The innovation—cognitive science interface: Implications for engineering and technology education

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1 Introduction

The intent of this paper is to highlight the construct of Technological Innovation[1,2] and its significance to modern developed and emerging economies. Examination of this construct in the context of university engineering and technology department responsibilities to develop graduates with increased inclination for, and capability with, technological innovation has led the authors to explore the potential of cognitive science in helping us achieve this goal.

2 Technological Innovation and its Significance

Leaders around the world have come to recognize the importance of innovation to the economic well-being, and the quality of life. Furthermore, as evidenced by the establishment of thousands of centers[3] working to advance innovation for a variety of purposes, universities, regional governments and corporations have also recognized the innovation imperative. Among the most frequently addressed purposes for innovation-focused initiatives are economic development, workforce development, quality improvement, efficiency and sustainability enhancement and technology advancement. Quality of life and competitiveness are both frequently cited as chief motivators. It is critical to note that this is not just a North American phenomenon – it is occurring across the world and in both well developed and

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developing nations. Analysis of innovation oriented activity revealed a spectrum of activity including creativity, invention, research, development, commercialization, and entrepreneurship.

In the USA, the National Academies' Committee on Comparative Innovation Policy, President Obama, Business and industry's Task Force on American innovation, an alliance of America's leading companies, research universities, and scientific societies, all have pointed to innovation as being the prime way forward out of the current economic morass. Governments; local, regional, and national; have pinned their hopes on innovation as a way towards prosperity. One outgrowth of such concerted attention was the enactment of the America Competes Act in August of 2010.

University engineering and technology programs have a critically important role in developing professionals with substantial technological understanding and capability. Fortunately they have established a solid record of performance in doing so as is evidenced by TAC (now ETAC) ABET's criteria and list of accredited programs. But, is this sufficient? How is our profession addressing and inculcating innovation?

A proposed cognitive science-based model of the individual who actually generates the innovation will be presented and extrapolated to identify imperative changes needed if our departments are to graduate students with a higher capacity and propensity to engage in technological innovation.

The opportunity to capitalize on diversity in the student body is an additional factor contributing to the significance of innovation as a major focus for university level engineering and technology education programs. More specifically, since a breadth of experience and perspective enhances the likelihood of creative/innovative input for consideration when engaging in technological problem solving/innovation the augmented range of such input provided by a diverse student body becomes important to enhancing innovation. Furthermore, this enhanced input itself becomes an object lesson that demonstrates the value of diversity to our students.

3 Critiques of Engineering /Technology Education

Engineering and Technology Education has, in the USA at least, been subjected to a spate of criticisms[4] as the country noted its economic downturn and the closing of the science and technology gap from other nations. Clearly in the USA, there has been considerable discussion about the quality and nature of its engineering and technology education and efforts to envision a way forward are underway[4, 5, 6]. Just recently, in fact, Bement, Dutta, and Patil (2015), working under the auspices of the National Academy of Engineering, have released a book entitled *Educate to Innovate: Factors That Influence Innovation: Based on Input from Innovators and Stakeholders*[7].

4 University Approaches to Innovation

Typically universities have tripartite missions that involve teaching, research and service vectors of activity. Often other terms are used; such as learning, knowledge development, and engagement; to refer to these missions. Certainly universities vary in the degree of relative emphasis they place on these activities but in general universities seem to have employed a relatively small number of strategies to address innovation and even fewer to address technological innovation. The following two subsections will overview traditional and newer approaches to innovation employed by universities.

4.1 Traditional Approaches

The primary university response to address technological innovation has occurred in the engagement mission and it involved the establishment of research parks and incubators. More recently the concept of entrepreneurship has risen to prominence and this led to the establishment of increasing numbers of programs that are best classified as part of the teaching and learning mission of the university. More often than not, however, such programs have been minors or certificate focused – a lesser number of outright majors are offered.

