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Engineering Education at a Crossroad: An Integrative Approach

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ABSTRACT: The engineering technology is a dynamic one. Therefore, the curriculum must continuously follow a suit. Tt must give the student a thorough background in the fundamentals with an eye on more challenging applications and it must engender sufficient versatility to permit the inclusion of subject areas that develop as the nature of the industry and its technology change. Creating a vibrant learning and teaching culture is admittedly an idealized vision that needs to be tempered with the reality of limited budgets, societal needs, and other pressure points such as employment opportunities and industrial demands. Nevertheless, great potential for a change of perspective exists within the universities if this vision of dynamic and broad-based learning and teaching culture is held up as a beacon by students to direct their learning and by faculty to direct their teaching.

1 INTRODUCTION

A modem engineering curriculum, beyond the traditional focus of a specific engineering discipline, must provide the graduating engineer with a working knowledge of thermodynamics, fluid dynamics, transport phenomena, numerical analysis, advanced mathematics, rock mechanics, safety, experimental methods, computer programming and computational devices, and information technology. The courses should be structured İn such a way as to meet this goal. The challenge is to incorporate this broadened working knowledge into an engineering curriculum without diluting the traditional emphasis of the specific field. Perhaps a vehicle to approach this challenging problem is the direct incorporation of some of this working knowledge into those courses where traditional areas and subjects are discussed. This strategy can give the engineer a greater versatility, in not only solving new problems in a specific engineering field but also solving engineering problems in general. Today, it is not uncommon to find a mining engineer modeling a contaminant transport problem both around active mine areas and in fresh water aquifers. Similarly, a drilling engineer can be found designing drilling programs for oil and gas extraction or for ore reserve estimates or for environmental remediation purposes or fresh water supply. A mining engineer can be found designing pipelines for water, gas, or coal slurry transport. The same engineer can be found designing a network system for information management. It is very clear that a modern engineering curriculum must be broad-based in such a way that all these various facets are accommodated

The current practice of engineering is a far cry from the days of slide rules, charts, and tables. With the quantum leap in computer technology, an engineer now has a very powerful tool at his/her disposal. With the strike of a few keys İt is possible to simulate various production scenarios of a plant. Voluminous amounts of information can be processed within a short period of time so that the engineers can quickly make decisions that may guide the overall project direction. Only a decade ago, this was inconceivable. However, inherent in every opportunity there is a danger. A curriculum can run the risk of over-emphasizing the use of 'canned' software packages to the extent of making the engineer a hostage rather than the prime mover. It is of paramount importance that a robust engineering curriculum equips the student with theoretical backbone as well as the mechanics behind the model. Thus, the engineer will be capable of properly interpreting the results generated. Furthermore, the engineer so trained should have little difficulties in implementing the same knowledge base to similar problems in other areas.

Why is a broad-based curriculum for today's graduating engineer advocated? Is it primarily because of the shift in the job market in whereby an engineer is expected to possess a good 'skill mobility*? Or, is it because the graduating engineer needs to be positioned in such a way as to be more marketable in our ever-changing economy? The answer to both questions is a resounding yes! A quick look at the changing nature, *albeit* structure, of the industry will shed some light on these issues.

2 CHANGING PHASES OF ENGINEERING PROFESSION

We do not have any choice. Change is all around us. Why are we so afraid of change? It was once said in a most elegant way: "It's not so much that we're afraid of change, or so in love with the old ways, but it is that place in between that we fear....It's like being between trapezes." (Ferguson 1986). Change is a fact of life. Engineers and the engineering profession are not immune. During recent years engineering has continued to evolve, resulting in what seems to be very different career trajectories for engineers than even two or three decades ago. Job change is much more frequent. Teamwork is the primary focus. Industry conducts less long-term, fundamental research. Engineers now spend much more time on management and other human resources related tasks. The workforce is more diverse and engineers today receive extensive continuing education and in house training.

