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Understanding the NSF Transforming Undergraduate Engineering Education Report – Why are Industry and Academic Pathways toward Knowledge Development at Odds?

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Introduction

On May 9-10, 2013, the first of a series of workshops titled 'Transforming Undergraduate Education in Engineering' (TUEE) was held in Arlington, VA. Hosted by the American Society of Engineering Education (ASEE), the event brought together program officers from the National Science Foundation (NSF), staff from the ASEE, professors from academic institutions involved in engineering education research, as well as a diverse complement of industry professionals with an interest in engineering education. A cursory scan of the people invited to the workshop from industry reveals individuals from a variety of industrial career paths. Companies providing hardware and software to educational markets, designated educational specialists and liaisons from large companies, and practicing engineers were all represented.[1]

The mission of the series of workshops, as stated in the TUEE executive summary is "to develop a new strategy for undergraduate engineering education that meets the needs of industry in the 21st century. *Transforming Undergraduate Education in Engineering* aims to produce a clear understanding of the qualities engineering graduates should possess and to promote changes in curricula, pedagogy, and academic culture needed to instill those qualities in the coming generation of engineers."[1]

Such a process will likely influence how change in engineering education will happen inside the academy, as well as areas of emphasis that will be funded in the future by NSF. Past efforts, such as the *Engineer of 2020*[2] have demonstrated the potential of the approach in redirecting education reform. Engineering education professionals must take them seriously, both in the positive change of course they may offer, as well as false starts that may distract from society's larger interest in how engineers are educated.

In a series of breakout sessions, KSAs (Knowledge, Skills, and Abilities) were crowdsourced from participants. After this, they were aggregated, and then divided for discussion regarding their relative value. Participants were asked to rate and rank importance of the given KSAs now and ten years from now, as well as divide responsibility for education of these KSAs among societal partners – students, academia, parents, and industry. Prior to the workshop, the 26 industrial partners and seven academics were queried on KSAs aggregated a priori from a number of works, including *The Engineer of 2020*[2], as well as ASEE conference papers on attributes of the 'Global Engineer.'[3]

As is typical with these types of inventories, the KSAs were exhaustive – 22 technical and an additional two dozen professional attributes, with a truncated end list of 36. There appears to have been little effort to synergize the list to a more manageable set of guiding principles. Instead, KSAs apparently were added to the list based on the authority of the participants. Arguments offered were brief, and in this author's view, often arbitrary and unsupportable. Highlighted in the report was the following example:

> "One twosome lamented a perceived lack of depth in math. An on-the-job consequence, they agreed, is that young engineers are unable to intuit the boundaries they're working within, and also try to solve problems without truly understanding them."

Math, as practiced in most standard undergraduate curricula in engineering, is primarily an algorithmic process, such as solving a linear differential equation with constant coefficients using Laplace transforms. How stretching this to include evolving particular engineering insight eludes the author. In fact, a more rational argument might be that constant algorithmic process encourages suppression of the larger heuristic that the authors argue as needing to be emphasized.

KSAs included the typical kinds of expected outcomes for engineering education: communication skills, engineering fundamentals, ability to identify, formulate and solve engineering problems, teamwork skills and ability to function on multidisciplinary teams. The KSAs were designated either as knowledge, skills or ability in parentheses at the end of their statement in the report.

It was not at all clear to the author on what separated knowledge from skills, nor skills from abilities. In fact, the semantic inconsistencies in the report were glaring. For example, KSA 14: Teamwork skills and ability to function on multidisciplinary teams (ability) was called an *ability.* Yet the term *skills* was used inclusively inside the description. This crossover carried on to other KSAs, such as KSA 18: Ability to use new technology and modern engineering tools necessary for engineering practice (*skill),* and KSA 31: Ability to deal with ambiguity and complexity (*skill).*

The point of this criticism is not to demand absolute consistency. But while the semantic inconsistency was easily identifiable, the various conceptual inconsistencies would require multiple papers to resolve. And if the process is supposed to develop an evolutionary roadmap for the engineering education enterprise, it may be helpful more to ask what social evolutionary goals exist than accepting implied direction from an arbitrary process dependent solely on the authority of the participants.

