first phase included a broad internet-based search to obtain a list of universities that offered graduate programs in Science, Technology, Engineering, and Math education, including those located outside of the United States. This first search resulted in forty-five different university programs that matched this description. The second phase focused on refining the results from the first phase, and the objective was to obtain a list of universities that held the following characteristics: the graduate program must be offered at a four-year institution, be housed within a school of engineering or within the engineering discipline, and the university be recognized as lawfully based within the United States. This second search resulted in twenty-nine different universities with STEM education graduate programs that matched the criteria, thus far. The third phase of this selection criteria further refined the results by stating that the graduate program must be at the doctorate level, contributing to the field of engineering education research. The results of this search led to nine university programs that successfully fullfilled all of the selection criteria posed by the three phases of these searches.

2.3 Overview of Selected Cases

The nine university programs that resulted from the search performed for this study included: Arizona State University, Clemson University, Louisiana Tech University, Ohio State University, Purdue University, University of Georgia, University of Michigan, Utah State University, Virginia Polytechnic Institute and State University. The characteristics of these programs are provided in Table 1.

Table 1. Overview of Programs Selected for Analysis.

	Program Name	Origin Date	Faculty	Eng/STEM* B.S. Required
Arizona State University	Engineering Educations Systems and Design	2016	9	Yes
Clemson University	Engineering and Science Education PhD Program	2006	9	Yes
Louisiana Tech University	PhD in Engineering - Education Concentration	2005	16	Yes
Ohio State University	Engineering Education	2018	6	Yes
Purdue University	Engineering Education	2004	22	Yes
University of Georgia	PhD - Emphasis in Engineering Education and Transformative Practice	2016	5	Yes
University of Michigan	Engineering Education Research	2018	6	Yes
Utah State University	Engineering Education	2003	8	Yes
Virginia Polytechnic Institute and State University	Engineering Education	2008	15	Yes

**Engineering or STEM Bachelor of Science degree required for admission into program*

3 RESULTS

The analysis of the separate institutions yielded a variety of methods and applications through which the four attributes of learning environments have been incorporated within the doctoral graduate programs. Several similarities appeared to be shared amongst the institutions concerning the impact and the degree to which the learning environments were embodied. The aspects of the learning environments and their inclusion in the programs will be discussed below.

3.1 Student-Centered Attributes

In analyzing the individual graduate programs, the development of a student-centered environment consisted largely upon the mental health of students entering the program, as well as key elements that might influence a students' identity, including self-worth and believed capabilities. Several programs continued to compare the perception of a student's identity with the likelihood for continued matriculation within their respective programs. This might be captured in the program's efforts to understand career identity building, empowerment of students through the tailoring of curriculum and research to their interests, and integrating diversity initiatives in student learning outcomes, inter alia. Some programs, for example, paid attention to the differences that cultural norms may play in overall student success, providing student support services to help retention. The focus of student-centered environments commonly overlapped with knowledge-centered learning environments in regards to how a student's motivation might influence the development of learning models. Student-centered environments also were integrated with knowledge-centered environments for determining what type of learning model would be applied for instructing first-year students within core curriculum courses based upon their respective level of knowledge prior to beginning the course.

3.2 Knowledge-Centered Attributes

Within knowledge-centered environments, many of the graduate programs covered topics related to the influence and incorporation of technology; including physical classroom enhancements, online mobile platforms, video game design, and tools or devices for students to utilize themselves in order to gain a better understanding of principles being discussed. Other types of knowledge-centered activities focused on the effectiveness of transitioning traditional teacher-centered environments into student-centered environments. These types of techniques also overlapped with assessment-centered learning environments in regards to the need for constant assessment to be occurring in order to determine the effectiveness of knowledge transfer. Several institutions were also applying discipline-based instructional methods to implement problem-based learning, specifically in regards to developing skills at handling ill-structured problems

3.3 Assessment-Centered Attributes

The inclusion of assessment-centered attributes for learning environments commonly were interactive with other attributes that focused on evaluating or assessing how different learning models influenced the future outcome of students. The types of assessments covered by universities were both formal and summative in nature, depending on the type of information was being sought by the facilitators of learning. Formative assessment was highly common for developing metacognitive skills amongst students via continual discussion and reflection upon decisions and thought patterns are occurring while performing problem-solving activities. Summative assessment was the chosen method for most institutions for evaluating success patterns of students when new or innovative methodologies were employed for facilitating knowledge transfer.

3.4 Community-Centered Attributes

At almost every institution within the analysis, the desire to have a multi-disciplinary, diverse community fulfilled the characteristics of a community-centered environment. Several graduate programs even included the development of techniques to include students who might otherwise be unable to attain the understanding necessary to become an engineer with the traditional methods of instruction, such as being visually impaired. The other aspect of being a community-centered environment was focused upon developing engineers that will be conscious of the impact that certain decisions may cause both ethically and socially. The desire to alter the perceived cultural norms of engineering, encouraged several institutions to focus on how such norms might be influenced, both within the classroom and in the community.

4 CONCLUSIONS

4.1 Discussion

With the advent of ABET's ([1]) Criteria for Accrediting Engineering Programs, the nature of engineering programs shifted from traditional learning strategies into more student-centered and holistic-based learning practices. Consequently, this transformative context motivated the creation of engineering programs that focused on the teaching aspects that would lead to the development of such student-centered environments to engineering students. These programs offer the integration of pedagogical aspects - like those illustrated in the *How People Learn* model - into engineering content in order to effectively train scholars on the necessary characteristics for the development of this type of student-centered environment ([5]). As the number of engineering graduate programs that offer doctorate degrees in engineering education continue to increase, it becomes critical to understand how, exactly, these programs address several of the key attributes associated with the *How People Learn* model ([7]). This is important because as this model is a pedagogical guideline for the implementation of student-centered strategies, the professional developed by these programs will have incorporated the key characteristics needed to develop a new and more holistic type of engineering professional. This will be in line with the intention of ABET's ([1]) Criteria for Accrediting Engineering Program curriculum changes.