In the teaching/learning arena, innovation as a specific topic seems rarely taught – at least using the proxy measure of undergraduate or graduate program course titles with an explicit mention of innovation. However, it is clear from the readily observed trend of having more capstone, design, pbl and similar activities incorporated in the curriculum – at least in US universities that at least more innovation oriented activities are occurring even if not by specifically innovation named courses.

Arguably the least prevalent addressing of innovation has occurred in university research activity. In making this point, note, the authors make a distinction between entrepreneurially focused research and research focused specifically on the process of innovation and/or technological innovation.

4.2 Newer Approaches

With respect to the university mission of engagement, the authors believe that they have observed a gradual shift in university approaches to innovation. These institutions have greatly increased their flexibility in how they are prepared to interact with the private sector and also with their own faculty and students with an innovative idea. More liberal attitudes towards IP ownership, profit sharing, and types of partnerships with the private and public sectors also seem to be in evidence.

Arguably, some might also claim that there has been a significant shift towards the teaching of entrepreneurship and innovation. While this paper's authors would certainly agree with the former we would take issue with the latter and would even claim almost a total absence of programs with technological innovation as their primary focus. A few notable exceptions that do target innovation and perhaps even technological innovation are observable. Among them are the Bachelor of Innovation offered by the University of Colorado at Colorado Springs[8] Colorado, the Bachelor of Innovation and Entrepreneurship at the University of Adelaide in Australia, the Bachelor of Design and Technology Innovation at Flinders University in Australia, Arizona State University's Bachelor of Technological Entrepreneurship and Management, the Bachelor Programme in Technology Innovation and Entrepreneurship at Norway's Østfold University College and the d.School of Stanford University.

Unfortunately, and with the exception of entrepreneurially focused research and innovation research focused on economic development, the actual profile of university research focusing on the process of innovation and or technological innovation is nascent at best. If all innovation, technological or otherwise, occurs first in a person's mind or arises out of the collective interaction of a small group of individuals, then research into this phenomena is minimal or at the very least so scattered across the disciplinary fields of the universities that no evidence of critical mass or coalescence seems visible.

Perhaps the primary optimistic light in this otherwise bleak landscape might be the growing body of research activity, both nationally and around the globe, addressing the process of design thinking[9]. To the extent that these initiatives address technology and how the individual thinks about it as they design new artifacts, procedures, and generate solutions to problems, such research is directly aligned with the point of this paper. For example, Beckman and Barry in Innovation as a Learning Process: Embedding Design Thinking[10] cited, in Figure 1, Owen's depiction of building and using knowledge by designers provides useful guidance to researchers seeking to apply cognitive science to design and innovation processes.

