Re-engineering Education: Deconstructing the barriers to disruptive innovation

J. Somasundaram* and M.G. Rasul
School of Engineering and Technology, Central Queensland University
Rockhampton, Queensland 4702, Australia
**Corresponding author's email:* somas@bigpond.com

Introduction

The Nature of Scientific Revolutions

Paradigm changing discoveries in the physical sciences beginning in the sixteenth century fuelled the rapid advancement of the physical sciences (Kuhn, 1962, 1970). Engineering in turn applied these advances to create the industrial revolutions. Yet, these same revolutions had unplanned side-effects that have created major, complex, seemingly intractable problems such as climate change, obesity, unsustainable growth, interpersonal violence - wicked (Australian Public Service Commission, 2012) problems.

The success of the physical sciences both developed and imprinted (Marquis & Tilcsik, 2013) the reductionist methods of the physical sciences is psyche of the society. The human sciences (University of Oxford, 2017) – the sciences of how humans and human groups work – have proved resistant to reductionist methods[i].

The human sciences are now maturing to the point of delivering their own paradigm shifts (Somasundaram, 2018; Somasundaram, Rasul, & Danaher, 2019). Engineering, with its expertise in the application of science, is well placed to lead the creation of the social revolutions.

Yet, to paraphrase Max Planck, "Science advances one funeral at a time"[ii], an observation confirmed by empirical testing (Azoulay, Fons-Rosen, & Graff Zivin, 2019; Azoulay et al., 2015). Both humans and human institutions are resistant to acting on the implications of these paradigm shifts: resistant to disruptive innovation.

Research objective

The theme of this conference is *Educators Becoming Agents of Change: Innovate, integrate, Motivate*. It is important for change agents to understand the barriers to change. If humanity is to fully and rapidly adopt paradigm shifting developments in the human sciences, then understanding the barriers to such change is important. Clayton Christensen (1997, 2013) popularised the phrase *disruptive innovation* through the exploration of institutional resistance to paradigm shifting technology. This paper identified underlying (neurobiological) systems that cause such resistance at the individual human level. A resistance, which as Planck noted, exists even among scholars.

Contribution

This paper contributes to the conference on change and innovation by exploring emerging discoveries the human sciences that may explain resistance to paradigm changing ideas. This paper also contributes to the discipline of engineering by suggesting that it is well placed to lead a revolution that applies the human sciences.

Theoretical Paradigm

Framework

We adapt Crotty's (1998) four level framework for specifying the theoretical framework of social science research. These are (1) an epistemology, (2) a theoretical approach, (3) a methodology, and (4) methods. To this, we add a section on limitations. As scholars, we need to be open to new paradigms but also sceptical. We include this section early in the paper so that readers can consider (our assessment of) the limitations as they read the paper.

Epistemology: Institutional Logics

Institutional Logics is a meta theory originating from sociology and organisational studies. It is perhaps best understood by its' definition of a Logic *the socially constructed, historical patterns of cultural symbols and material practices, including assumptions, values, and beliefs, by which individuals and organizations provide meaning to their daily activity, organize time and space, and reproduce their lives and experiences (Thornton, Ocasio & Lounsbury, 2012, p2)*.

A Logic is conceptually the same as a paradigm, and we use both interchangeably. As an epistemology, our perspective is that logics are deeply embedded in the psyche of both individuals and institutions. Recognising that multiple logics exist in both individuals and institutions, we are better placed to view the interplay between logics more objectively, minimising the biases caused by considering one superior to another.

Logics may be complementary or conflicting. Institutions need to maintain coherence and harmony, and typically deal with conflicting logics (such as when paradigm shifts occur) by (i) decoupling; (ii) rituals of confidence and good faith; and/or (iii) a taboo of Inspection (Thornton et al., 2012, p23).

Theoretical Approach: Innovation as Applied Science

We approach innovation as an application of the sciences, both the physical sciences and the human sciences. Engineering is arguably the most mature of the applied sciences. While engineering undoubtedly originally focused only on the application of the physical sciences, there is now increasing recognition of the importance of the human sciences[iii].