Systemic and Structural Flaws

Though the process is still at its beginnings, it is important to recognize that there are serious systemic and structural flaws in both the process and product. These are:

1. Dependence on unsupported expert authority for KSAs and their priorities.

Few would argue that many of the KSAs are important parts of being an engineer. No one would declare, for example, that communication skills are unimportant. However, systematic prioritization is lacking in the document. The prioritization that is present is based on singular opinion and opinion polling. Opinion polling is a weak version of evidence-based decision making, in that it is only aggregated individual opinion – regardless of the expertise of the audience. Especially in the case of the work of TUEE, it is also aggregated largely in a particular social surrounding, with the incumbent human pressures to conform.

A better question might be to explore a priori the question 'Why do engineering professors emphasize a given KSA (such as math fluency) to the exclusion of others?' What is the social dynamic that creates these types of opinions, and how can we understand their basis in the real needs of our society? Are these opinions rational, and reasonably supported? Do they deserve the priority they are assigned, or are they a function of different social dynamics present in the professoriate? Or equally, 'why does the industrial audience think KSA # is important,' using the same train of logic.

Unpacking these lines of reasoning will reveal what Peter Senge [4] calls 'mental models' that communities naturally possess, and will prove more revealing on root cause of development of any dominant paradigm. Such self-examination, even if only supported with case studies, could yield insight on whether certain beliefs being expressed are supported by contemporary realities.

2. Ignorance of the developmental scales of the predominant audience in engineering programs – the age group of 18-22 year olds that make up the majority of engineering students.

In creating a pleasing metaphor/icon for the engineering graduate (the T-shaped graduate discussed in the report, where the student is socially broad on the top, while possessing core expertise in a discipline) discussion is non-existent in the limits of both engineering programs and young people's ability to comprehend information on large time and spatial scales – the building blocks of the T-shaped graduate desired.

Intrinsic in all of this are demands placed on young people to be *ubermenschen*, primarily implied in terms of developed empathy levels not expected in the population at large. For example, how many people are truly open-minded and ready to collaborate with individuals from a radically different culture on their first trip abroad? Can this be taught in the classroom? How many professors possess the professional KSAs listed in the document that are expected in the TUEE document? If professors do not possess these skills, who will model the behavior demanded of the new graduates? Who will break down the larger heuristics into a set of manageable practices that can be assimilated by the student body?

In addition, there is a lack of understanding, because of old cultural models present in the age cohort of the professoriate themselves, of how young people function socially, and what can be done to improve these vital characteristics. How much is actually realistic to accomplish in the four short years we have engineering students? Will adding more curricula on top of the current model result in a significantly more well-prepared graduate?

3. An absence of awareness and responsibility in the constituency served by engineers.

Early on in the report, the purpose of the workshop is stated as "designed to hear the "voice of the primary customer – employers." " While the author has an extensive background of interaction with industry – relationships over the course of a career with 60+ corporations, and over 270 shared and funded collaborative projects, the author would never state that the primary customer of an individual receiving an education was industry. The primary customers of an education are the student themselves -- they are paying. And society must always be the primary stakeholder. At a minimum, having an attitude of depriving young people of agency is likely to run counter to many of the KSAs listed, such as creativity, or development of leadership skills.

Yet there is no question that engaging industry is extremely important – not just for the development of students, but development and evolution of the professors themselves. The TUEE process could be an important first step. Up until this point, engineering curricula have largely evolved based on negotiated consensus of the professors involved. Adding an industrial customer for giving meaningful feedback and evaluation is important. But this simply cannot be the end goal of any educational transformation.

4. Lack of a consensus on the larger goals of an engineering education, and agreement on necessary developmental 'mile markers' for our own society.