What has remained unchanged in the engineering field is the design component It is universally accepted that the most important aspect of the engineering profession is the engineering process (sometimes called the engineering design process). If one were to review the engineering design process İn its entirety, immediately it would be realized that every aspect of the engineering profession had to be visited. The engineering design process will involve identification of customer need and opportunity, problem definition and specifications, data and information collection, development of alternative designs for various scenarios, evaluation of designs and selection of optimal design, and finally, the implementation of optimal design. The engineering profession over the course of years has completed a number of iterations on the design process, and one can trace the evolution of an engineering process through these iterations.

Engineering: where it has come from—Engineering_is as old as human beings and is concerned with everyday living, even survival, particularly in its ancient beginnings. It was once said that engineering represents the "desire of man and woman to harness and control the natural forces on earth to society's advantage—the wind, the seas, the tides, the soil, etc."

Engineering: where it is today—In engineering, yesterday's goals are still today's goals. However, today's engineers are working on problems of larger scales and greater complexities than hitherto. The significant increase İn population and resource use, greater awareness of our environment, and greater intellectual curiosity are the three main parameters that scale the size and degree of complexities of the goals of the engineering profession today.

Eneineenng: where it is going Today's challenges are tomorrow's opportunities and the engineer and engineering profession must rise to the occasion. Perhaps the most important challenge the engineering profession will be facing tomorrow is the presence of an information overload. At the touch of a button one can find millions of giga bytes of information. This information is available to everybody; thus, anybody can become a significant competitor. Therefore we will observe the emergence of a competition that will most probably become increasingly rougher. Yet, globalization efforts will have a compounding effect on the level of competition. The economic systems, eco-systems, and engineered systems will become more intricately tied together resulting in much larger systems. Therefore, tomorrow's engineer needs to be increasingly more adept in understanding the dynamics of interaction between these systems.

From this short discussion it is clear that engineering workforce and engineering profession are continuously evolving. It should be recognized that this evolution follows patterns that reflect the major shifts experienced in global economy.

3 CURRENT AND FUTURE FRAMEWORKS FOR ENGINEERING CURRICULA

The central goals of an engineering curriculum today and tomorrow should:

- provide students with skills to perform effective problem solving;
- assist the students to develop a logical thought process;
- introduce the students to basic engineering tools;
- increase students' spatial and temporal analysis skills;
- help students develop appropriate planning skills;
- teach the students how to read and/or interpret technical presentations; and
- help the students develop an ability to think both critically and creatively, in an independent and cooperative manner.

A typical contemporary engineering curriculum contains courses in general education, basic sciences, engineering sciences, and engineering design. Most of the materials covered in these different groups of courses are taught in a capsulated form. In other words, the existing interrelationships between these focus areas are not emphasized. In one classroom students leam how to solve a high order non-linear partial differential equation without realizing the equation represents various analogous physical phenomena in a variety of engineering fields. One or two years later, the same student in another classroom sees the same differential equation in a different form and even leams how to solve it using specialized software without recognizing that he/she is solving a partial differential equation that he/she had solved earlier. Similar examples can be found in fundamentals of ethics and engineering ethics or freshman physics laboratory experiment on equipotential contours and streamlines and transport problems in porous media. An effective integration of courses taught under different focus areas will result in the following enhancements to an engineering curriculum:

- students not only learn mathematics and science but also develop an understanding why they need to know it;
- it takes less time to cover the engineering material and the resulting time savings allow for team training and team development; and
- students develop a sense of community so that they regularly attend class, study in groups, and help each other.

It should be recognized that a vibrant curriculum with teachers and students energetically participating İn the learning process requires dedicated interaction between teacher and learner. Both quality teaching and quality learning require hard work, diligence, and major time commitment. Within the higher education institutions the focus has been essentially on improving the teaching process. The future curricula will have this attention redirected towards the students* role in the learning process by working on the question "what are the more essential elements required to learn?"

