An adaptive response model to describe emergent engineering education system properties

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Abstract*: To meet current and future challenges, engineers are needed that have different ways of thinking and one way this can be achieved is by attracting and retaining more diverse people from more diverse backgrounds. Student retention and attraction have been studied extensively in engineering education; however the underlying cause is still not well understood. This paper reports the results from the conceptual design and development of a theoretical model to better understand attraction and retention of engineering students and the influences on overall system properties. The proposed adaptive response model, developed by the authors, extends person-environment fit theory and Attraction Selection Attrition theory by introducing temporal scales and multiple hierarchical scales ranging from individuals to organizations. The findings that emerged from this study highlight the system attributes that result from low and high person-environment fit and the impact of the person-environment fit of people within the system on cognitive outcomes.*

Context

Issues of student retention and attraction within engineering education are not well understood (Engineering Education Research Colloquies, 2006; Watson & Froyd, 2007). Moreover, reports in the last century indicate that the current educational system is not producing the engineering graduates needed for today and tomorrow's challenges (Dowell, Baum, & McTague, 1994; Engineering, 2005; Report on the Committee on Evaluation of Engineering Education," 1955; The Boyer Commission on Educating Undergraduates in the Research University, 1998). We content that this points to a larger systemic issue concerning the development of the engineering education system in the light of recent sociological, ecological, technical, and economic challenges. To explore this systemic issue we propose a new adaptive response model that links individual student fit to the development and adaptation of the engineering educational system. This is based on the person-environment (P-E) fit and Attraction, Selection, and Attrition (ASA) theories.

Research Purpose

This research attempts to fill a gap in educational research and specifically in engineering educational research by synthesizing work from education, business, social sciences, systems, and ecology into a coherent theory that will bring light to the issue of change in educational systems. The purpose of this paper is to develop a temporal and hierarchical model of the engineering education system of individual student's attrition and retention and the subsequent systems-level properties of that environment.

Theoretical Framework

This research is based on open systems theory that looks not only at the person embedded within their environment, but also how the person and environment exert pressures on one another. This ecological perspective 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 (von Bertallanffy, 1969). The boundaries are open, not closed, which is critical to the concept of learning environment expressed here as well as the new adaptive response model that will be presented.

Specifically within open systems theory, this work is framed within the P-E fit (Ellis & Tsui, 2007b) and ASA theories (Schneider, 1987; Schneider, Smith, & Golstein, 2000) that have emerged from work in Psychology and Business. The P-E fit theory extends Lewin's field theory (Lewin, 1936) in that it considers not only that the person and environment influences an individual's behavior, but that the fit between the person and the environment influences behavior. P-E fit theory focuses on the positive outcomes of having a close fit between a person and their environment (Ellis & Tsui, 2007b). ASA theory differs in that it stresses the negative outcomes of having a close fit between a person and their environment with the resulting system being homogeneous, rigid, and not innovative or creative (Schneider, et al., 2000). A lesser fit between a person and their environment results in a more heterogeneous, flexible, adaptable, and innovative organization of the system.

Methodology and Model Development

To develop a theoretical model to explain attraction and retention of engineering students with a systems perspective and to explain the influence of the relationship of people within the system and the socio-cultural environment on the system's and individual's attributes, the authors extended the P-E fit and ASA theory to include temporal scales and the individual to organizational emergence.

This proposed theoretical model attempts to further explain the correlation between the fit of a person and their environment and the emergent organization of the larger system. The proposed adaptive response model is presented in figure 1. Students arrive in engineering with traits, motives, and self concepts. The fit between a person and their environment is at an individual level and is subjective. A subjective fit is critical, because although there may be an objective fit, if the individual does not perceive a fit the fit may as well not exist (Edwards, Caplan, & Van Harrison, 1998). The level of fit is then assessed between the individual and their perceived environment. If the fit between the student and the environment is high the student will continue in the environment and reinforce the larger-scale attributes, thus remaining at equilibrium. However if the fit between the student and their environment is low, the student will have an adaptive response and either 1) change themselves or the environment to create a better fit or 2) not change themselves or the environment but remain in the environment in spite of the bad fit. In the following sections the person, environment, and adaptive response will be described in more detail.