4.2 Summary

The purpose of this contribution was thus to better understand how universities that offer doctorate-granting, engineering education programs, within the United States, incorporate aspects of the *How People Learn* model into the conceptual framework of their graduate programs. Using a primarily theoretical approach, wherein the Four Attributes of Learning Environments from the *How People Learn* model provided the basis of comparison, we analyzed the various ways in which nine selected university programs addressed these characteristics of a transformative learning environment ([5]). This analysis provides a comparative understanding of how existing doctoral programs in the United States for engineering education have transitioned from the traditional lecture-based culture into an environment that exists with four interrelated attributes of successful learning. Through this analysis, efforts focused on developing an innovative, adaptable and societal impactful professionals will be highlighted.

4.3 Continuation of ENGE Programs

Ultimately, the initial shift in engineering education described in this paper was anchored in the expectation of an engineer's abilities in the twenty-century workforce as rapidly expanding into a very dynamic role ([3], [13], [18]). This shift can largely be attributed not only to the recent advances in technology, improved rate of data manipulation, as well as the availability of new systems for accessing information but also to demanding societal needs for personalized medicine, personalize learning and saving energy. In accordance, the training provided to engineering professionals needed to integrate characteristics that would result in the development of a problem solver, a problem identifier, a creative thinker, and a socially savvy entrepreneur simultaneously ([3], [13]). The production of engineering education doctorates from the programs analyzed in this study have arguably led to the development of a potential excellent pool of facilitators of learners that have the ability to transform other engineering programs (at different universities) and produce these holistic style engineers ([6]). Furthermore, the scholarly based activities generated by these facilitators of learning will have an additional multiplier effect in producing documentation to continue to guide the transformation of engineering educational programs that produced a holistic style and socially impactful engineering professional ([3], [6], [13]).

REFERENCES

[1] Accreditation Board for Engineering and Technology [ABET]. *Criteria for Accrediting Engineering Programs*. Baltimore, MD: ABET, Inc., 2000.

[2] B.E. Seely, "Patterns in the history of engineering education reform: A brief essay," *Educating the engineer of 2020: Adapting Engineering Education to the New Century*. pp. 114-130, 2005.

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

[4] H. Anderson, "Collaborative learning communities: A postmodern perspective on teaching and learning," in *The Handbook of Educational Theories* (B.J. Irby, G. Brown, R. Lara-Alecio, & S. Jackson, eds.), pp. 515-527, Charlotte, NC: Information Age Publishing, Inc, 2013.

[5] J. Bransford, A. Brown, and R. Cocking, *How People Learn: Brain, Mind, Experience, and School*. Washington, D.C.: National Academy Press, 1999.

[6] D. Grasso and M.B. Burkins, *Holistic Engineering Education*. New York, NY: Springer, 2008

[7] L.C. Benson, K. Becker, M.M. Cooper, O.H. Griffin, and K.A. Smith, "Engineering education: Departments, degrees and directions," *International Journal of Engineering Education*, vol. 26, no. 5, 2010

[8] A. Akay, "A renaissance in engineering PhD education," *European Journal of Engineering Education*, vol. 33, no. 4, pp. 403-413, 2008.

[9] O.H. Griffin, A. Aning, V.K. Lohani, J. Kampe, R. Goff, M. Paretti, M. Alley, J. Lo, J. Terpenny, T. Walker, and H. Aref, "Designing and implementing graduate programs in engineering education," in *122nd American Society for Engineering Education Annual Conference and Exposition*. pp. 3083-3092, 2005.

[10] M.H.G. Murzi, M.P. Shekhar, and L.D. McNair, "Comparative analysis of PhD programs in engineering education," in *122nd American Society for Engineering Education Annual Conference and Exposition.* age. 26, p.1, 2015.

[11] P.E. Arce, J.R. Sanders, A. Arce-Trigatti, L. Loggins, J.J. Biernacki, M. Geist, J. Pascal, and K. Wiant, "The renaissance foundry: A powerful learning and thinking system to develop the 21st century engineer," *Critical Conversations in Higher Education*, vol. 1, no. 2, pp. 176-202, 2015.

[12] R. Felder and R. Brent, "Active learning: An introduction," *ASQ Higher Education Brief*, vol. 1, pp. 1-5, 2015.

[13] National Academy of Engineering, *Grand Challenges for Engineering*. Washington, DC: The National Academies Press, 2017.

[14] E. Duckworth, *The Having of Wonderful Ideas and Other Essays on Teaching and Learning.* Ann Arbor, MI: Teachers College Press, 2006.

[15] P.E. Arce, "Principal objects of knowledge in colloquial approach environments." in *108th American Society for Engineering Education Annual Conference and Exposition.* vol. 3413, 2000.

[16] A.L. Brown, "The development of memory: Knowing, knowing about knowing, and knowing how to know," *Advances in Child Development and Behavior*, vol. 10, pp. 103-152, 1975.

[17] B. Adams, J.R. Sanders, P.E. Arce, "Review - the inflection point of engineering education and the impact of innovative pedagogical techniques to shift towards a learning-based culture," in *Student Research and Creative Inquiry Day, Graduate Chemical Engineering Session*. 2018

[18] J.J. Duderstadt, "Engineering for a changing world: a roadmap to the future of American engineering practice, research, and education," in *Holistic Engineering Education* (D. Grasso and M.B. Burkins, eds.), pp. 17-35, New York, NY: Springer, 2010.