There is some discussion about where industry and societal trends are going to take us. This discussion is linked to the necessary modification of knowledge products and abilities in new graduates. But there is little introspection inside the gathered community on how to get there, or any realistic understanding of the educational physics that might take us in the right direction.

This is simply not the fault of the participants in the current exercise. Educational theory, in the opinion of the author, is for the most part scattershot, poorly formed, and non-evolutionary. Agreed consensus theories like Bloom's Taxonomy [5] suffer from profound overlap of information in the various levels, and there is sparse work where higher-level application of mathematical paradigms to educational theory, such as orthogonality, emergence, or nonlinear behavior are dealt with in a more substantive vein. For all the talk of the importance of mathematics among the academics present, there are few higher-level guiding principle analogs present in the educational philosophy advanced.

There are hopeful, though limited examples of larger understanding on education, such as enumerated in the book *How Learning Works* [6]. But these systems thinking principles need to be applied in the current process. Delineation of cause and effect of particular topics discussed would add deeper thought and more weight to the outcomes.

5. A generalized lack of awareness of what the participants implicitly believe about the process of engineering education, in spite of data and case studies, (or lack thereof) and how their perspectives modify their opinions.

There are reasons why academics and industry think so differently about many things – not just engineering education. Academics seek to maximize *reliability* of information, which manifests itself as repeating information that the larger academic community has vetted and believes to be true. Industry seeks to maximize *validity* – actually solving particular problems that customers have, so that they can make money. One can find excellent definitions for reliability and validity, with examples, in Martin's *Design of Business* [7] ,which contrasts the differences between algorithmic and heuristic thought that are at the basis of this difference.

The sources of these variations in perspective come directly out of differences in the social structures of the two organizations. Academic organizations, with their Byzantine assortment of titles, encourage status-based, non-empathetic and externally defined relationships (e.g. whether one likes it or not, I will always be a professor).

And industry must find solutions to real problems, using all data available, including customer preference. Customer preference may or may not be logical or particularly reliable. Understanding customer preference is also intrinsically empathetic, relying on connection with the customer. As such, engineers in industry must cultivate independently generated, trust-based relationships for evaluation of independent data sets associated with each customer. Titles matter very little – how prestigious an individual one associates with doesn't help your bottom line if they won't buy your product. This creates very different ways of knowing that often result in conflict. Academics pride themselves on not taking the emotional content of their real primary customer – the student – into consideration. Such behavior in the industrial sector would lead a company to bankruptcy.

What realization needs to happen to move the TUEE process along? It could start with the recognition that everything humans do is laced with a combination of internal personal bias, along with external influences that force conformance with established norms.

This could start with the insight that the setting of the TUEE effort – in a hotel in Virginia, in breakout groups with moderators – is a standard academic venue. Industrial participants traveled to the venue, were fed into a system where abstract, unrelated KSAs, without evidentiary support, were then generated in the breakout sessions, and placed in front of them to rate and rank, in full view of the collaborating faculty members and NSF staff. It is not surprising that many of the industry participants changed their views on a variety of issues after being placed in this type of venue. If there were compelling arguments offered, there was little evidence in the TUEE document.

And this would be expected. The idea of *xenia* – the ancient Chthonic Greek embodiment of the guest-host relationship – clearly states that the role of the guest is to not offend the host, much as it is the role of the host to provide appropriate hospitality, food and drink to the guest. A good guest does not walk into the house of the host and insult them by contesting long- and closely-held beliefs, like the academic engineer's fixation with mathematics. And two days is not long enough to establish the more profound relationships that might lead to deeper truth-telling between the two camps. Additionally, placing industrial guests in an academic environment also creates other types of social pressures to act, and think like an academic. Social environment matters.

Contrast this to a more modern, well-accepted industrial protocol for discerning a customer's needs. A sales engineer, or a team will visit the customer on-site and spend an intensive period attempting to understand the customer's process and production needs. Upon returning to the office, there may be follow-up focus groups to further inform the service provider. When this process is completed, and a specification is developed, once again, the service provider contacts, and negotiates a final specification before a contract is drafted.