3.1 *Engineering versus science—a change of perspective*

Osborne Reynolds in 1868 said: "Science teaches us the results that will follow from a known condition of things; but there is always the unknown condition, the future effect of which no science can predict." Throughout the years engineering curricula always faced the challenge of striking a good balance between engineering topics versus science. The neophyte engineering student often asks the question why does he/she need to take the science courses if he/she is going to become an engineer. Osborne Reynolds' remark indicated that engineering is anchored on science.

Eric Laithwaite (1984) in his book Invitation to Engineering said: "An engineer İs a man who uses the earth and tries to capture the sun's energy more effectively. He controls the rate of destruction of matter and tries to find alternative sources of energy and new materials. He invents new shapes of matter and strives to improve the quality of life in whatever form he finds it."

If we attempt to combine Reynolds' and Laithwaite's remarks we will come up with the following deduction—scientists want to know the reasons behind the life and engineers want to improve the standards of life based upon what they have learned about it through science. This is why throughout the history of engineering education engineering and science have been hand-to-hand with some degree of variations in the relationship. Figure 1 shows the changes that have taken on the quality and the extent of relationship between science and engineering over a large time scale. In Figure 1, we see that engineering *comes* to an existence without using the scientific reasoning. Later, the engineering field recognizes the importance of science as science starts to push the envelop for the fundamental understanding of issues which start to appear in increasingly complex domains. At the present time, fields of science and engineering provide much needed feedback to each other. However, *the* presence of this symbiotic relationship does not necessarily imply that there is no polarity between the engineers and scientists. It is quite often possible to see the engineers with the perception that scientists have the tendency to become tangential to the needs of the society. At the same time scientists may think of engineers as narrowly focused practitioners because they are not dynamic in their thought process. This perceived controversy arises from misconception since in truth science forms the bedrock for engineering. However, the line of demarcation between science and engineering is opaque. This is why any effort that utilizes the synergy between science and engineering sets a trajectory that brings us to the solution in a much more efficient manner.

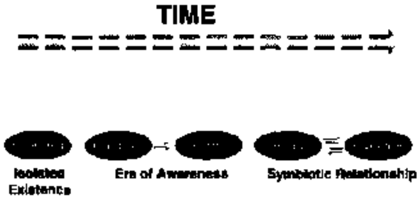

Figure 1. Engineering and science from isolated existence to a symbiotic relationship.

3.2 *The methodology of curriculum design*

Engineering is a field where one can experiment with creativity. In this field, the abstract ideas of the physical sciences and the insistent demands of society driven by a high-powered economy converge. In this conjunction the engineer is the synthesizer or the creator. The methodology of curriculum design has to honor this essential underpinning of the engineering field. It is a generally accepted fact that there is a mounting concern among the industrial organizations about the impact of traditional engineering education on the creative potential of future engineers. A lack of creativity is clearly problematic in a rapidly changing, technologically oriented world where generating new ideas is essential to survive. Therefore, as shown in Figure 2, the first step in curriculum design is the correct identification of the problems that are going to be addressed by the graduates of the engineering program. Obviously, the societal and industrial needs (which are fully linked to each other) have to be considered. In structuring the curriculum, the second step, the overall objective is to provide opportunities for students to learn meaningful concepts meaningfully. Here we identify three distinct components: (i) meaningful learning, where a person attaches meaning to the concepts under study, (ii) concept formation, where a learner organizes ideas and information to formulate new ideas and concepts, and (İÜ) problem solving, where an individual uses information and knowledge in various new ways to solve problems. While watching these three components closely, we note that these large scale adjustments in engineering education are put on new trajectories by the advancement of teaching and learning methods, controlled by the institutional resources, and watched by the accrediting bodies. Therefore, these existing external and internal forces will always provide the necessary and much needed boundary conditions. The implementation and evaluation phase constitutes the third step of the curriculum design methodology. The advisory board (ideally composed of industry representatives and academicians from other institutions), external examiners, visiting scholars, and feedback from the industry at large will provide the paths for infusion of ideas and much needed objective and constructive criticism during this phase.

