Engineering Education Reverse Engineering the Need for an Improved Disciplinary Design

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Abstract: *An academic foundation is crucial to the successful development of engineering education as a discipline, in that it not only provides academic recognition to this process but also creates a common understanding, logic and therefore goal about the direction of study that needs to take place. This paper discusses the importance of providing and academically legitimate foundation for the further development of engineering education (EE) as a discipline. In building this foundation the issues of appropriately categorizing EE, assigning a disciplinary type, is discussed. This is followed by an analysis of the complexities involved in the study of emergence of EE as a discipline and the rare academic opportunities this study presents for EE scholars. To complete a common understanding, in relation to a legitimate and academic foundation for further study of EE as a discipline, Paradigm theory is applied to EE as an initial tool and starting point for further development.*

Introduction

Technical engineers are enthusiastic, rigorous researchers and practitioners in the classroom context. Engineering education (EE) has previously been conceptualized as a practice driven knowledge community, however, to improve the application of education there needs to be a more developed academic and theoretical underpinning and structure to inform the practical. This paper suggests that despite the significant and valid research that is being conducted by engineers, the lack of a defined, formal, goal orientated and cohesive structure, the absence of a paradigm, is preventing engineering education from developing into a legitimate discipline. The impact this pre paradigmatic condition has on the teaching of engineering cannot be ignored. Valuable insights into education, developed by engineers, cannot be effectively disseminated or implemented to reform the engineering education system (EE) without a paradigm.

It must be acknowledged that a study of this academic magnitude can not be undertaken without an academically legitimate foundation. As a basic outline in creating an academically legitimate, this paper firstly defines the current organizational state of EE. This organizational definition is then elaborated upon by clarifying the complexities involved in studying an organization of this kind and

the necessary employment of qualitative research tools in doing so. With the initial level analytical areas clarified it is then viable to apply Paradigmatic theory to EE in its current state which will complete an academically legitimate foundation, logic and understanding on which further study into the evolution of an engineering education paradigm can be based.

What type of Organization is Engineering Education?

Engineering education has been referred to with the use of numerous and academically diverse terminologies; an emerging discipline (Haghighi, 2005), a field (Borrego, 2007) and a community (Lohmann, 2005). This diversity in an initial reference point to EE has also been recognized Borrego (2007) who states that there has been dialogue on how the organization of EE has been categorized but also acknowledges that this categorization needs to be explored further. The important point to emphasize is that these three terms; community, field and emerging discipline are academically disparate by definition which creates academic chaos when they are used concurrently referring to the same organization of EE. This disparity, therefore, needs to be explored and dissolved.

A brief analysis of these three terms or categorizations enables two of them to be deemed academically inappropriate and therefore eliminated from use in relation to EE in its current state. One way to begin analysing these three forms of organizations is to note that they are organizational components in the higher education system (Becher, 1989, p.19). It is then logical to label these organizational components 'disciplines' as opposed to organizations and observe their levels of disciplinary formality and which level of discipline, community, field or emerging discipline best describes the current state of EE. Furthermore, it is important to note that in the higher education system this categorization is crucial, "Whether or not a field [or community] may be said to be a discipline will affect the research effort, academic and professional definition and identity, policy making, and related investment, for example, in funding for university staffing and research (Harland et.al., 2004, p.731)." The appropriate categorization, leading to the appropriate steps in developing less formal types of disciplines into formal disciplines is crucial in the academic success of a particular area of study.