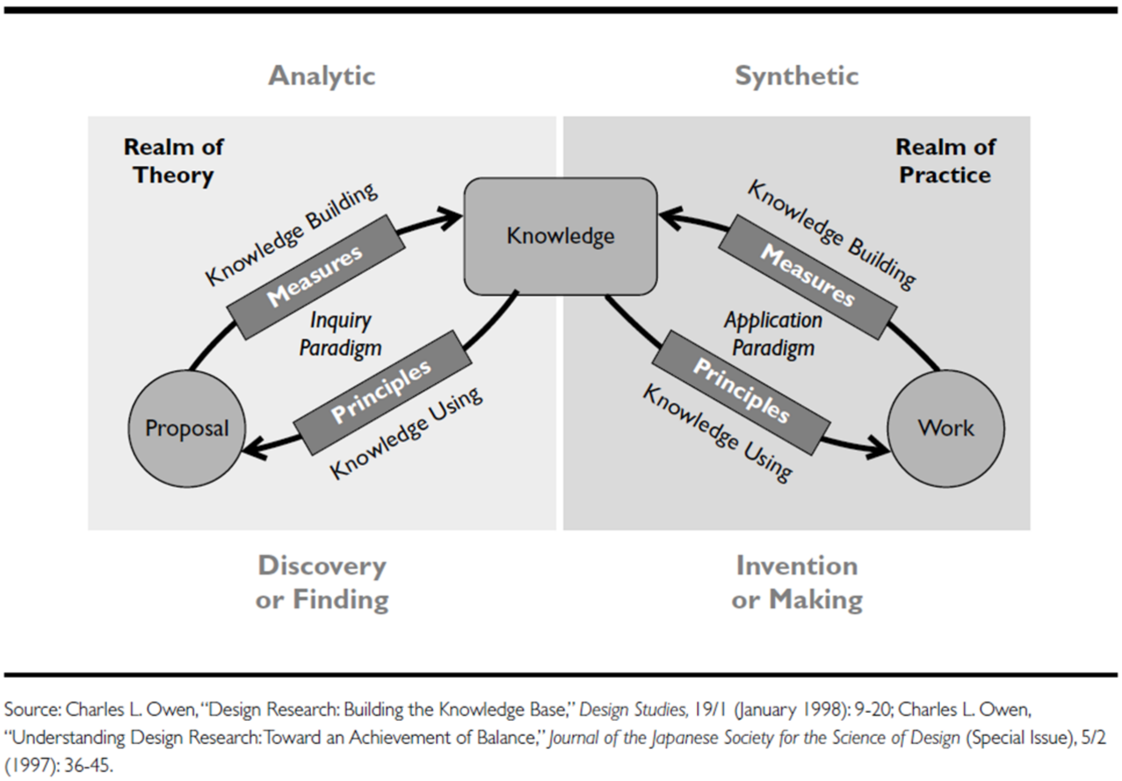

Fig. 1. Potential framework for guiding innovation research

4.3 A problem remains

But, the authors would claim that there is too little actual research occurring with the focus on the process of technological innovation or even simply the process of innovation in any of its variants. Furthermore, the bulk of what the authors have seen is driven by an education perspective and situated primarily in the K-12 STEM education context. Now with at least Purdue University and Virginia Tech (Virginia Polytechnic Institute and State University) offering strong engineering education programs there are increased research reports about university level engineering and STEM education. But, this paper's authors would claim that the majority of these studies have employed an education or educational psychology perspective and not enough of attention has been paid to cognitive science and how it and its methodologies might further our understanding of who innovates, why, and how they go about it.

5 The Cognitive Science-Engineering/Technology Education Interface

Figure 2 below was generated by one of the authors of this paper in the attempt to provoke his thinking about how cognitive science and innovation might interface.

Augmented by participation in an invitational conference of innovation – while this model depicts formal and informal learning and the results thereof, the latter structured using the conventional three domains of learning outcomes, and it includes personality characteristics, it is totally lacking in terms of depicting the key processes involved, i.e., the heart of cognitive science.

Essentially cognitive science is the study of the mind, how it/we process information and/or stimuli, i.e., think, transform it, store and retain it, perceive it, reason, emote, and otherwise employ cognitive functions for a variety of purposes. For the purposes of this paper, our interest is how these topics affect not only our proclivity to innovate but also our capability to do so. In essence we are asking why do innovators see new patterns or connections or possibilities that others did not? Why are they able to solve problems in ways that were not visible to others? How do they do it?