Of course, with these types of situations, it is difficult to come up with the best process for developing outcomes that will satisfy the broad directive mandated by this grant. But it is not expecting too much to borrow some hybridized form of similar, industry-based customer process as part of such an overarching directive – fundamentally transforming undergraduate engineering education – if, as a community, we are serious about treating industry as a customer.

Creating an Awareness of Educational System Physics

"Would you tell me, please, which way I ought to go from here?"
"That depends a good deal on where you want to get to," said the Cat.
"I don't much care where –" said Alice.
"Then it doesn't matter which way you go," said the Cat.
"– so long as I get *somewhere*," Alice added as an explanation.
"Oh, you're sure to do that," said the Cat, "if you only walk long enough."
Alice in Wonderland, Lewis Carroll [8]

One of the greatest obstacles facing advances in education is its current structure – an authoritarian/legalistic hierarchy, taxonomically grouped around teaching a smorgasbord of subjects. This knowledge is defined and maintained by siloed disciplinary experts who historically have resided in institutions of higher learning. The roles of these institutions have largely been unquestioned in their primary responsibility-- the reliability and vetting of knowledge. For time immemorial, universities have been responsible for 'knowledge security' – making sure that what knowledge was communicated was correct, and verifiable using current state-of-the-art practice.

Because of this clear, and until recently, uncontested beneficial societal mandate, universities and their faculties have not spent much time questioning their relational structure, which explains much of why they do what they do. Nor have they attempted to engage in understanding themselves from a variety of external viewpoints. This lack of engagement with institutional self has been shaken from time to time, most notably with subjects such as various diversity initiatives. But there has been very little progress in understanding ourselves from core principles – how academics actually think. Advances in neuroscience might offer new insights that launch a general confrontation of educational paradigms, but the field is in its infancy.

One of the most revolutionary concepts in actual knowledge construction came from outside the academy, when computer programmer Melvin Conway in 1968, stated:

"organizations which design systems ... are constrained to produce designs which are copies of the communication structures of these organizations
—M. Conway [9]

In other words, organizational structure dictates product structure. If one wants a particular product, one must structure the organization to produce that product. Conway's Law, as it has been termed, has been verified through study of software products. [10]

Pezeshki extended Conway's Law, [11] positing that there was an intermediate step between social organization and design realization – the knowledge structure that had to be created before the product could be realized. He called this 'The Intermediate Corollary', and the implications of this interpretation are vast. Instead of assuming that a given social organization could produce any type of knowledge, the development of the structure of knowledge in a field would be dictated by the communication paths inherent in the social structure that created the knowledge.

Further, Pezeshki then posited that the nature of the communication channel – either duplex (two-way) or simplex (one-way) would then dictate the level of synergies extant in a given design, or knowledge structure. And that characteristic would be embodied in the level of developed empathetic connection in the organization. Simplex organizations could be simplified as non-empathetic (one-way) communication structures. Duplex organizations could be simplified as possessing empathetic communication structures.

Pezeshki then posited that empathetic structures were much more likely to create nonlinear interactions, with the appropriately rich set of potential nonlinear behaviors (such as jump phenomena, multiple solutions, sensitive dependence on initial conditions, and potential chaotic transitions – or in more human terms, post-interaction, the individuals were more likely to have a merged perspective, or change their minds) than more linear, simplex communications (the authority speaks, and the receiver listens, with no opportunity for modification – only the aggregation of noise in the message.)

