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The Human Challenge in Engineering Design*

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The fundamental need for engineering in the new century is to acknowledge and embrace the human nature of its endeavor. This paper describes a spectrum of humane concerns beginning with straightforward design issues and escalating to philosophical assumptions about the nature of man. It is my contention that engineering must either enthusiastically incorporate a broad view of humane concern, or make room for a profession that will.

HUMAN BEHAVIOUR AND ENGINEERING DESIGN

It wasn't long ago that engineering could treat humans as servomechanisms with statistically distributed dimensions and questionable reliability. Times have changed. The last two decades of the twentieth century have seen remarkable changes in geopolitics, economics, technology, science, biology, and even philosophy suggests that the engineering profession should take people far more seriously.

What happened? To begin with, the Berlin wall came down, reversing the Sputnik-era engineering emphasis on large aerospace and military systems. Economic rivalry became more important than military competition. Companies downsized and increased work loads on employees. Design of consumer, office and health products moved from the periphery of engineering concern, much closer to the center. These same geopolitical changes also enabled the globalization of free enterprise economics. Product design and manufacturing have both quickly become international activities.

Changes in technology in the same period have transformed the nature of products themselves. Prior to the 1980s, consumer products in the United States were on a relatively stable plateau. Automobiles, household and office appliances, telephones and TVs were mature and changed little over time. While this was true, and Taylorism held sway, it was possible to have the utility of a product designed by an engineer, the form created by an industrial designer, and the means for production conceived by a manufacturing engineer. Because products were stable, only evolutionary changes were required. Marketing departments could use statistical means to locate opportunities for refinement with some confidence that changes would be successful.

Digital technology upset this apple cart. The fundamental nature of products has changed, as have the means by which they are realized. Where engineering design used to be primarily concerned with the delivery of straightforward mechanical utility, today it must contend with utility that is complex and which unfolds over time. As a result, designers are now designing behaviors and experiences for people, not just artifacts. This means that the engineer's role has become quite entangled with the form-giving role that traditionally belonged to THE industrial designer.

> *1. Engineers must understand that when they design products for human use, they are designing behaviors and experiences for users as well as providing functional utility. How can engineers be made aware of the issues involved in designing behavior, as well as hardware?*

The conception and realization of products is no longer neatly divisible into a sequential progression of professional concern. Decisions are enmeshed and intertwined. The proliferation of computer aids to communication and design have compressed the development cycle to the point where concurrent interdisciplinary design is an absolute necessity. Even more challenging, technological possibility is evolving so quickly that traditional marketing techniques are unable to anticipate what should be done next. Engineers are routinely being turned to for initial product concepts.

The net result of these changes is that engineering can be involved in the entire process of product creation to the full extent of its appetite to do so. This is the question: How big is the appetite? To be effective in the overall process, understanding people has to become as important as applying technical knowledge and technique. Product utilities are so complex that the user must be

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constantly considered as a fundamental reference for decisions. This requires lateral thinking across a wide range of manufacturing and end-user processes. Lateral interdisciplinary integration is the current reality. When compared to engineering education, there is an increasing misfit between what engineers are taught, and what they need to know in order to perform as leaders in practice.

2. Engineers must understand the interdisciplinary nature of design, and possess the people skills necessary to serve effectively on interdisciplinary teams. How can engineering education encourage an understanding of human nature that allows graduates to both create better products and to work effectively with diverse individuals?

Successful products require the presence of three things: utility, usability and meaning. The design of utility is well understood by engineers. While analysis is still more valued in universities, design process and creative problem solving are increasingly well taught. Usability involves the interaction between product and user. Problems here occur when people are asked to adapt to hardware rather than visa versa. Viewing products from a user's perspective requires a shift in values that can be hard for engineers. Nevertheless, usability and consumer testing are beginning to receive increasing attention in engineering education. Awareness of the third product requirement, meaning, is largely lacking. Meaning-making requires sensitivity to cultural and social differences, including the views of other cultures and minorities. It requires listening to, and valuing, the stories that people tell about their lives. Little in most engineer's education, dominated by engineering analysis, equips them to seriously consider, value, or be sensitive to such concerns. Indeed, it may be argued that the 'McLuhan message' in the medium of engineering education itself argues against taking people and culture seriously as factors in design.

Some may assume that exposure to excellent humanities courses will somehow equip the engineer in this regard, and also provide the moral foundation to make wise and ethical decisions. However most campuses have a strong techie/fuzzy split that encourages little knowledge transfer between the two domains. Engineering faculty know how little carries over between related technical classes – they should be able to easily imagine how little carries over from humanities courses. This is particularly true when there is no reference made to these subjects. Meaning certainly hasn't made it into any course syllabi I have seen. In fact, engineering itself is largely taught as if it had no overall meaning.

