# Multiple Perspectives: Key to a new Introductory Engineering Course

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*Abstract* - **Concepts such as the Grand Challenges for Engineering in the 21st Century present the potential for a major shift in engineering education. Colorado State University developed a new first-year engineering course based on the concept of the grand challenges. We developed an approach to frame the in-class discussions called the divergent-convergent approach. This method encourages students to think broadly about the technical and non-technical issues society faces –diverging from a narrow disciplinary mentality. Then the class presentations and discussions converge towards technical discussions illustrating elementary engineering concepts. At this point, bringing the students back to readdress the major non-technical challenges completes the cycle. One of our main goals is to focus students to critically analyse topics from multiple perspectives. The National Academy of Engineering's Grand Challenges provide an opportunity to make major changes in engineering education. To affect this change, faculty need to consider new pedagogies that fit the breadth of the types of projects engineers of the 21st century will face.**

*Index Terms* – Engineering Grand Challenges, Global, Interdisciplinary, Energy

## INTRODUCTION

The challenges and problems that engineers will be called upon to solve in this century will require their ability to understand largely interdisciplinary issues. For example, issues of providing solutions for future energy needs can be characterized in two manners: 1) no one source of energy will be sufficient, either in availability or reduced environmental impact to solve affordability and capacity problems, and 2) every individual energy source solution requires knowledge that spans multiple technical and nontechnical fields.

Engineering educators have developed the skills and pedagogies necessary for successfully teaching specialized knowledge [1]. Whether it be the lecture presented by highly specialized faculty or repetitive problem solving drills common to many engineering courses, or some combination of these, these approaches have worked. The current literature is replete with numerous examples of newer pedagogies that often focus on better methods for teaching the still accepted highly specialized engineering knowledge common in engineering curricula.

The authors of this paper elsewhere have called for the undergraduate engineering curricula to break, at least partially, from the standard highly specialized curricula and include more cross- or interdisciplinary content in the curricula. Following such an approach will demand new pedagogical methods that are tailored for presenting interdisciplinary content.

Herein we discuss recent work related to an interdisciplinary course developed by the authors that demanded different pedagogical methods. Specifically, two techniques were used extensively to teach first-year undergraduate engineering students, along with a smaller number of students from other disciplines, interdisciplinary topics such as energy.

## BACKGROUND

To set the stage for what we mean by engineering on the boundaries we start with a simple story of an energy project at our home university. In 2008 our university announced plans for developing a wind farm to produce 150 megawatts of electricity. This project served as a key component to a goal the university set of reaching carbon neutrality by the year 2020. The original project announcement occurred in 2008. Colorado State University owns property that was donated for the purpose of creating a research farm. With the site available, the university entered into an agreement with a wind energy firm to develop the project. In the fall of 2009 the university terminated the contract with this firm due in part to lack of progress towards the site development. A second firm was engaged in the summer of 2010 to take over the project. Then in December 2010 the university announced its decision to abandon the project. Substantial fees were paid to the two organizations.

The failure of this project to reach the desired goal cannot be attributed to one particular reason. A series of issues around the project caused difficulties from its very beginning but it is worth highlighting several issues that are directly related to our objective of developing an approach to engineering education that might lead to different approaches to these types of projects in the future. It is important to note that the project did not fail because of a lack of technical ability to produce the electricity from wind turbines. Instead, it was a combination of issues, some technical, some not, which led to the abandonment of this particular project. Carper [2] indicated, as quoted in [3] that "There is always a technical/physical explanation for a failure, but the reasons failure occurs are often procedural …. Procedural causes are usually interdisciplinary, involving communication deficiencies and unclear definition of responsibilities." Although this quote is pointed at the physical failure of engineered structures, it is equally applicable for the failure of a project to be completed, such as this wind energy farm example. It is necessary to identify the cause of failure regardless of whether it is a structure or a planned project that has failed.