These insights were then mapped to the emergent, evolutionary self-similar societal/individual human development model called Spiral Dynamics developed by Clare Graves, Don Beck, and Chris Cowan. [12] The basic idea behind Spiral Dynamics (SD) is that societies and their organizational structures, as well as the people in them both evolve and devlove, oscillating back between 'I' modes and 'We' modes. Lower levels are also embedded by each higher mode. Once a societal level of relational sophistication is achieved, it not only captures the newer modes of thought emergent at that Spiral level, but also all lower forms of behavior. The basic SD levels are:

1. Survival (I - Beige) – characterized by individual survival/ short term temporal needs (water, food, shelter)
2. Tribal/Magical (We - Purple) – characterized by group-shared rituals and belief structures, but no strong leadership structure.
3. Authoritarian (I - Red) – Groups of people organized roughly into a power structure, with an individual or groups of individuals occupying stratified positions of power and privilege in the group, as well as independent decision-making authority. Often characterized by arbitrary knowledge construction by the authority at the top of the system.
4. Legalistic/Absolutistic (We - Blue) – Groups of people organized into hierarchy that, like the authoritarian structure, occupy stratified positions of power and privilege, but are subject to a body of law that applies to all, and restrains individual power and decision-making capability. Importantly, the Legalistic/Absolutistic v-Meme is the first where there is recognition of intuitive, consequential thinking. Laws are passed with the notion of consequent, societal benefit, which in turn, develops the actors creating the laws.
5. Achievement-oriented/Entrepreneurial (I - Orange) – Societies that follow this relational mode, or have some of this feature embodied in their structure are the first to value highly independently formed relationships. Instead of a rigid hierarchy of people or laws, group structure is dependent on achieving a goal or some level of culturally desirable performance.
6. Communitarian (We - Green) – People-oriented societies that highly value each individual in the society, and are based around egalitarian principles and laws that enshrine the individuals' rights in the context of the group.
7. Global Systemic (I - Yellow) – Recognizes the relational dynamics present in all lower levels and opportunistically combines these to achieve higher goals and purposes
8. Global Holistic (We – Turquoise) Combination of various Yellow 'I' mode thinkers devising larger systems that span larger expanses of cultural relational dynamics and incorporating these together to achieve goals on a global level
9. Bodhisattva (I – Coral) Ascendent, Self-Aware 'I' committed to sublimation of their own desires to benefit all of their connected humanity.

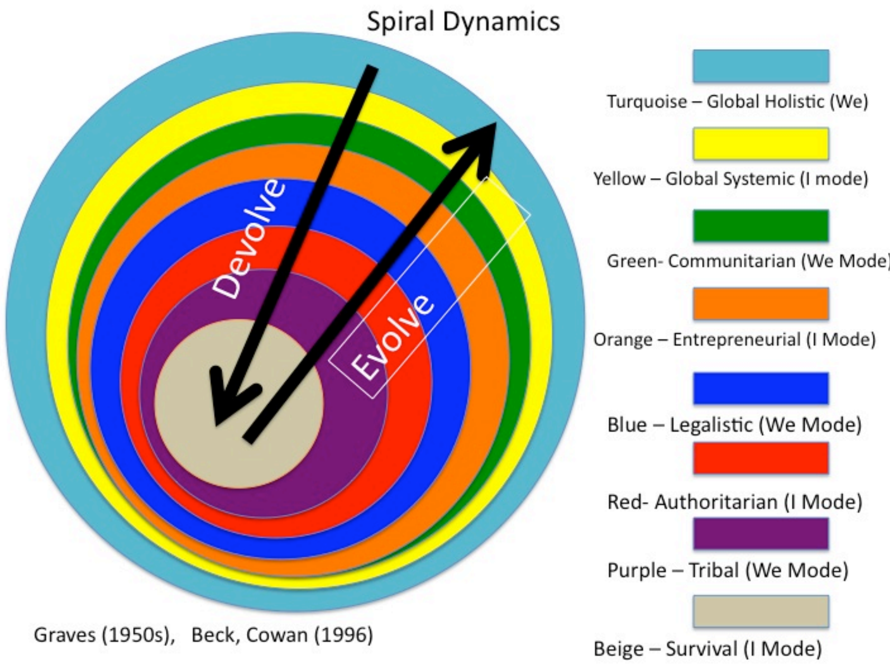

Figure 1. Plot of Spiral Dynamic Levels

The emergent nature of Spiral Dynamics is captured in Figure 1 above. Societies can both evolve and devolve, accessing modes as needed and available according to their level of social evolution.