While a community is a necessary element of a formal discipline, it is the least formal disciplinary type. EE is stated as having an emerging global community which is supported by seminars, conferences, journals and workshops (***see attached sheet**). However, the use of the term community is ambiguous and proses the question; of a 'community of what?' In an academic setting the answer may be a community of scholars, knowledge or researchers. However, as engineering education scholars have assessed, the areas of scholarship and legitimate research leading to new knowledge are all in need of improvement (Streveler and Smith, 2006), EE more appropriately fulfils the requirements of a field; it crosses traditional academic boundaries, in this case the boundary between education and technical education (TE), it involves a form of scholarship that engages with professional practice and it generally lacks qualities displayed by a discipline such as theoretical development and academic coherence (Harland et.al., 2004, p.731). Yet it is possible for a field to reach a stage in its development when it can argue to be a discipline (Lowenstein, 2004; Myers, 2003). To achieve this stage a field must display disciplinary qualities, which fundamentally concern the development of a defined cohesive structure, or a paradigm to guide the academic endeavours. As a field EE must first of all fulfill the criteria associated with being a field before it can be an emergent discipline. Therefore a working order is presented in relation to developing engineering education from a field into a formal discipline.

Complexities and Opportunities in Emerging Discipline Studies

Within the engineering education knowledge community there is a growing group of scholars concerned with emerging discipline studies (Lohmann in Grose, 2006). Current research in this area is primarily focused on developing explicit, key structural and research criteria which relate to developing the discipline of EE. It is generally acknowledged by EE scholars that developing these

criteria will contribute to the evolution of an EE paradigm, the foremost and essential characteristic of a legitimate discipline. However, there is current disagreement over the appropriate theoretical grounding necessary for approaching this evolution.

The current debate compares and contrasts the paradigmatic theories of Fensham and Kuhn as approaches to paradigm development. It is interesting to note that Fensham and Kuhn are essentially presenting the same theoretical perspectives. It can be observed that the sociologically based perspective of Kuhn is the predecessor to that of Fensham and Kuhn is in fact the 'father' of paradigmatic theory. His work is more academically comprehensive, solid and legitimate. In contrast, Fensham has a more pragmatic, scientific approach and has broken down the theory of Kuhn to its simplest form. Fensham's theoretical approach is therefore more attractive, in terms of academically uncomplicated practical application, to the hard scientist who has had little need for grounding in the soft sciences. While Fensham makes an important contribution to paradigm studies in the science and technology disciplines, it must be considered whether his theoretical approach is comprehensive enough by itself to gain academic legitimacy and acclaim outside of the science and technical science (STS) disciplines.

When reflecting on the challenging nature of emerging discipline studies and the immense academic complexities involved in developing an explicit paradigm for engineering education it must also be acknowledged that emerging discipline studies of any kind are not grounded in any *one* academic discipline. It is too academically simplistic to approach the emergence of the EE discipline from the perspective of one scholar or from one academic discipline. Furthermore, EE emerging discipline studies will not gain academic recognition if research is carried out in this manner. It is fundamentally important that as scholars researching the emerging discipline of EE the goal is to inform disciplinary elements that are not yet fully developed. In the same way the study of emerging disciplines as a whole, of which that of EE is a part, is itself an emerging discipline.

Emerging discipline studies, inclusive of that of EE, are post modern fields of study as opposed to the study found in traditional university disciplines. Post modern disciplines and areas of study pursue knowledge without being constrained by the structure of single disciplines, subject matter, theories, methods or schools of thought (Mourad, 1997, p. 125). For example, in EE it is required that in forming a paradigm and ultimately a legitimate discipline researchers must find and culminate methodologies, subject matter and theories from a number of different established disciplines. Two of the obvious established disciplines are technical engineering and education. Likewise, emerging disciplines studies as a whole are still in the process of constructing, culminating and refining a set of academic tools, of which paradigm theory is of primary importance, that necessarily transcend established disciplines. Therefore, the product of post modern disciplines is the creation of a hybrid, dynamic *new* discipline, such as engineering education, that yields new concepts and offers new academic contributions to those already presented by traditional, established disciplines (Mourad, 1997, p.126).