So what were the issues? In the announcement of the termination of the project several were listed: financial considerations, siting issues, and lack of transmission capacity to potential partners. Other than the financial markets situation, which seems to change daily, the other issues clearly existed at the beginning of the project. The site for the wind farm was established because the university already owned the property. The existence, or lack of, transmission capacity to share the energy produced was a critical component, but once the site was chosen this lack of distribution capacity should have been obvious. So why were these, what seem like obvious, problems not identified early in the project and dealt with early on. We contend that these issues are often at the boundaries of the project definition phase and therefore are often ignored until it is either too late or they become the source of "unexpected" problems. There is not enough room here to do an in-depth analysis of this case study but we will return to this concept of boundary issues as it relates to our approach to teaching engineering students about large energy-related problems.

In a recent announcement by the United States' National Academy of Engineering [4], several energy-related challenges were included in its list of Grand Challenges that engineers will work on in the first several decades of this century. The list includes: make solar energy economical and provide energy from fusion. In a class we recently developed for first-year undergraduate engineering students, these two topics were included in the syllabus. The authors have pointed out in earlier papers [5,6] that the nature of these topics differs from what is traditionally covered in engineering curricula. An important aspect of these challenges is the interdisciplinary nature of the problems. No single engineering discipline "owns" these challenges. As well, none of these challenges has a current solution, that is, they are all open-ended problems. The magnitudes of the problems are also extremely vast and will require immense efforts in their resolutions, if not solutions.

Our rationale for developing new pedagogies for teaching *engineering on the boundaries* can be illustrated graphically, as shown on Figure 1, where we model the entire ream of social issues and technical approaches with the levels shown. In this figure we attempt to show how technical issues relate to the non-technical issues for engineering projects. On the left-hand-side the level of societal issues are illustrated with local concerns at the center, and as one moves outwards the concerns become more global. On the right-hand-side of the figure we attempt to show the level of technical knowledge in terms of localized (specialized) versus global (transdisciplinary) definitions. At the center is the highly specialized knowledge that seems most valued in [5] engineering education today. For our energy discussion this might include knowledge related to ignition systems for nuclear fusion or knowledge of plasma behavior. As we move out from the center, similar to the societal concerns, the knowledge becomes more global, or as shown in the figure more interdisciplinary. In simple terms for our purposes, multidisciplinary refers to the case where two or more disciplines are working in parallel with each other, but little to no interaction occurs. Here students may learn about the design of mechanical systems for containment such as super-coolant systems that have to be placed alongside the magnetic field generating machines. When work becomes interdisciplinary, as the multiple disciplines work on a project, they communicate and inform each other as work progresses. At this level knowledge about materials capable of surviving the fusion process are related to the mechanical features of the containment facility to create a safe facility. Finally, trans-disciplinary work refers to the case where the interaction of multiple disciplines results in entirely new solutions that transcend any disciplinary approach. This stage of knowledge may not have been reached in our example of nuclear fusion power!

Connecting the two sides in Figure 1 are paths from social issues on the left to technical solutions on the right. These paths represent the beginning phase of the engineering design process, often referred to as problem definition. An important question is where along the path does the problem definition start. Problem definition, in its traditional sense, tends to occur close to the point where the pathway intersects with the right-hand-side of the figure. One of our goals is to get engineers involved with what we term problem conception [5] by starting the process closer to the left-hand-side, or the beginning of these paths.

Our contention is that the origin of the path plays an important role in the type of solutions developed. Much of traditional engineering starts with a path somewhere, often close to the center, on the right-hand-side of the figure. Our intention is to start students on the left, or the social issues side first. For example, path A starts from a local point of view. This path tends to intersect closer to the center of the right side. With this as a starting point, a solution will evolve outwards (Path D), requiring that more disciplinary contributions be added to the specialized-centric starting point. Alternatively, as the path starts further out on the social concerns the more likely it is to intersect further out on the technical knowledge continuum, therefore incorporating more interdisciplinary knowledge at the beginning of a project. For example, the decision might be made to develop and implement a community water ethic for conservation versus a new pipeline, dam, or desalination plant. Then the solution may be refined by proceeding in the reverse direction shown for Path D to support this solution with appropriate technologies if necessary. This is the goal in our approach to teaching first-year engineering students: get them thinking in an interdisciplinary manner from the start.