When coupled with Conway's Law and the Intermediate Corollary, the concept of Spiral Dynamics becomes very powerful indeed. What it then says is individuals have access only to specific knowledge structures dependent on their level of social evolution – and that their level of relational formation is directly dependent on their level of empathetic connection. In short, as we relate, so we also think.

It is important to understand that higher levels, because of their emergent nature, coupled with the fact that they encapsulate lower-level knowledge structures, must be appropriately scaffolded using knowledge structures from these lower levels. One cannot have a functional goal-based Orange organization without appropriate Legalistic/Absolutistic scaffolding and below. In engineering terms, design teams will need analysis personnel and appropriate subject experts. You cannot hit the design target without appropriate support from structural analysis.

If more complex and synergistic knowledge structures are dependent on lower-level knowledge, then SD coupled with Conway's Law also gives a roadmap for identifying and teaching knowledge structures inside engineering education. And it also defines what types of classroom social structures will be most useful for teaching particular subject matter. And because this coupling is fundamentally emergent in nature, the problems of content and conceptual overlap, rife in theories such as Bloom's Taxonomy, and most of the KSAs listed in the TUEE effort, vanish. One can plot an expanding set of exercises, and the social/relational/empathetic environments necessary to impart information emergently, and efficiently.

Figure 2 below shows the coupled empathetic model that supports the various SD levels. The various empathy levels are explained in [13] in more detail. But to sum, they divide up into four basic levels, once again emergent from the level below.

1. Subconscious empathy, or mirroring behavior, which can be as simple as behavior present in yawning, some crying, etc., but can embody for short time scales in extremely complex cognitive as well as neuromuscular behavior.
2. Emotional empathy – primarily a limbic-level response to others' emotional reaction, characterized by short time and spatial scales.
3. Rational empathy, which is the first level where one sees directed conscious thought, longer temporal and spatial scales, and consequential behavior.
4. Global empathy, which is omnipresent (shock and loss over something like a tsunami or jet liner crash,) but still poorly understood.