Methodology: Scholarship of Integration

In his influential treatise, *Scholarship Reconsidered: Priorities of the Professoriate', Ernst Boyer (1990) divided the responsibilities of the academic profession into four: the scholarships of Discovery; Integration; Application; and Teaching*. The scholarship of discovery typically applies reductionist methods to establish isolated, interesting facts. In contrast, the scholarship of integration is to *… give meaning to isolated facts, putting them in perspective. By integration, we mean making connections across the disciplines, placing the specialties in larger context, illuminating data in a revealing way, often educating non-specialists, too (Ibid, p18).*

While engineering is usually classified as a scholarship of application, engineering has typically integrated as well. Not only the integration of the traditional physical sciences of physics and chemistry, but application requires the integrated application of disciplines such as economics and management science. Current synonyms (with subtle differences (Somasundaram, Howard, & Reed, 2016)) include multidisciplinary and trans-disciplinary studies, and translational medicine.

Methods: Environmental Scanning and Triangulation

Ancient hunters had scouts and ships had crow's nests to scan the environment. The term environmental scanning grew from the explicit use of these tactics in the discipline of Futures Studies (Gordon & Glenn, 2009).

Triangulation has traditionally been a method used in navigation and the social sciences for getting a more accurate and reliable assessment of an object of interest (Carter, Bryant-Lukosius, DiCenso, Blythe, & Neville, 2014). While our use of triangulation also serves the purpose of improving the reliability of the object of interest, triangulation is a core tactic for integration. We use triangulation like a spider shooting strands to build a solid web, to anchor with and build bridges between different disciplines. While traditional reductive methods are perhaps analogous to the anchoring of buildings with solid foundations, integrationist methods are comparable to building cities in space

Limitations

We instinctively seek patterns. Spotting the leopard in the dappled forest is an essential primitive life-skill. Patterns, paradigms, logics, models, are all integrations of discrete elements to create a bigger abstraction – of gazing at the stars and creating constellations. Box warns us that *all models are wrong but some models are useful* (Box, 1979, p2). Constellations gave us navigation, and astrology led to astronomy. Contrasting paradigms should perhaps be approached not as replacements but as alternative tools in a toolbox. Like light as both particles and waves. We are certainly not suggesting that the reductive methods should be retired.

This paper integrates multiple paradigms, some of which may not be familiar to some readers. Reductionist research in a familiar paradigm can be done with limited space. Furthermore, the linear characteristic of writing aligns (cf. s2.2.1) itself to the reductionist method. We have sought to provide a more holistic approach by using endnotes, and numbered paragraphs to reference back to linked concepts.

We suggest three underlying physiological characteristics as possible causes of our reluctance to apply disruptive paradigms. As investigators of genetic causes of disease have found, in human systems, effects are often the product of multiple causes, each weak, but having a synergistic result. Furthermore, not only are these basic sciences rapidly evolving but the reductive and integrative methods used to examine them are also rapidly evolving.

The nervous system and the endocrine system are our principal control systems[iv]. They are not simply integrated but enmeshed in positive and negative causal loops that are difficult to untangle.

Three physiological characteristics that are likely to be barriers to paradigm shifts

The storage of knowledge

The brain achieves the long-term storage of knowledge by physical changes to itself, via a technique called neuroplasticity – the strengthening of synapses that correspond to that memory. Furthermore, memories are not necessarily stored in a single location. Knowledge and paradigms that have been reinforced over time will be strongly wired in multiple locations.

It is extremely difficult, therefore, to unlearn deeply learned paradigms. It is not like deliberately flicking a single switch in a railway network to cut off a path that is no longer needed. Rather, the sub-net needs to naturally decay with time.

The Dominance hierarchy

Dominance hierarchies are prevalent in social animals – including humans - with distinct neural networks for the recognition and experience of hierarchy (Chiao, 2010). Each gender maintains its own hierarchy. When humans are placed in single gender groups, the male group establishes hierarchy faster than females (Mast, 2002).