3. Engineers must be able to understand products at the level of meaning. How can engineers be educated to exhibit cultural sensitivity and to appreciate and value the significance of their own work?

Roger Sperry's Nobel Prize-winning work with epileptic patients began a remarkable period of growth of knowledge about the brain that continues unabated today. Since then, over 20,000 scientific articles have been published on the subject of Right/Left hemisphere specialization alone [1]. We now have a good understanding of the complementary nature of neocortex brain functioning. Our left-brain processes sequential information, while our right handles simultaneous information. Language and logic are thus processed in the left hemisphere, and creative big-picture imagery is generated in the right. In this way we are marvelously equipped with the ability to think analytically and comprehend the gestalt. Both functions are necessary to do anything well. As I write this paragraph I must find and record individual words one at a time (LB) while simultaneously being aware of the overall message I wish to communicate (RB). And before this I had to generate the various forms this discussion could take (RB) and choose which strategy I would use (LB). Unfortunately, schools stress the verbal, mathematical and logical skills of the left brain, and discourage the perceptive, intuitive, and comprehensive skills of the right. The result is a homolateral, unintegrated way of viewing the world that reinforces a tendency to focus on disconnected mechanical process at the expense of overall meaning.

4. Engineers must be able to integrate both analysis and meaning making in their work. How can engineering students be taught to become ambidextrous thinkers, that is, to effectively use both right and left brain skills in their creative process?

Productive thinking has been found to involve more than integrating right- and left-brain functioning. Paul McLean's triune brain theory tells us that our forebrain is unable to function unless the survival needs of our reptilian brain are satisfied. We must feel safe in order for our 'newer' frontal lobes to come into effective use. The role that the limbic system plays in long term memory is also now better understood. All long-term learning takes place in an emotional context. When knowledge is retrieved, we also access the emotional state that existed at the time of learning. If we learned facts or procedures during conditions of fear or anger, we become afraid or mad when we recall them. This is literally true – our body will secrete the same hormones, and we will manifest the same state in our entire body, be it pleasure or pain, joy or sadness.

In times of rapid change, technical knowledge has an increasingly short half life. For this and other reasons, everyone agrees design engineers must be life-long learners. While it may have been acceptable in the past for education to be brief and unpleasant, life-long learning must be graceful if the learner is to remain healthy. The healthiest and most joyful form of learning for all mammals is play. Regretfully, children in our contemporary society are increasingly divorced from unstructured playtime by highly structured music lessons, competitive sports, television, video games and too much homework. If someone has never learned to play with things, they are unlikely to be able to play with ideas [2].

5. It is important that engineers be able to learn fast and easily during their entire careers. How can engineering education value emotional awareness, make learning joyful, and instill playful and curious attitudes?

Neuroscience, linguistics, and the cognitive sciences are increasingly verifying the reality of mind and body unity. It is becoming clear that neurological functioning, including 'abstract thought,' involves the whole body [3]. Learning is literally the creation of new dendritic connections and the myelination of involved neurons [4]. Because of this unity, we can't think about something without neural activity occurring throughout our body. And we can't do things with our body without neural signals traveling from our muscles back to our brain. With use, axons grow thicker myelin sheaths, which are then able to transmit action potentials at a more rapid rate. Visualization of anticipated behaviors thus increases neurological and physiological ability when the event actually occurs. The opposite is also true: body condition, posture, gesture and movement all affect how and what we think. Another way to say this is to say that all cognition is 'embodied'. Furthermore, we are not aware of the involvement of our neural processing as we think and learn. 95% or more of thinking and learning takes place at a subconscious level. We learn with our whole body, and our body knows what we know. When we say you learn 10% of what you hear and 90% of what you do, it is true precisely because it is the whole body that learns. This is what John Dewey meant when he said we 'learn by doing'.

6. To be more effective, all education, including engineering, needs to recognize and incorporate the unified nature of our mind/body. How can engineering educators take advantage of new research findings about effective learning strategies? How can we honor the unique learning style of each student's mind and body system?

Mind and body unity has far-reaching philosophical implications. It will upset our current way of thinking about life and our environment. Western philosophy has evolved a dualistic understanding of objective realty that incorporates a split between mind and body. The result is a false distinction between objective reality (out there) and subjective experience (in here). When the mind is assumed to be separate from the body, what Arthur Koestler called the Cartesian Disaster [5], the result is two conflicting views of reality. The first, scientific realism, assumes that reality exists 'out there' independent from man. The second, more recent postmodern deconstructive view, believes that reality, including science, is a social construction that has been mutually agreed to by all members of a culture. Most engineers and scientists reject the socially constructed view as it clearly does not account for the very repeatable nature of contact with the physical world. However scientific realism doesn't incorporate the fact that thoughts are not separate from the physical world.