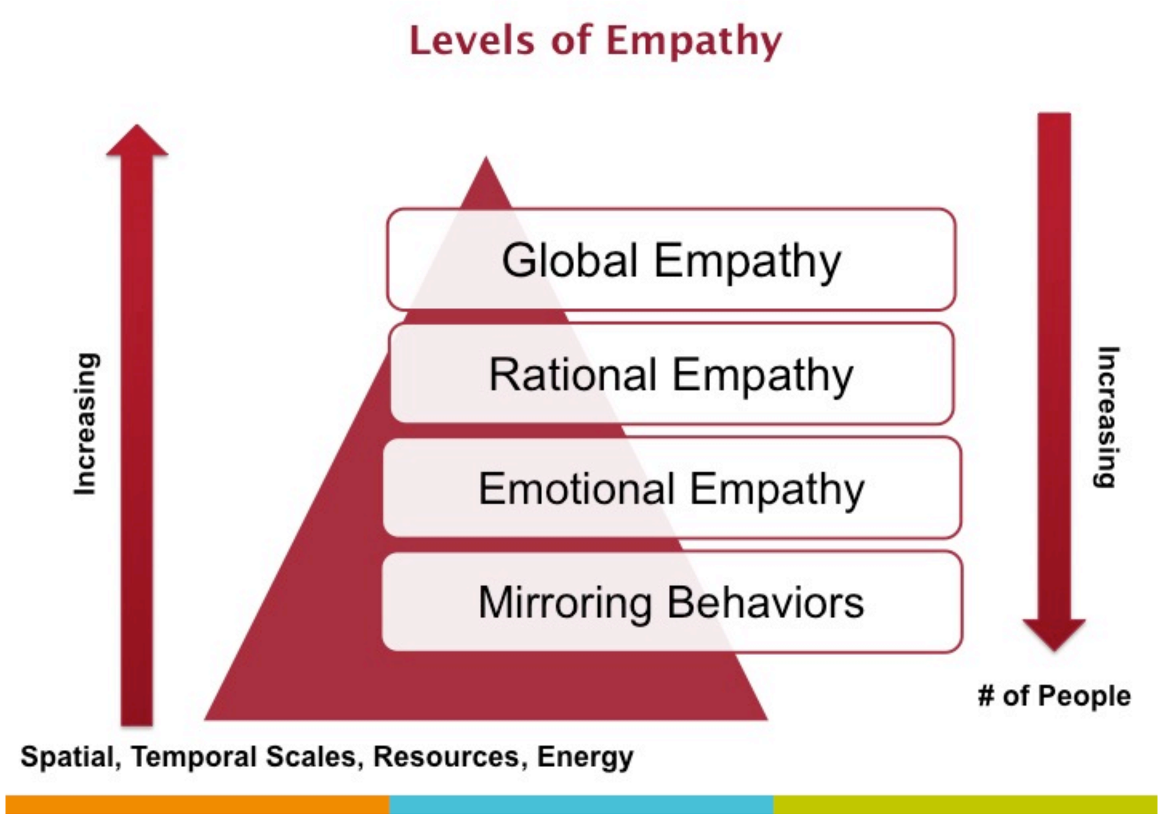

Figure 2 – Empathetic Development in Humans

This leads to direct takeaways as far as knowledge structures, which then map both to the idea of a developed subset of particular types of knowledge, similar to the KSAs used by the TUEE initiative, as well as social environments where such knowledge structures might be more easily learned by students, since those environments will be self-similar to the knowledge structure itself. Additionally, it also directs the educational community toward a roadmap for development of students that further research could correlate with their appropriate age, as well as a roadmap for knowledge development.

Social/Relational Structures and Their Associated Knowledge Structures

What then are the associated knowledge structures that correspond to given relational structures? One can divine what these might be from the motivators for individuals inside a given social structure.

- Survival – ephemeral knowledge fragments, with short-time temporal and spatial range and specifity (where do I get coffee, schedule for today.)
- Tribal/Magical – knowledge fragments embedded in temporally indistinct stories, with shorter spatial scales, for knowledge preservation and resistance to signal corruption. Knowledge is characterized through a short time/long time lens.
- Authoritarian – knowledge fragments, in control of a higher authority, potentially embedded in stories or other knowledge preservation frameworks (specific material properties or behavioral phenomena, like the function of resistance in a material due to temperature, etc.)
- Legalistic/Absolutistic – algorithmic/rule following knowledge, primarily single answer, regardless of multiple inputs (thermodynamic problem-solving, free-body diagrams, Kirchhoff analysis, most of academic work including undergraduate mathematics.)
- Performance or goal-based behavior – development of heuristics for design, complex problem solving, and critical thinking where multiple solutions are possible. Beginning evolution of 'design thinking.'
- Communitarian behavior – development of more complex heuristics involving collaboration with others and awareness of cultural influences, along with development of larger metacognitive skills – recognizing others' expertise in subject matter relative to your own.
- Global Systemic – Further development of complex heuristics predicated on a profound metacognitive shift – deep awareness of what you don't know, as well as what expertise one possesses. Incumbent shift in responsibility upwards.
- Global Holistic – Guiding principles, holistic association coupled with metacognitive growth.
- Bodhisattva – All of the below, coupled with correct placement of self in the system and a commitment of helping others achieve their potential.

Once this list is understood, major revision could then begin on the KSAs enumerated in the list, as well as the necessary decoupling and deconstruction of many of the items – for example, real leadership is actually an heuristic, requiring (in an abbreviated list) empathy, some algorithmic thinking, as well as the ability to draw on a set of motivational stories – not a skill.

