WHAT DO SUSTAINING LIFE AND SUSTAINABLE ENGINEERING HAVE IN COMMON?

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Abstract: Medical Education professionals in the U.S. have realized that medical education now consists of three main features: diagnosis, cure and in the case of chronic illness, health management (sustaining life). In a similar way, engineering education may be characterized by problem definition (diagnosis), problem solving and in the case of chronic engineering problems, problem management. Medical education has taken steps to modify its curriculum and pedagogy to reflect this new awareness whereas engineering education has not. What can engineering education learn from the medical education community? And, in particular, how do further challenges of sustainable engineering impact how engineering education should change?

1 INTRODUCTION

Since at least the end of WWII, engineering has been characterized as "problem solving," and engineers as "problem solvers." When asked, first-year engineering students often provide this answer when they respond to the question: What is engineering? But, it is not just engineering students who answer this way, even engineering faculty characterize themselves as problem solvers and several of the leading books on the reform of engineering education by Sheppard, et al, (2009) and Jonassen (2013) also describe engineering as problem solving. Most of the current engineering curriculum reflects this emphasis on problem solving and the information mastery necessary for problem solving.

In a recent article on the whole professional (Denning, 2014) based on the book by Goldberg & Somerville (2014), states that one of the principles of being a whole new engineer is to "Demonstrate competent performance in solving engineering problems," and further that one of the skill sets of the whole new engineer is "Analytical ability to rigorously analyze problems and apply scientific and mathematical principles to their solutions." This emphasis on problem solving isn't a criticism of the whole new engineer, in fact, many of these principles and skills are extremely important for engineers. But, we believe that this emphasis on problem solving leads to serious issues in both engineering education and the engineering profession.

Even the web site of Olin College of Engineering (2015) that states its commitment to changing engineering education states: "Olin was founded to radically change engineering education with the goal of fuelling the technical innovation needed *to solve* the world's complex future challenges," (italics added for emphasis).

But is engineering as problem solving sufficient? In an excellent paper from an earlier EESD conference, El-Zein and Hedemann, (2013), argued that this emphasis on problem solving "determines the mode of engagement with the world and limits our ability to tackle root causes of social and environmental issues in technologically advanced societies." They discuss the idea that engineering demands more than problem solving by adding problem definition to the role of engineering and that engineers must "enunciate the *public good* that they are mandated to build or protect." The authors even propose that the titles of the various engineering disciplines be changed to reflect the public good that the discipline supports, for example, water or habitat engineering.

Downing (2005) and Siller and Johnson (2010) have argued quite effectively for getting engineers involved in the "problem definition" phase as a way to return engineers to professional status and to lessen the idea of engineering as a commodity by adding engineers to the list of stakeholders. However, it might be more complicated than just getting engineers involved in the problem definition.

When examining the National Academy of Engineering's list of Engineering Grand Challenges for the 21st Century (2010), one is struck by the notion that many of these challenges do not have solutions in the traditional sense, rather they represent situations where the "solution" is the management of the challenge. This seems true for our energy needs, access to clean water and improved sanitation, the nitrogen cycle, the carbon cycle, medicine and many others.

Trevelyan (2014) in his recent book, The making of an expert engineer, has studied practicing engineers in the field and reports that one of the main misconceptions of engineering students is that engineers are problem solvers. It turns out that this is not just a misconception of engineering students. As stated above, engineering faculty as well as others also hold this misconception and this significantly limits the role that engineers play in our society.

Put another way, if engineers solved problems the problems would go away. But, in fact, many of our technologically based problems seem to be exasperated by our so-called solutions. Because we are only solving small problems and the big problems call for management rather than solution, where should engineering educators turn for help?

2 ANALOGY WITH MEDICINE

For many, many years, the medical profession has also thought of themselves as curing (solving) medical problems. In some cases, this is true. Surgeons are often able to remove tumors or other growths that form the basis of what is referred to as an illness. The older problem solving approach is also still evident in such medical research fund raising activities as "Race for a Cure." Yet, over the years many illnesses have proven impossible to cure (chronic illness) so a new approach has developed, that of so-called managed care. Example chronic illnesses include hypertension, diabetes, Alzheimer's, MS, Parkinson's, HIV/AIDS, ALS, MDS, and many other forms of cancer, etc.

Like engineering problem solving, when medical professionals think they can cure (solve) a problem, the interactions basically come down to the patient-doctor relationship. Obviously, in the case of surgery, there is a professional team approach to the surgery, but the patient (client) only directly interacts with the surgeon and it is the surgeon who has solved the problem. This is directly analogous to an engineering team solving a problem for a single client without considering the needs of other stakeholders who may be involved with the problem.