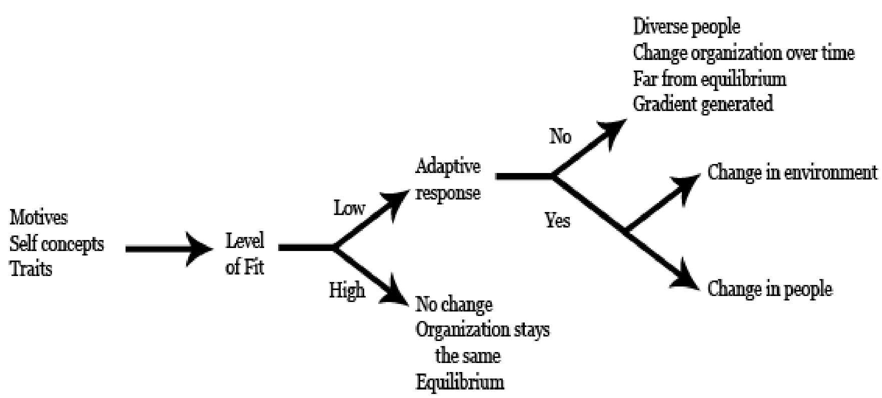

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Figure 1: Proposed, theoretical adaptive response model

Person

Students enter engineering school with a set of hidden competencies including motives, self concepts, and traits (Spencer & Spencer, 1993; Walther & Radcliffe, 2006). The motives, self concepts, and traits of the students may be influential in the decision to major in engineering, i.e. the attraction to engineering. Motives can range from getting a job upon graduation, making money, helping people, or even proving someone (or yourself) that you can be successful in engineering. Self concepts are the way that an individual perceives themselves. Traits are the characteristics or attributes of an individual. These hidden competencies typically go unnoticed as they are not as apparent as visible competencies of knowledge and skills. Additionally, these hidden competencies are difficult to empirically evaluate (Walther & Radcliffe, 2006). Motives, self concepts, and traits change over longer time-scales than competencies of knowledge and skills. In this proposed theoretical model, these hidden competencies are what an individual benchmarks to their socio-cultural environment to determine whether or not a fit exists.

Visible competencies are knowledge and skills and are related to student outcomes, the basis of many educational accreditation processes, including the Accreditation Board of Engineering and Technology (Edwards, et al., 1998). Knowledge, skills, and outcomes are influenced by the hidden competencies of a student (motives, self concepts, and traits) and are influenced by the environment. The hidden competencies are more influential in the assessment of a person's fit with their environment, while the outcomes (including knowledge and skills) are influenced by the environment and the fit within the environment.

Environment

The 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 (Moos, 2002a). Learning environments include the "atmosphere, ambience, tone, or climate that pervades the particular setting (Johnson, 2002)." The learning environment is the environment as perceived by the individual; therefore it is different for each person with their specific antecedents (Sergiovanni, 1986) or stream of life events (Aviolo, 2000). Learning environments include people and relationships among people, and 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 (Moos, 2002b). If people can learn in spite of a learning environment that does not mean that the learning environment is acceptable (Moos, 2002b).

Adaptive Response

Students with specific motives, self concepts, and traits that do not align with their learning environment are faced with a dilemma. They can cope with a bad fit by either remaining in the environment in spite of the bad fit or they can have an adaptive response to achieve a better fit. An adaptive response includes changing the local environment by changing majors, dropping out of school, or changing themselves so that they better fit within the environment. A person can alter their outward appearance, change the way that other people perceive them, or eventually change their traits, self concepts and motives (hidden competencies) to achieve a better fit.

Findings

To this point we have only discussed an individual person's movement through the adaptive response model. However, the strength in the proposed, theoretical model lies in the relationship of the individual with the overall system properties. The following will discuss the relationship between individual adaptive response behaviors and the resulting organizational system properties.

Relationship Between the Individual and the Larger System Properties

When analyzing the adaptive response model within a systems perspective, the individual trajectories contribute to the behavior and the organization of the larger system. In other words, system organization emerges as a result of the movement of multiple students along the P-E fit and adaptability trajectories. The following figure describes the trajectories of an illustrative cohort of 10 students moving through engineering school (see figure 2). Please note that this is not an empirical study of a set of 10 engineering students, but is theoretical set of students that help illustrate the relationship between an individual student's fit with the environment and their adaptive response with the larger, systemic properties of the engineering education organization.