We tend to avoid discussions about the dominance hierarchy. This is probably because it conflicts with egalitarianism, a major logic in modern western society (s. We use And as typical in dealing with conflicting logics. Nevertheless, hierarchical behaviour is ubiquitous and often subliminal (Pratto & Shih, 2000).

Academic institutions are hierarchical. Even an external observer notices the distinct ceremonial robes and rules of precedence during an academic procession. Academic hierarchy is based, not on physical power and social connections, but on scholarly contribution and reputation. Paradigm shifts are deeply disruptive to the existing knowledge structure of the discipline, and by extension to those who have aligned themselves to that structure. Paradigm shifts are threatening to the existing dominance hierarchy of the academic community.

Two modes of thinking

The brain has two principal pathways for thinking, which Daniel Kahneman characterised as thinking fast and slow ((Kahneman, 2011). The former uses areas of the brain called the Default Mode Network (DMN) and the latter uses areas such as the prefrontal cortex called the Task Positive network (TPN) (Fox et al., 2005). The former is associated with intuition and daydreaming while the latter is associated with rational and rigorous thought (Evans, 2008; Evans & Stanovich, 2013). Western philosophy and culture has tended laud the latter, ‘rational’ mind, and disparage the former, ‘intuitive’ thinking (McGilchrist, 2012).

Oakley (an engineer and polymath) and Sejnowski (a computational neuroscientist), treat the modes as distinct tool, which we can use for different purposes. (Their on-line course, ‘Learning How to Learn’ is currently the world’s most popular course.) They give the example of Thomas Edison who would sit holding a steel ball over a metal plate, and doze as a way of tricky problem. The DMN, which has now been associated with creativity, is active as one is falling asleep. As Edison’s hand muscles loosen, the sound of the ball hitting the plate wake’s him, and the DMN may have solved the problem. Salvadore Dali used a similar technique (Oakley & Sejnowski, 2014).

The DMN is good at rapidly connecting multiple different neural pathways. This allows complex decision-making. However, the multiple factors influencing the decision are unlikely to be fully and logically reasoned and weighted. The mind will be influenced by deeply wired paradigms, even when it knows they are wrong. Decisions that cause status disruption and social turmoil will be avoided.

Conclusion

To be successful agents of change, we need to be able to overcome the barriers to change. Engineers are applied scientists, and in this paper, we suggest that our resistance to paradigm change may be linked to underlying neurobiological control subsystems. Engineering has a role in understanding and applying the science.

Even more important, our students, the engineers of the future need to understand the science fuelling the human revolution. They may not directly work on the likes of the Big Blue Project (L'Ecole Polytechnique Fédérale de Lausanne, nd), but understanding human behaviour is critical to the success of any project.

Universities originally resisted the paradigm shifts that led to the industrial revolution, continuing to teach the traditional disciplines of grammar, rhetoric, dialectic, music, arithmetic, geometry and astronomy (Enders, 2006; Perkin, 2006). It took the Humboldtian paradigm that reset higher education to meet the needs of an industrial society. The human sciences are maturing rapidly. New paradigms beckon. And just as with the industrial revolution, engineers can lead us into this brave new world.

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Endnotes:

[i] Postmodernism and qualitative methods have grown to overcome this resistance.
[ii] Planck's exact words were "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it" (Planck, 1949, p33-34). Research that set out to test Planck's observation have found that that at the demise of a leading scholar, papers with contrasting perspectives increase (Azoulay, Fons-Rosen, & Zivin, 2015).
[iii] For example, subjects that explicitly seek to teach interpersonal skills.
[iv] Engineers are comfortable with the word control and appreciate its substantial body of technical literature. Many lay-people, however, are resistant to the word control, perhaps a fear of a loss of autonomy. The term influence systems may be more appropriate – these systems are stochastic rather than deterministic.