The move to managed care changes these relationships. Often a team of physicians and other medical professionals are directly involved with the patient as well as others on the patient's side such as other family members, other medical organizations, insurance company boards, etc. This shift to a managed focus rather than a problem solving focus enables an easy expansion of the role of other groups of individuals. The same would be true of engineering problems; if they are managed rather than solved, the role of other stakeholders is much easier to include in the team approach to management.

Because early diagnostics in medicine becomes so important with respect to treatable but not curable illnesses, medical education has put an increased emphasis on diagnostics and team-based approaches to diagnostics noting that it has become nearly impossible for one medical specialty to be able to diagnose across medical specialties. Again, diagnosis is analogous to the engineering problem definition stage as discussed by Siller and Johnson (2010). Both medical diagnosis and engineering problem definition require that doctors and engineers ask smarter questions and acquire the appropriate data necessary for decision making.

3 TRENDS IN MEDICAL EDUCATION

Medical education began undergoing a transformation in the early 1980s when patients began complaining about the lack of time that physicians spent with them. At the same time, it was also acknowledged that many individuals in society suffered from chronic illnesses that demanded a regime of health management rather than being cured. Certainly some specialists such as surgeons still needed to be taught how to perform surgeries but this came at a later point in medical education. In the case of medical education, the reform was driven by the medical accreditation agency. Over about a twenty year period, the medical education pedagogy was changed from information mastery to team based collaborative critical thinking. The approach now was patient centered with groups of students, in teams, deciding on tests for the case study patient, and then developing a strategy for health management. Groups of teams then debated their approaches with active learning replacing the passive learning approaches of traditional lectures. Flipped classrooms were introduced to provide students the opportunity to do preliminary work on their own and then work in teams on solving small problems and developing management plans for the significant chronic problems. The students also learned that what works today might not work tomorrow or the next day and that the plans always have to be reconsidered and redeveloped. For example, patients with a chronic illness often develop a second chronic illness with unknown medicine interactions.

It has been very hard for medical educators to adopt this new active learner approach but the accrediting agency has been quite forceful in holding medical schools to the new standards with threats of dropping accreditation, if necessary.

It should be pointed out that managed care was not the only reason for change in the medical education curriculum. Other issues centered on the need for re-examining the length of medial education programs, not being learner centered in general, inflexible and not outcomes based. For a much fuller account of the medical education reform discussion, see Irby, et al (2010).

4 IMPLICATIONS FOR ENGINEERING EDUCATION

Does it make sense for engineering educators to examine what the medical education community practices in this regard? If this is the case, should engineering education include topics such as diagnostics and management, similar to current medical practices that now focus on diagnostic and management of illnesses rather a cure, recognizing that a cure is not possible in many cases and the important problem is to sustain life as effectively as possible. We believe the answer to this question is 'yes.'

Sheppard et al. (2009) describes a need for more hands-on engineering education based on project-centered learning. We believe that this method would be very effective in the development of skills and techniques for problem management but that it does not include the necessary elements to include problem definition unless the students also develop their own team based projects. We have actually tried this in a course that is described in the next section.

Active learning has been promoted by educators for many years. An active learning course does not have to be a hands-on course. Active learning may even be incorporated in traditional lecture courses by having the lecturer stop about every fifteen minutes and introduce a question that the students work on for a few minutes, again in groups, and then report to the class. No matter how this is done, to develop engineers who are better at problem management will require new approaches to engineering education.

5 ENGINEERING EDUCATION FOR SUSTAINABLE DEVELOPMENT

At this point it should be clear that we believe that engineering education needs to transition from the fundamental principle of engineering as problem solving to engineering as: problem definition, some problem solving and problem management for chronic problems. Several years ago the authors decided to develop a new course for first year engineering students at our home institution. We chose the National Academy of Engineering Grand Challenges (National Academy of Engineering, 2010) as the context for introducing students to the engineering profession and its various disciplines. The Grand Challenges have many connections to sustainable engineering, including topics related to energy, e.g. solar and nuclear power, along with the issue of global warming, e.g. carbon sequestration. A panel chose these topics, as it is believed that they both represent the major challenges for the early decades of this century and they are problems that can be "solved" during this time.