The academically exciting and challenging aspect of the above discussion is that the modern university setting has provided a rapid increase in emerging disciplines, such as engineering education. This setting has, however, been characterized by a, "…shift from scholarship to teaching, where discipline matters less and the job role becomes increasingly similar to that of secondary school teachers (Becher and Trowler, 2001, p.16)." These emerging disciplines have risen predominantly in the hard sciences. The possible reason being that there is a larger academic gap between the soft science of education and the hard sciences, than vice versa, which calls for the emergence of new disciplines to deal with the educational side of the established, existing discipline. Whatever the reason for this rise in emerging disciplines, it has created the need for the practical application of generic emerging discipline theory. The most fundamental and academically proven initial step is to impose a paradigm externally in order to legitimize the emerging discipline (Kuhn, 1962). After this initial step, however, there are countless opportunities to contribute to the development and refinement of emerging discipline studies generic theory.

It is necessary that engineering education emerging discipline scholars recognize the potential in developing and externally enforcing a successful paradigm for EE, thus forming a legitimate discipline. This would involve both an original culmination of theory from inside and outside emerging discipline studies and the development of new theory which has been tried and tested on the EE case study, but is transferable for use in other emerging disciplines. The ground breaking nature of this research and the rare opportunity for academic recognition and acclaim adds to its initial importance of forming a cohesive, well structured and therefore effective discipline.

The Application of Paradigm Theory to EE

What is a Paradigm?

In simple terms a paradigm, in an explicit sense, means there is consensus about disciplinary elements such as research methodologies, what counts as useful or legitimate knowledge, the definition of appropriate problems, the use and development of distinct theories, concepts, pedagogies, terminologies and all the academic elements which differentiate one academic discipline from another. A paradigm, more specifically the theory it produces, is also an indicator of a legitimate, mature and scholarly discipline (Fensham, 2004, p.101). A paradigm provides the structure and agreement that is needed to function as a cohesive research field.

A paradigm can be divided into two main parts when discussing and defining its meaning. There is an explicit, or conscious, part to a paradigm which refers to the extent that a particular discipline, or an emergent discipline, has clear ways of defining, ordering and investigating knowledge, as has been discussed (del Favero, 2008). With the development and formalization of this explicit paradigmatic structure, which is typically visible and articulated in disciplinary textbooks or handbooks, comes the implicit part of the paradigm that is acquired through the practice of the explicit paradigm. It is this implicit, or unconscious, paradigm that prepares a student for membership in the particular scientific community with which he or she will later practice, by providing an unconscious set of core values that will guide the member (Kuhn, 1970, p.175). Therefore, the first of two important points in relation to an implicit paradigm is that it is responsible for transmitting knowledge that cannot be explicitly articulated such as beliefs, values, behaviour, academic etiquette and ethics relating to a particular discipline. It creates a distinctive disciplinary world and transmits a disciplinary culture which is equally as important in terms of success as the acquisition of technical knowledge (Polyani in Kuhn, 1970, p.44). The importance of the implicit part of a paradigm and the disciplinary culture and values it produces is that it creates requisites for membership in the academic discipline (Kuhn, 1970, p.168).

These requisites are learnt through the shared educational experience that members of a knowledge community undergo, where they absorb the same technical literature, language, techniques and culture. This common experience allows a knowledge community to perceive phenomena in the same way and allows the unanimity of their professional judgement on many disciplinary elements such a legitimate research problems, methodologies and contributions, disciplinary boundaries and even appropriate genres in which to present this research (Kuhn, 1970, p.182-193). Subsequently, the second important point to note on implicit paradigms is that without one, common perception is not possible and therefore consensus and cohesion within a discipline becomes hard to achieve. Therefore, both the explicit and implicit parts of a paradigm are essential in creating an effective discipline.

Why Does EE not have an Established Paradigm?

There is an obvious need for engineering education to be a dynamic field which adapts and responds to the increasing complexities of the engineering profession itself. EE has evolved out of the explicit need of engineers to develop curricula and educational practices that are directly related to the specificities of technical engineering disciplines. EE has emerged out of practical necessity rather than as a result of disciplinary specialization, which is a significant point in understanding the nature of engineering education.