Though not executed in the list, the concept of specific Knowledge easily maps to the Authoritarian level, and could be taught initially with an augmented lecture format with rote memorization and demonstration. Skills, in a more refined sense, map to algorithmic learning, and lend themselves to a combination of lecture, demonstration, and practice session with drill. Abilities might require more thought, but would be better characterized by heuristics.

Additionally, one can see the function of relational environments in dictating learning styles and place of the instructor in the classroom. Pure 'Knowledge' would be more suitable to the current Authority-based framework present in most classrooms. Design Thinking, based primarily on heuristics, requires the instructor to demonstrate more profound metacognition on areas of expertise in order to build the empathetic trust-based relationships necessary for their execution. Active learning, projects and authentic audiences naturally fall out as preferred methods for teaching at the Heuristics level.

There is much more here to unpack – a thorough review of all the KSAs could be done that would be much more directive toward future outcomes. Doing this is beyond the scope of this paper.

Conclusions

In this paper, the author has pointed out the inconsistencies and problematic circumstances in the current TUEE process. In order to fix these problems, the author has developed a guiding principles model of knowledge structure that maps to optimal social structure for educational purposes. With further research, it could also be linked to developmental levels of students in the transition to full maturity, and appropriate goal setting could be done by such a team as has been assembled for TUEE initiative.

But in order for that to happen, participants in the initiative must search for deeper answers inside the customer's community as well as their own. The rewards would be immense. Not only would a coherent road map for engineering education emerge, but the individuals themselves would find themselves as thought leaders down the path toward larger, global understanding of both current and future directions, as well as failures in engineering education.

References

1. American Society of Engineering Education, 'Transforming the Undergraduate Engineering Experience', May 9-10, 2013, Arlington, VA.
2. Phase, I. I. (2005). *Educating the Engineer of 2020:: Adapting Engineering Education to the New Century*. National Academies Press.
3. Hundley, S., Fox, P., Brown, L. G., Jacobs, A., Didion, C., Sayre, D. R., & Hoyer, H. J. (2012). Attributes of a Global Engineer: Field-Informed Perspectives, Recommendations, and Implications. In *American Society for Engineering Education*. American Society for Engineering Education.
4. Senge, P. M. (2006). *The fifth discipline: The art and practice of the learning organization*. Broadway Business.

5. Bloom, Benjamin S. "Taxonomy of educational objectives. Vol. 1: Cognitive domain." *New York: McKay* (1956).
6. Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., & Norman, M. K. (2010). *How Learning Works: Seven Research-Based Principles for Smart Teaching: Seven Research-Based Principles for Smart Teaching*. John Wiley & Sons.
7. Martin, R. L. (2009). *The design of business: why design thinking is the next competitive advantage*. Harvard Business Press.
8. Carroll, Lewis. *Alice's Adventures in Wonderland*. Google Books, (originally 1865.)
9. Conway, M. E. (1968). How do Committees Invent? *Datamation* , 28-31.
10. Herbsleb, J. D., & Grinter, R. E. (1999). Architectures, Coordination, and Distance: Conway's Law and Beyond. *IEEE Software* , 63-70.
11. Pezeshki, C.,, and Kelley, R. (2014) "It's All about Relationships – How Human Relational Development and Social Structures Dictate Product Design in the Socio-sphere", *Product Development in the Socio-sphere: Game Changing Paradigm for 21st Century Breakthrough Product Development and Innovation*, Springer Verlag, NY, NY.
12. Beck, D., & Cowan, C. (1996). *Spiral Dynamics: Mastering Values, Leadership and Change.* UK: Blackwell Publishing.
13. Pezeshki, C, (2014) "Understanding Engineering Relational and Knowledge Structures for Facilitation of Collaboration and Global Development", *ASME IMECE 2014,* Montreal, CA.