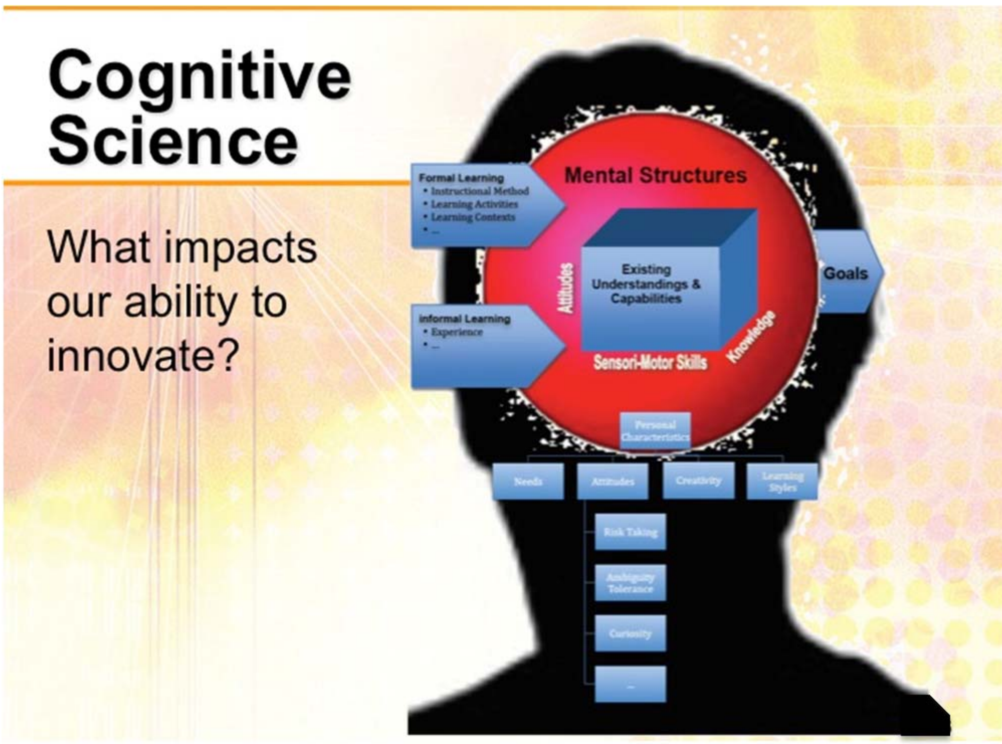

Fig. 2. Initial model for the locus of innovation

Perhaps the rise to prominence, during the last two decades, of the constructivist view of learning as an activity has prompted the authors to consider the process of learning as a significant variable in enhancing the innovativeness of our students. Even more so, the incredible permeation of digital information technologies into almost every facet of most of our lives prompts the question of how this affects our innovativeness. For example, no less significant an agency than the National Academy's Keck Future Initiative[11] has investigated this topic and stated:

> …as humans continue to venture into the digital frontier, it remains to be known whether access to seemingly unlimited information is actually helping us learn and solve complex problems, or ultimately creating more difficulty and confusion for individuals and societies by offering content overload that is not always meaningful.

6 Implications of the Interface

At this point the authors wish to advance a set of possible implications derived from the interface between innovation and cognitive science. Finally, and most importantly, the authors conclude by detailing a set of research-grounded[12, 13] implications of cognitive science for the practice of engineering and technology education at the university level.

6.1 For Practice

Consider the multiplicity of initiatives/activities to which the appellation of innovation has been applied. How might we making sense of the complexity? We encourage readers to think of innovation not as any single process but rather as a system and continuum, as shown in Figure 3, beginning with a creative insight and, if successful, evolving into a viable product or service. This continuum of activities occurs within a context that feeds inputs to the continuum and that receives its outputs. This context influences the innovation process significantly in terms of how the innovator thinks and what they think about/consider.