Before we proceed it is valuable to refine our definition of engineering on the boundaries. Figure 1 lets us discuss two sets of boundaries. First, we consider the gap between the societal concerns and the technical knowledge side of the figure as a boundary to the engineering profession. A second and perhaps more subtle set of boundaries exist, the demarcation between the levels of either the societal concerns, or between the levels of technical knowledge. These boundaries can be just as problematic as the one between the two sides of the figure. Finally, when we refer to engineering on the boundaries we are thinking about how engineers can work and think about what lies on the other side of these boundaries and how that can be incorporated into engineering education.

## PEDAGOGIES

We decided early on in the development of our course that we needed to use very different pedagogies if we were going to reach our goal of getting students to think in an interdisciplinary manner. Herein we describe our approach to teaching students about the grand challenges, specifically focusing on the energy-related challenges of solar and fusion based power production. To encourage interdisciplinary thinking in the classroom we used a technique we call divergent-convergent thinking [7]

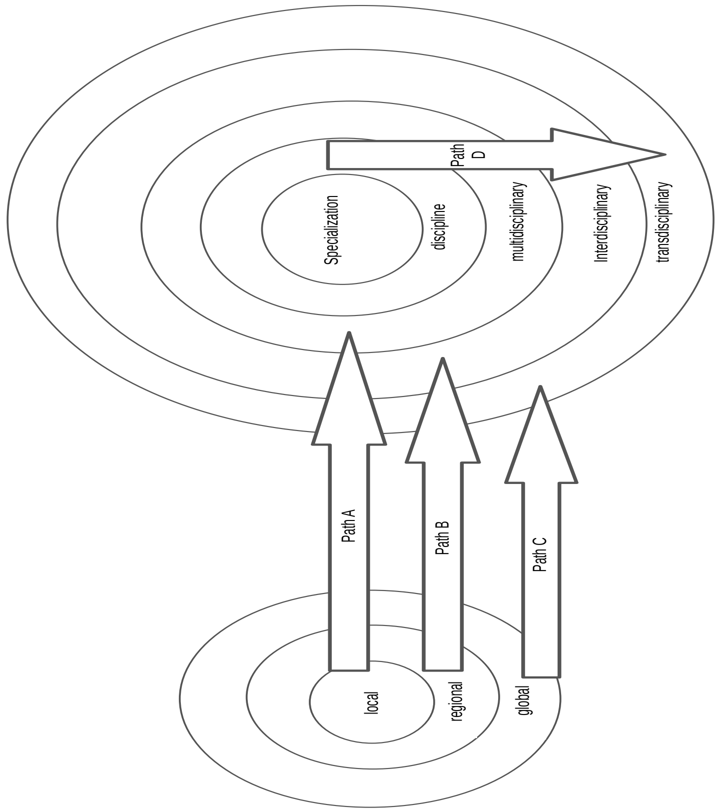


FIGURE 1

We would start the discussion for each topic by attempting to get the students to discuss the big-picture issues, typically related to the left-hand-side of Figure 1. During this phase we use a software package called Inspiration that was developed for group brainstorming exercises. The students were asked to speak out short phrases that were indicative of some aspect of what energy meant to them. If students were too wordy, we asked them to shorten their comments to just include the necessary idea they were trying to communicate.

New ideas were incorporated into bubbles on the diagram and placed randomly on the screen by one of the instructors. This process would continue until the students exhausted their thoughts on energy or until the discussion began to become repetitive. This discussion could continue easily for an hour. We were often amazed at how much the students knew about the various challenges. Figure 2 illustrates a typical session based on energy as a topic. Note that at this point no organization exists within the figure, only brief unconnected bubbles containing key energy terms as expressed by first-year engineering students.