As we started to teach this course, we became increasing convinced that these challenges do not represent problems that shall be solved! For example, the issue of energy will probably never be solved in the traditional manner wherein a solution is created that eliminates the issues around energy, i.e. the energy problem goes away. Instead, for each new fuel source found and developed new issues are created such as the long-term supply of fuel and the resulting impacts to the environment. This is most obvious with non-renewable sources such as carbon based or fossil fuels that are being consumed much faster than they are replenished. But this is also the case with renewable sources, for example wind turbines are having unintended negative consequences on the habitat of wildlife, such as birds and bats, and increasingly, noise issues. The more time we spend on these challenges the more our thinking and teaching approach shifted towards a focus to understand there are no ultimate solutions to these sustainability-related problems -they will always remain with us. This became a significant educational challenge: how do you teach engineering students the value of working on problems without solutions?

Educating engineering students to see beyond the predominant rhetoric of problem solving can be difficult as it runs contrary to why many students entered engineering in the first place. Based on our experience it might be better to start in the early years before the standard message is too deeply embedded in their mindset. The first step we take with the students in our class is to have them define what they see as the great challenges we will face in this century. The student responses have always been to identify global challenges, e.g. energy, health, water as big broad challenges. Contrast the students' thinking with the specificity of the NAE list that includes: making solar power more efficient and nuclear fusion power practical. When one reviews the NAE list it becomes clear that the manner in which they defined the challenges look more like solution statements instead of problem statements, whereas our students focus more on the fundamental problems. This observation helped us realize that students who are not already deeply trained in finding solutions define problems more broadly than engineers who have expertise in particular classes of solutions.

To build upon this broad-thinking mentality of first year students we have developed an approach where we engage the students in developing a deeper and broader understanding of the challenges, and then later discuss how engineers contribute to these efforts. We believe that getting students to understand the definitional aspects of a problem is a critical step for both the NAE Grand Challenges and the bigger issue of developing a sustainable world. The students are encouraged to think in a divergent manner while trying to define and understand the challenges. It appears that first year engineering students have a capacity to see the many connections that make the Grand Challenges interdisciplinary in nature and that there are no simple solutions on the horizon. One of our concerns is whether they can maintain this outlook as they progress through a curriculum that values solutions to the types of local problems found in math, science, and engineering textbooks?

So what should we do next? Returning to our observations from the medical profession is helpful. Medical doctors are now a part of a larger enterprise, typically referred to as the "Health Care System." So even though doctors cannot cure (solve) all illnesses, they contribute to the management of those chronic health diseases while also contributing to local solutions, such as surgeries that do at times provide cures, or solutions, to individuals. We believe this observation has parallels in engineering for a sustainable world. There will be local solutions that come from engineering but engineering also has to better position itself to be a contributor to a much larger system, what we tentatively think of as the Technology Enterprise, similar to the manner that medical doctors contribute to the health care system - as partners with many more contributors working together, e.g., skilled nurses, pharmacists, insurance boards, medical researchers, etc. As Miller indicates "… sustainability is implemented through policy and regulation." (Miller 2014) For engineers to contribute to this technology enterprise working on sustainability they must be prepared to work with policy makers, regulatory agencies, and society in general. This represents a movement away from a focus on local solutions to more global problem management.

For many years engineering educators have been encouraged to broaden the curriculum, e.g. ABET Inc. (ABET 2013) learning outcome (h) which states that engineering graduates should have: "the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context." Unfortunately this has proven to be difficult. Our contention is that much of the difficulty arises because faculty see no role for non-STEM courses in problem solving and therefore we fail to show the relevance of this outcome to the students' future careers. With a shift to positioning engineering within a broader enterprise of technology, similar to the health care system, we can highlight the value of this learning outcome, and similar ones, so that engineers understand that long-term management aspects of sustainability requires the contributions of many professions working together. This move to pedagogy for problem management naturally strengthens the relevance of the humanities and social science that are major contributors to management techniques. For engineers to naturally operate in the greater technology enterprise, similar to medical doctors in the health-care system, requires a new approach to engineering education.

The medical profession has also recognized that chronic diseases do not go away. In fact, they often lead to additional diseases that can then lead to conflicts between medication treatment and health management. Similarly, as with chronic health issues, chronic challenges such as energy production often lead to related challenges, e.g. access to clean water (recognizing that a large portion of water use is for energy production.) Therefore engineering also faces the situation where technological approaches for one chronic challenge can be in conflict with technical approaches for a related challenge. In engineering education we have stuck with the reductionist approach championed by science for many years that often ignores these recurring interactions between related challenges and proposed *solutions*. The time has come to change this paradigm. The activity of sustainable engineering does not end with a solution because environmental conditions are in constant flux. Management, which is now necessary, is an ongoing activity that must be continuously re-examined and redeveloped as new information is acquired. Preparing engineers for this new reality must embrace management as part of the new foundation for engineering education.