An appropriate example of disciplinary specialization, as opposed to practical necessity, can be observed through the nineteenth century split between the incredibly influential theory of Hegelian

idealism, now philosophy, and the devotion to the scientific research of it, now psychology (Dirks, 1996, p.13). In this example it is conceivable to conclude that these two contemporary disciplines originated from a common and established paradigm. Their separation was due to a clearly defined methodological discrepancy. This discrepancy reconfigured their separate disciplinary identities and, over time, formed separate academic paradigms, although both philosophy and psychology were still originally constructed on the common Hegelian paradigm.

However, EE has emerged out of the needs of a fundamentally different discipline (technical engineering); it is a tool for the successful transmission of technical engineering knowledge. A tool that has become so essential to the success of TE that it is now widely considered an autonomous field of study and therefore an emerging discipline in its own right (Haghighi, 2005; Borrego, 2007).

The significance of the way in which EE has emerged, through necessity, is that there is no pre established paradigm. In fact, it is described as "pre paradigmatic" (Fourez in Silveria et al., 2007, p.1). As Borrego notes, "while scientific fields like physics, chemistry and some traditional engineering fields have seen paradigms come and go…the field of engineering education (if it can be considered a field) has not yet developed its first paradigm" (2007, p.1). There is much work still needed to lay the paradigmatic foundations for the emerging discipline of EE, the nature of which will necessarily transcend disciplines.

What Problems are caused by not having a Paradigm?

Del Favero states that pre paradigmatic fields are characterized by

> "…a high level of disagreement as to what constitutes new knowledge, what are appropriate methods for inquiry, what criteria are applied to determine acceptable findings, what theories are proven, and the importance of problems to study" (2008, p.2).

Kuhn remarks that in the pre paradigmatic stages of an emerging discipline, research is disparate and fragmented. Kuhn labels this "research" as fact-gathering as opposed to scholarly research (1962, p.15). It is characterized by an accumulation of non structured data, numerous partial solutions and seems to be very slow in the progress it makes (Kuhn in Mitra, 2000, p.6). However, Kuhn also recognizes that this complex and chaotic practice of fact gathering is essential to the emergence of a paradigm (in Nandi, 1996, p.2).

The "slow progress" that Kuhn refers to can be attributed to the point that, when a paradigm has been accepted and internalized by a knowledge community there is no longer a need to continually justify concepts and basically reconstruct the discipline anew in every piece of research (Kuhn, 1970, p.20). While the constant repetition of detailed background information which reconstructs the emerging discipline slows down disciplinary research progress, at the other end of the spectrum so too does a lack of consensus.

The most urgent problem arising from this pre paradigmatic lack of cohesion is that it becomes a gruelling task to gain consensus which is vital to the development of a paradigm and therefore legitimating a discipline. The task of consensus is made difficult by the fact that knowledge which is produced in this pre paradigmatic stage is ambiguous, not refined and therefore its meaning can be interpreted in many different ways. Its value to the field of knowledge thus appears to be dubious. Therefore, knowledge that is produced in pre paradigmatic emerging disciplines is not well grounded. The theory of Positivism, developed by Auguste Comte, supports the connection between the quality of knowledge that is produced by a discipline and the level of consensus that is achieved by it. Comte states that a well grounded knowledge forms the basis of consensus, and can also be applied to remove causes of disorder (Marshall, 1994, p.405). Consequently, producing rigorous knowledge is crucial to gaining consensus within an emerging discipline.

Ambiguity is also recognised by scholars from the newly emerging virtual reality branch of ICT. These scholars have commented that the lack of a clear paradigm "paints a confusing picture" where there is too much ambiguity for the diffusion of knowledge to the larger community to take place (Swann and Watts, 2002, p.51; Woolgar, 2002, p.59). Thus it is hard for knowledge to be disseminated, understood, debated and agreed upon, which slows down the development of the paradigm and the emergence and growth of the discipline.

How Does Paradigm Theory Relate to EE?

Pre paradigmatic characteristics contribute to general academic incoherence; the pre paradigmatic discipline does not function in a cohesive manner. Anthony Biglan (in Muffo and Langston, 1979), well known for his taxonomy of academic disciplines, recognises that disciplines with less-developed paradigms have low consensus of knowledge bases and modes of inquiry, and can therefore be viewed as less cohesive.