This first part was the divergent thinking where students would develop lists of all the issues surrounding a challenge. In fact, this broad-based thinking led us to combine the solar and fusion challenges with wind, and hydropower since the students saw the bigger picture being energy first, then specific potential solutions, e.g. solar versus fusion. The students consistently identified topics that belonged to both sides of Figure 1, but most fell on the outer boundaries of these plots. In this opening discussion, students listed topics such as: public acceptance, public perception, waste disposal, conservation programs, and sustainability.

The result of the divergent phase of the discussion was that we could clearly establish student thinking consistent with our goal of establishing starting points on the social issue side along with starting the technical discussion near the outer boundaries. The next step was to establish a path heading towards the center of the technology side of Figure 1. This phase we term the convergent discussion. Here we would lead students towards an understanding of the technical issues related to the energy challenges. For example, we eventually reached a point where we discussed various specialized approaches to creating the fusion process, including the lasers being used at the National Ignition Facility at the Lawrence Livermore National Laboratory and the plasma approach in England [8].

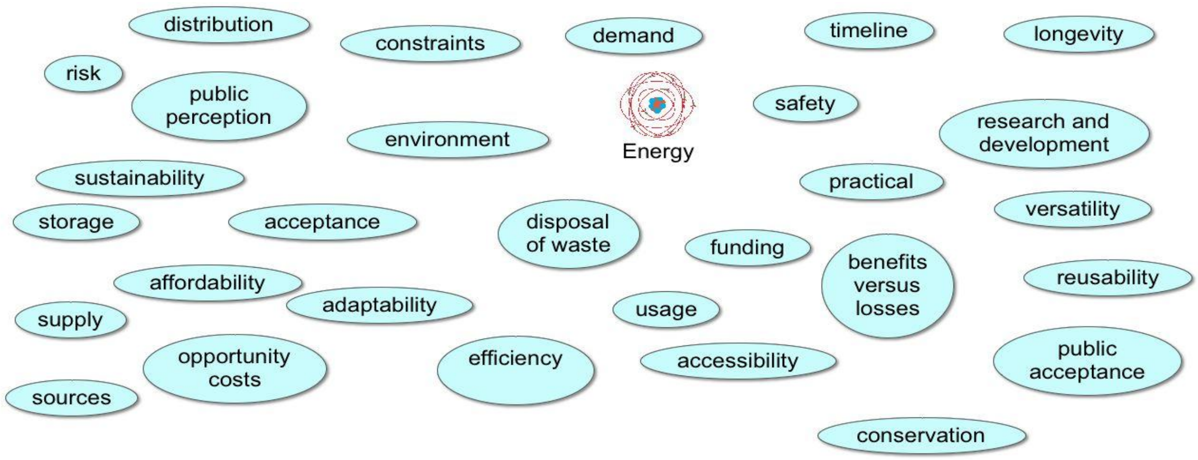


**FIGURE 2**

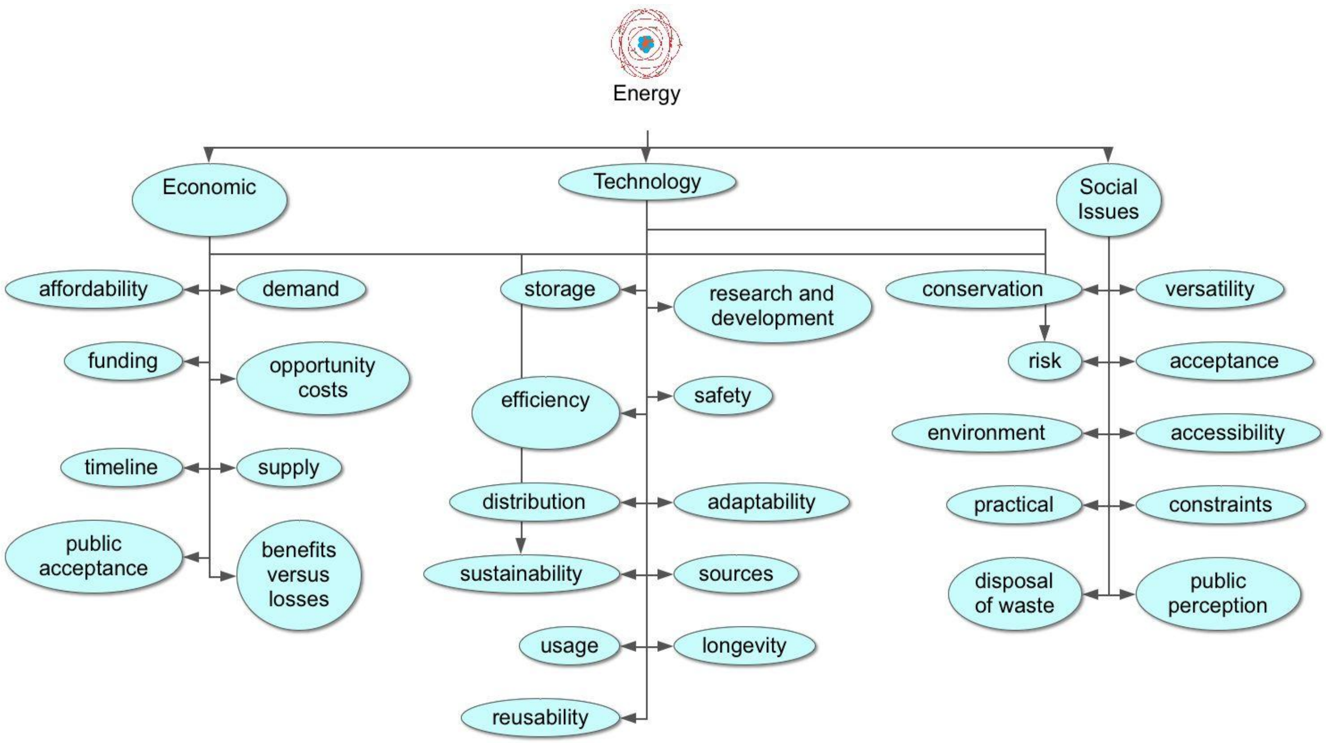


**FIGURE 3**

This convergent phase consisted of our making connections among the bubbles shown on Figure 2. The connecting lines indicated some element of knowledge organization. The results of this phase are shown in Figure 3 that has been reformed to indicate the clustering of topics.