Thinking doesn't occur 'in the abstract'; it happens in the neural circuitry of our entire body. There is no separation between us and physical objects. Including the observer in reality doesn't mean you can't have good science. In the words of George Lakoff, 'What has always made science possible is our embodiment, not our transcendence of it, and our imagination, not our avoidance of it' [3, p. 93].

A consequence of our dualistic separation between 'in here' and 'out there' is that we objectify ideas as well as artifacts. Concepts like truth, justice, love, or even 'good design' become real things. Linguists are coming to realize that when the embodied metaphors we use to describe these *a priori* ideas (e.g., love as a force, or love as a journey) are removed, there is little left. The metaphor is the idea. Thus, *a priori* ideas don't exist divorced from the embodied metaphors we use to conceptualize them.

7. What are the implications of mind/body issues in the practice of engineering? How can we insure that design engineers are familiar with the philosophical underpinnings of their culture and profession?

Dualistic thinking causes our culture, and engineering, no end of problems. It separates man from environment, and individuals from their work. It is too easy to say feelings don't matter, and that the end justifies the means. It makes us assume that causes are separate from effects, and then 'treat' identified problems in isolation. We then wonder why our solutions only yield short-term success. When engineers objectify people, they become comfortable treating them like billiard balls, containers to be filled, or products that can be run down assembly lines. When engineers objectify goals they are treated as reachable fixed solutions rather than moving cultural targets.

In engineering design, dualistic thinking leads to the belief that design processes can be separated from the designer, and perhaps can thus become a design 'science' with mathematical rigor [6, 7]. There is some irony here. First-generation artificial intelligence researchers assumed that human thinking could be reduced to the manipulation of abstract symbols. While this has proven to be unreasonable, it has taught us a great deal about what it means to be human [8, p. 50]. It feels like attempts to create a design 'science' will retrace the same voyage.

Research into how to do design well is useful. Reducing this knowledge to methodologies is useful. But teaching these techniques as if they were the essence of design, is profoundly misleading. When this happens, useful tools like the *House of Quality*, become methodological straight jackets, like *ISO 9000*. There are simply too many design variables to put into any matrix or equation. Consider this simple analogy: according to Peter Farb, it would take 10,000,000,000,000 years to utter all the possible English sentences that use exactly twenty words [9, p. 222]. English has about 50,000 words. Surely the 'vocabulary' of design possibility is much larger.

8. When engineers include human concern in their designs, they must work comfortably under conditions of generous possibility combined with uncertainty, insufficient information, conflicting demands, judgement calls, and even paradox. They must be able to create and use design tools while simultaneously recognizing their limitations. How can engineering programs integrate their current math/science focus with these 'fuzzy' conditions?

DISCUSSION

This paper has explored what it means to include concern for humanity in the practice of engineering. This concern manifests itself in two domains: how designers view consumers of engineering, and how designers view themselves. In both domains, focus may be turned outward, that is, only pay attention to observable external behavior, or it may include inward vision as well. The oversimplified 2×2 matrix summarizes the spirit of the above analysis in terms of these divisions.

	People	**Designer**
External (observable)	Objects Utility Usability	Methods Process Teamwork
Internal	Thoughts Feelings Meaning	Creativity Motivation Learning

Examples of external focus include attention given to utility and usability in the case of consumers, and to teamwork and methodologies for engineers. Internal issues include the thoughts and feelings of individuals, and the designer's own motivation and creativity. At the subconscious level, internal issues include physiological, perceptual and neurological functioning and dreams, stories and myths. At this level cultural meaning becomes important, and, as we have seen, serious philosophical and metaphysical issues may be raised.

Design must incorporate the entire spectrum of humane concern in its practice. Twenty years ago a chairman of my own Mechanical Engineering department emphatically stated that engineering does not have anything to do with people. This pronouncement clearly draws a line staking out a position which essentially excludes engineering from serious design. Given our current circumstance, this view is no longer defensible. Engineers are involved in products that impact man and his environment in very direct ways. Most engineers are probably comfortable drawing a line that includes external, observable behavior, but which excludes internal phenomena. Unfortunately, this position will not generate successful products, nor will it provide designers with complete access to their own creativity and interpersonal abilities. This 'disembodied' position will also become increasingly philosophically untenable as mind/body unity continues to be verified by science.

Humans are warm and fuzzy. Design has to do with humans. The big question for engineering design education in the new century is how can hard and cold engineering warm up to, and soften into, the human challenge of design? Given the entrenched math/science value system of engineering in academia, the question may not be how engineering can rise to this challenge, but whether it can at all. If engineering is unable or unwilling to accept the challenge, there will be a need for a technologically savvy design profession that can.

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