We do believe that our developing approach for our first year class is a step in the right direction, and working with first year students is the place to start, even though we have not addressed the issue of management very well. In the fall of 2014 we added a new component to the class: the EWB-International design challenge (2014). Similar to the approach to developing medical students' diagnostic abilities before they have mastered all the required knowledge content, this project involves engineering students working on challenges before they have developed all of the knowledge mastery of the engineering curriculum. Students get quickly engaged in working on the challenges and discover areas of missing knowledge as they develop a better definition of the problems at hand. They also quickly recognize the role of engineering as being a team member that requires many areas of expertise.

Finally, although we have introduced the concept of problem definition into our first year course, in part because the students are so good at it, the next step of introducing long-term management of challenges still eludes us. Several questions arise: What does a good pedagogy for developing this type of management look like? What does management of chronic technological related challenges look like? When should management be introduced into the curriculum? That is why we are looking to draw parallels from the medical education system as they also recognize the role of management in the health care system in which they operate.

6 RECOMMENDATIONS AND CONCLUSIONS

In the previous section we identified some starting questions we think need to be addressed if engineering education is going to shift in a manner similar to medical education. But it is important to point out the medical education is also still in a state of transformation. Therefore, we recommend that a joint workshop be developed for the interaction of both medical educators and engineering educators to further consider the parallels that exist between these two professions. We have much to learn from each other. The transformation of engineering education, like medical education, is not a problem to be solved but an ongoing endeavor that requires a management approach. Like other great social issues, we need to start working in interdisciplinary teams to transform our educational approaches and engineering and medicine can learn from each other.

Engineering can no longer be characterized as problem solving especially in a world trying to grapple with the ideas of true sustainability. Engineering has to be re-characterized as problem definition, some problem solving and problem management. Otherwise engineering will quickly be viewed in an instrumental manner by society –resulting in a very limited role. This needed re-characterization requires a modification of the engineering curriculum and pedagogy. Moving toward active learning scenarios and project centric, team based study represent a good first step in this direction. It also requires the development of a more formal structure to the foundations of this re-characterized profession, a topic being explored by the authors in a paper in development.

References

ABET. 2013. Criteria for Accrediting Engineering Programs. http://www.ABET.org.

Denning, P. J. 2014. The Profession of IT, The Whole Professional, *Viewpoints*, CACM, **57**(12): 24-27.

Downey, G. L. 2005. Keynote Lecture: Are Engineers Losing Control of Technology? From “Problem Solving” to “Problem Definition and Solution” in Engineering Education. *Chemical Engineering Research and Design* **83**(A8): 1-12.

El-Zein, A. H. and C. Hedemann. 2013. Engineers as Problem Solvers: A Deficient Self-Definition for the 21st Century, Proceedings of The 6th International Conference on Engineering Education for Sustainable Development Cambridge, U.K.

EWB-International. 2014. http://www/ewbchallenge.org

Goldberg, D. and Somerville, M. 2014. *A Whole New Engineer: The Coming Revolution in Engineering Education*. Three Joy.

Irby, D. M., Cooke, M. and O'Brien, B. C.. *Calls for Reform of Medical Education by the Carnegie Foundation for the Advancement of Teaching: 1910 and 2010.* http://journals.lww.com/academicmedicine/Fulltext/2010/02000/Calls_for_Reform_of_Medical_Education_by_the.18.aspx

Jonassen, D. H. 2013. Engineers as Problem Solvers. *Cambridge handbook of engineering education research*, A. Johri and B. M. Olds, eds., Cambridge University Press.

Miller, G. 2014. Exploring Engineering and Sustainability: Concepts, Practices, Politics, and Consequences. *Engineering Studies*, **6**(1): 22-43.

National Academy of Engineering, http://www.engineeringchallenges.org

Olin College of Engineering. http://www.olin.edu/about/. Accessed 5 January 2015.

Sheppard, S., Macatangay, K., Colby, A., and Sullivan, W. M. 2009. *Educating Engineers: Designing for the Future of the Field*, Jossey-Bass, Inc., San Francisco, CA.

Siller, T. J. and Johnson, G. R. 2010. Specialization: A Detriment to Problem Conception. *Bulletin of Science, Technology & Society*, **30**(3): 214-221.

Trevelyan, J. P., 2014. *The making of an expert engineer*, Taylor & Francis Group, CRC Press, London, U.K.