The major headings are now economic, technological, and societal. This phase represents the knowledge organization phase. During the term we begin by doing this organization for the students but later in the term we ask the students to undertake this phase comparing their results among student groups.

At this point, we can burrow into any of these bubbles for a deeper discussion involving engineering concepts, parameters, or any other feature of interest. For example, Figure 4 shows a new diagram representing the bubble "storage" from Figure 3. Here the headings represent different storage technologies: thermal, mechanical or kinetic, potential, electrical, and chemical. Other bubbles may also be discussed where we do not limit ourselves to only the technology bubbles, but rather might discuss "benefits versus losses," "disposal of waste," or the impact on the "environment."

A new technique we introduced during the second offering of our course we called scope maps or scope plots. Figure 5 illustrates this concept. Essentially the axes of this plot are radial lines emerging from the center of the social issues and technology plots in Figure 1. Proposed solutions to the energy challenge could then be placed where students thought they fit the axes' scales. These plots served two purposes: 1) we used them during class to bring focus to our discussion and to make explicit the connection to the path between the boundaries in Figure 1, and 2) they served as the basis for homework assignments. For homework we asked students to use this plot, and other similar ones, to analyze energy challenges. As part of this assignment the students were required to justify where they located the challenge. This really encouraged students to think both about the social issues and how they related to the sophistication of the technology. The students provided some wonderful discussions where they made connections between the social impacts of a technology as it relates to the complexity of the technology.