It is interesting that EE is not the only emerging discipline to experience difficulties surrounding paradigm development. A distinct lack of cohesion is also observed in other necessity driven emergent disciplines such as Nursing Education, Academic Planning, Public Relations and Business Succession Planning (Williams, 2004; Goldstein and Carmin, 2006; Hatherell and Bartlett, 2005; Ip and Jacobs, 2006). For this reason it should be considered that the historic disciplinary specialization that has formed the traditional academic structure of universities is, by nature, very different to the recent emergence of necessity driven fields, such as EE. Necessity driven fields have tended to focus on 'use-directed' research and have approached this research as practitioners rather than researchers (Borrego, 2007, p.2). This practical focus is given priority over paradigm development as it is the reason the emerging discipline is required in the first place. However, this does leave the necessity driven discipline open to academic incoherence, which then needs to be addressed in order for the emerging discipline to become legitimate and its research to become effective. More comparative research needs to be done on how paradigms have affected necessity driven disciplines, as their difference impacts on the methods of inquiry used to study them.

In the context of Engineering Education, this incoherence can be viewed from inconsistencies in terminologies and language through to a lack of foundational knowledge categorizations which order intellectual property. Radcliffe (2006, p.1). requests the definition of consensus on methods of inquiry in EE, which are currently incongruent Haghighi (2005, p1) alerts us to various questions which aim to build a coherent research agenda, as EE is currently disparate in terms of its academic focus and priorities. He also argues that as Engineering educationalists we need to begin producing distinct disciplinary knowledge, concepts and theories (2005, p.1). This has not taken place yet. A lack of scholarship has been acknowledged by scholars such as Streveler (2006), Borrego (2007), Smith (2006) and Haghighi (2005) who have all attempted to define a more rigorous research tradition in EE. The lack of a paradigm, which provides an overarching research structure, has also meant that research findings have remained context specific studies. They have produced context specific 'facts' that cannot translate into new, generic theories which will advance the engineering education system as a whole. Instead, there tends to be many questions posed with no answers, numerous research findings with no way to structure them and solutions that are not entirely academically convincing (Kuhn in Mitra, 2000, p.6). Subsequently engineering education research has produced few answers to fundamental questions (Grose, 2006, p.1).

Essentially a strong paradigm allows the progression of scholarly research to take place, which leads to the development of discipline specific theories and concepts. It enables the emergent discipline to develop a body of knowledge that is distinct to any other discipline thus legitimizing the need to be a separate discipline in the first place. In the case of engineering education, a paradigm would prove why it should be considered as an autonomous discipline rather than a sub discipline of technical engineering, a separate discipline to 'pure' education and more specialized than the generic science education.

It becomes evident that. While the challenges to EE in the classroom context, which were discussed in the beginning of this paper, are important, it is essential that priority is given to research surrounding the development of an EE paradigm. Without a paradigm, EE will continue to suffer from the pre paradigmatic conditions of a lack of cohesion, difficult dissemination of knowledge, research which lacks academic rigor and direction, and therefore a slow and stunted development into a legitimate discipline. As Fortenberry notes, "A cohesive Engineering Education research community would better be able to raise awareness of educational reform issues, and push for the implementation of the solution (2006, p.4)." It must be acknowledged that these problems are not independent of each other. They are all the result of not having a paradigm, and would be amended with the development of one.

Conclusion

This paper has used a qualitative style of research to provide an academically legitimate foundation for the advancement of engineering education as an academic field. It has been established that in its current state EE is best categorized as a field within the university setting. The criteria of a field should therefore be developed before moving towards emerging discipline status and the necessary criteria for doing so. Te study of EE as a field, the complexities and opportunities were also discussed and EE was situated within emerging disciple studies. Lastly paradigm theory was applied to the field of EE to provide a common understanding and foundation.

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