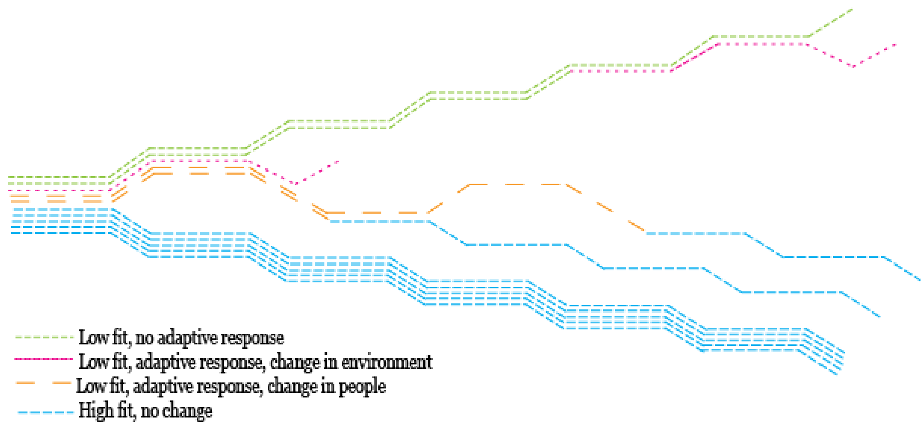

Figure 2: Trajectories of an illustrative cohort of 10 students moving through engineering school

If we observe the trajectories of a cohort of students moving through an engineering program, we can begin to observe patterns that are occurring at a larger, systems level. For example in figure 2 there are a group of illustrative students that are followed through a period of time in engineering school. The bottom five lines represent trajectories of students that fit well within their environment. These students stay in engineering and have no need to change themselves or their environment to realize a better fit. The two lines above those represent trajectories of students that do not fit within engineering and adapt themselves so that they fit better within the environment. The student represented by the lower of the two lines fits with the environment after one iteration of changing themselves while the student represented by the upper line takes two iterations of trying to change themselves so that they fit better within the environment. The line above those two lines (the third from the top) also represents the trajectory of a student that does not fit well within the environment; however this student changes their environment by changing majors so that they can find an environment that is a better fit. Finally, the upper two lines represent trajectories of students that do not fit with their environments, but stay in engineering in spite of the bad fit. These students do not adapt fit better within their environment. The student represented by the lower of these two lines eventually decides to change their environment to find a better fit.

Organizational System Properties

The emergent organizational properties that emerge from this theoretical model include homogeneity/ heterogeneity, flexibility/rigidity, responsive/unresponsive, and static/dynamic. These systems level properties result in cognitive outcomes.

The level of perceived fit between individuals and their environment has profound impacts on the overall system attributes, cyclically influencing the fit of individuals entering the system. A positive feedback loop occurs when the students entering the system are similar to the students within the system, thus reinforcing the current system attributes. This results in a static, unchanging, homogeneous, rigid, and unresponsive system. A negative feedback loop occurs when people entering the system are different than the people within the system resulting in a dynamic, heterogeneous, responsive, and flexible system.

When looking at this illustrative cohort of students one can see that most of the students are moving towards a state of equilibrium. The eight students that are represented by the lower eight lines all eventually fit well with their environment. These students do not encourage change within the system. This system has critical mass as more and more students are either naturally fitting with the environment or are changing themselves to better fit with the environment. The two students that remain in engineering in spite of the bad fit (the top two lines) are moving the system, albeit slightly, away from equilibrium.

Furthermore, the level of perceived person and environment fit and resulting distance from equilibrium influences the system attributes. A system that is near equilibrium or steady state is inflexible, unresponsive, and unchanging while one that is further from equilibrium is flexible, responsive, and changing. A system that remains in an equilibrium state harbors a higher rate of attrition from the system and eventually results in a more homogeneous, unhealthy, and mechanistic organization.