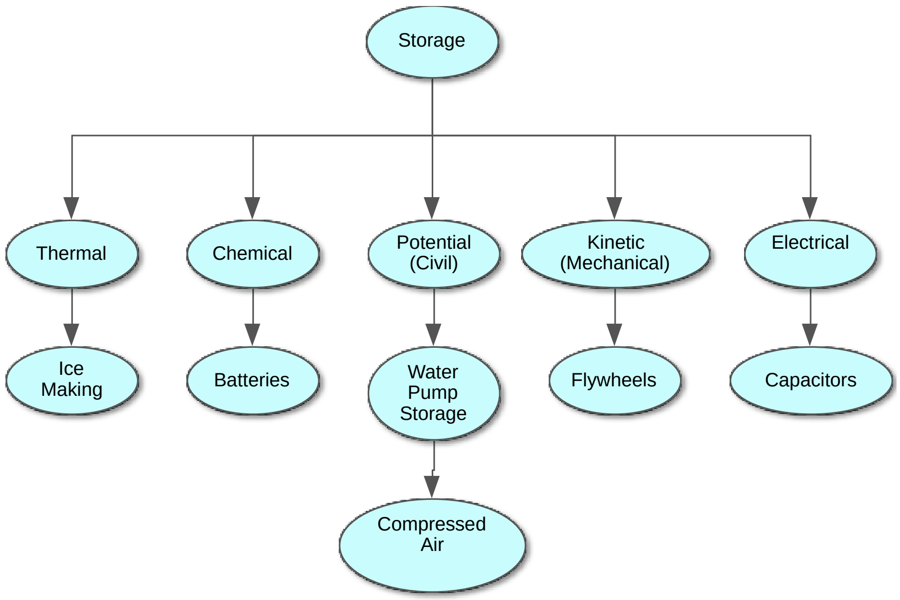


FIGURE 4

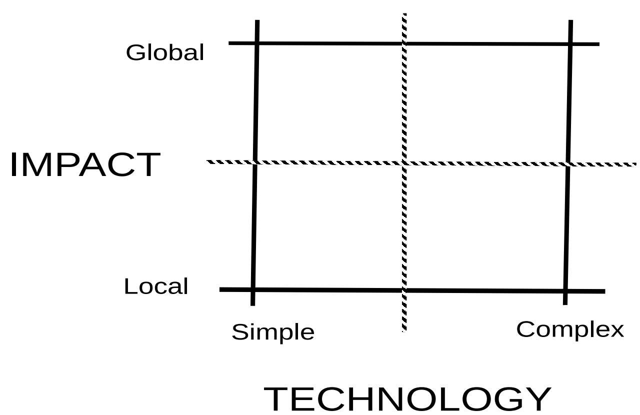


FIGURE 5

## SUMMARY AND CONCLUSIONS

Teaching a course on the engineering grand challenges for the 21st century turns out to be a grand challenge in itself. The breadth of knowledge required to provide even introductory descriptive materials is huge and presenting these topics to a young audience can be daunting but the rewards are significant. Plus, because the engineering design process should be organized in descriptive, analysis and synthesis stages, presenting descriptive knowledge in a first-year course is appropriate. In our case, the descriptive knowledge is not just technical but covers a broad range of non-technical information such as economic, societal, political and legal frameworks.

For example, had the wind farm problem been presented to our students, we are convinced that they would have listed geographic issues concerning wind turbine sites and lack of transmission capabilities at or very near the beginning of the project. This would have been forced by our use of scope, or context, maps to show the who and where as well as a societal framework indicating the remoteness of the existing land. Placing such issues early on in a project could have made for significant cost and time savings.

Using the engineering on the boundaries metaphor is a useful way to introduce the non-technical aspects of engineering design issues. It is certainly true that engineering is far less technologically based than nearly all engineering faculty believe. Most engineering design projects have assumed the solution concept during the stating of the problem so that specialists are called in at the very beginning of a project. This is clearly wrong because the problem conception phase is completely skipped in this approach. Even the grand challenges themselves suffer from being overly specified.

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