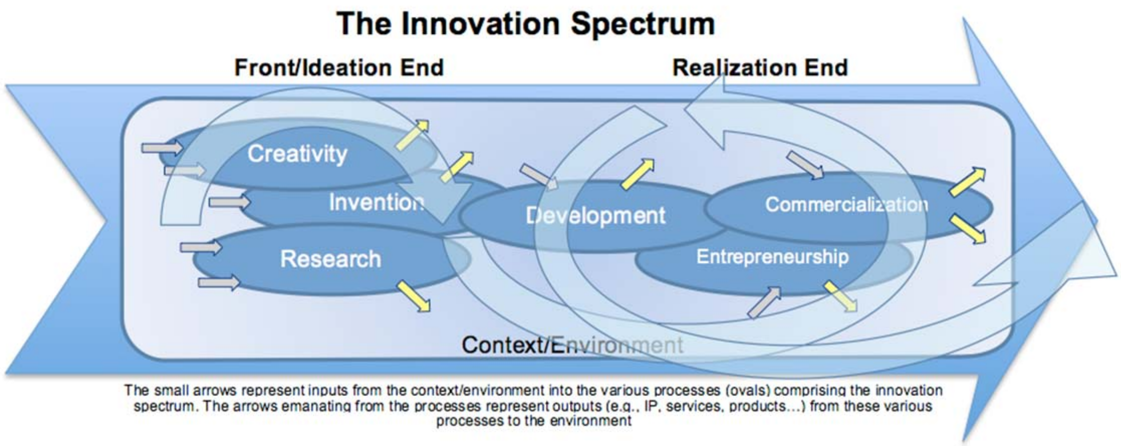

Fig. 3. The innovation continuum

The innovation spectrum depicted in Figure 3 highlights three phases of activity: (1) Ideation (involving creativity, invention, and research), (2) Development (involving refinement of an invention/innovation), and (3) Realization (involving commercial-ization and entrepreneurship). Additionally, it should be noted that this entire spectrum of activity occurs within an environment and therefore there are characteristic interactions of each phase with this environment. Engineering and technology education programs would be well advised to consider the potential of each of these phases and interactions for student learning activities. For example, the following constitute a sample of effective practice furthering our students' propensity for, and capability with, technological innovation:

Phase 1 Ideation: In an introductory freshman class using creative brainstorming of how technological problems are addressed differently in various regions of the world.

Phase 2 Development: Implementing a vertically integrated capstone project that teams students from each year of the baccalaureate program on an industry-based problem. Senior students mentor junior ones to develop advanced skills.

Phase 3 Realization: Students work with entrepreneurs, for example in the university's technology park or incubator, in implementing an innovation.

Interaction with Context:

- Students conduct a needs assessment to identify unmet societal needs in their community.
- Implementing EPICS[14] (Engineering Projects In Community Service) to address the identified need.
- Crowd sourcing and funding the implementation of a solution to the EPICs-identified need.

The practice of each of the activities along the continuum should be targeted for careful systematic research if we are to build a knowledge base of how our mind engages with or actually performs research, invention, creation, development, commercialization, and entrepreneurship. Similarly how do we consider environmental/contextual factors differently during each activity along the innovation continuum? What mental processes are involved and to what extent are we metacognitively aware of them? Then, once a critical mass of converging knowledge is assembled about what goes on at each activity, we might evolve a set of action research initiatives that would apply these to enhance the effectiveness of how we develop/advance the pertinent capabilities of those who come to learn from us. These insights might very well enable better performance as we engage in technology forecasting, technological horizon scanning, technology roadmapping, and technology SWOT analyses. This might well become the path to a more robust and sustainable future[15].

6.2 For Research

Shifting perspective from research focused on practice, the authors also want to highlight the importance on research on the actual substance and variants of innovation. We would hope for the evolving of a framework for research on innovation as a subject, i.e., engineering and technology researchers need to establish what kinds of innovation there are and where and when to best employ them. In essence we need a taxonomy that unifies our conversation about innovation and that provides the consistency and replicability that is at the core of every discipline. We need to be able define, open innovation, invention, what makes something innovative, measures of innovation, technology transfer and more.

7 Summary

This paper presented the construct of technological innovation and then overlaid it onto today’s context of significant challenges and in particular the sense that our engineering and technology education systems are not as effective as we deem necessary. A brief overview of traditional and newer approaches to addressing innovation by our universities was then shared but so was the conclusion that there remained a considerable shortfall in both practice and research. The potential of employing the perspectives and methodologies of cognitive science was then posited and at least some of the implications thereof were highlighted. Much work, however, remains to further explore and detail the latter.

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