Cognitive outcomes suffer in light of P-E fit. Over a short period of time P-E fit can increase productivity due to increased communication and decreased tensions; however over a longer period of time it leads to less cognition. It is a safe environment, but does not encourage people to consider multiple perspectives. Doing so would threaten the cohesion, cooperation, and harmony that was already established. This stifles creativity and innovation and results in groupthink.

Discussion

The proposed learning environment model is an extension of P-E fit theory (Ellis & Tsui, 2007b) and ASA theory (Schneider, 1987; Schneider, et al., 2000) in that it builds a theoretical foundation for better understanding through a systems perspective by examining multiple levels of organization (individual, environment, and system) across temporal scales. It builds on the idea of the fit between a person and their environment and differentiates between a good fit with positive consequences and a good fit with negative consequences.

Ellis and Tsui also developed a model of demographic fit that demonstrated the positive and negative effects of heterogeneity and homogeneity (2007a). Their model begins with antecedents, then moves into the level of fit and finally into outcomes (affective, cognitive, behavioral, and survival). If there is disequilibrium, there is an opportunity for adaptive or non-adaptive responses. Their model explains the short-term positive effects of high P-E fit and the longer-term negative effects of a high P-E fit.

The concept of learning environments has been explored in P-E literature. For example, in organizational studies, empirical research has revealed a positive correlation between uncertainty (thus diversity and complexity) and organizational performance (Bourgeois, 1985), and negative correlation between top management team consensus and organizational financial performance (Grinyer, 1975). Bourgeois differentiates further between stable and unstable environments, as in stable environments it may be safe to avoid uncertainty, but in unstable environments "uncertainty avoiders…were likely to perish (1985)." In the proposed model, stable environments are systems that are close to equilibrium that are homogeneous, rigid, mechanistic, and unlikely to survive when encountering change. Unstable environments are far from equilibrium systems that encourage heterogeneous people (diversity), resulting in an organization that is flexible, fluid, organic, and likely to survive and flourish when change is encountered.

Person environment fit research has also been conducted within higher education, although much more research has focused on the correlation between person environment fit with stability and school satisfaction than on the correlation of person environment fit with learning (Feldman, Smart, & Ethington, 1999). There are, however, numerous research studies in higher education that focus on the influences that contribute to student learning (Astin, 1985, 1993; Berger & Milem, 2000; Terenzini & Reason, 2005; Tinto, 1993). For example, Terenzini recently developed a model of the influences on student learning and persistence and discusses the student's antecedents, the organizational context, the peer environment, the individual student experiences, and the outcomes (2005). These multiple influences are included in the proposed model as they contribute to the P-E fit. Moreover, the proposed model is focused not only on the influences of the P-E fit and organizational attributes on the individual student outcomes, but the system and organizational attributes that emerge as a result of the fit of individuals with their environment.

Implications

Diversity is long been recognized as a critical issue within engineering education (Brainard & Carlin, 1998; Byrne, 1993; Chubin, May, & Babco, 2005; Clewell & Campbell, 2002). Engineering has been predominately comprised of white males and these numbers are not changing. As the world is faced with more complex problems such as climate change and energy shortages, it is becoming increasingly important to have people with different ways of thinking working on developing innovative solutions to these problems. Engineering is narrowly limited in problem solving and problem framing due to the homogeneity of the people within our organizations and the resulting system that is at equilibrium. How can we change the engineering educational system so that it can be flexible and adaptable as an organization and made up of people with diverse perspectives, which is critical in being innovative? The proposed model with a foundation in the organizational and systems literature may be an important first step in understanding the depth and breadth of the diversity issue and in understanding our roles as educators and researchers in this very systemic problem.

There are some engineering schools that are graduating large percentages of underrepresented groups (Chubin & Babco, 2003). Interestingly, these minority serving institutions typically specialize, serving one underrepresented group. This may help increase the student-environment fit, thus operating at a state that is near equilibrium. How can we move from these homogeneous systems to heterogeneous systems? How do we encourage a move from the comfortable, static, equilibrium state? How do we move towards a non-equilibrium state thus encouraging adaptability and flexibility? Encouraging an environment that values multiple perspectives and encourages differences is a first step towards reaching this goal. As people within engineering education systems become more heterogeneous, more diverse people will be attracted to the environment and will thus change the environment to one that is better suited to cope with our rapidly changing society.

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