3.3 *Attributes of an engineer and goals of engineering curricula*

The technical skills, inter-personal skills, and good citizenry skills constitute the three basic groups of skills that an engineer must gain during his/her engineering studies. These attributes of the engineer and goals of the engineering curricula must be in concert. Under the technical skills, the curriculum should provide opportunities to the student such that he/she is equipped with knowledge of mathematics and basic sciences, analytical and interpretive ability, empirical skills, system and process design skills, and problem solving skills. The communication skills, effectiveness as a team player, collegiality, and knowledge of contemporary issues will highlight the inter-personal skills that are acquired during the tenure of the student. Finally, the engineering curriculum must graduate engineers whose technical knowledge is tempered by professional ethics, professionalism, global perspectives, and environmental awareness which make the good citizenry skills.

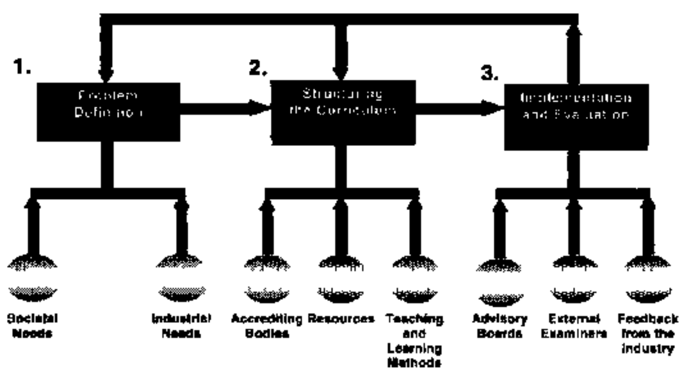

Figure 2. The methodology of curriculum design

3.4 *Framework of current engineering curricula*

The current engineering curriculum is designed to impart me attributes of the engineer as described in the previous section to its students. The framework for achieving this is well established as shown, in Figure 3. In Figure 3, engineering sciences, mathematics, basic sciences, and engineering design modules make up approximately two-thirds of the total number of credit hours covered in a typical engineering curriculum. Although it is very desirable to have all of the modules of Figure 3 integrated to each other, in reality today's engineering curricula follow a more or less fixed hierarchy. Most of the time, limited institutional resources will not allow each engineering discipline in the institution to redesign, optimize, and personalize the hierarchy shown in Figure 4 for each specific discipline. As a result of this, instead of an integrated curriculum, institutions end up with curricula in the form of a broken chain.

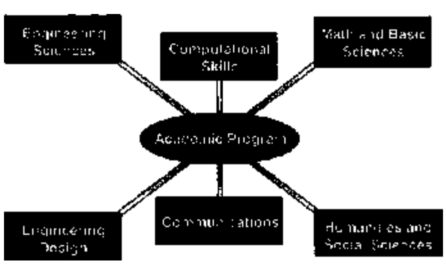

Figure 3. Framework of a typical engineering curriculum.

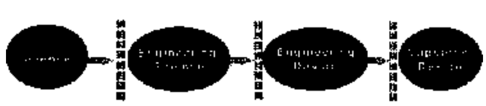

Figure 4. Broken-chain hierarchy of a typical engineering curriculum.

The following points capture the most salient weaknesses of a typical engineering curriculum:

- extensive compartmentalization;
- inadequate emphasis on communication;
- delayed exposure to the core curriculum;
- localized philosophy;
- inadequate emphasis on economics and management issues;
- intuitive rather than formal approach to ethics and professionalism; and
- overstrucfured and overloaded schedules do not permit independent learning.

3.5 *Winds of change*

In the previous section some of die well-known deficiencies of the current engineering curricula are highlighted. The good news is the wind of change is in the air. In this section we will look at the various forces dictating the changes.

Societal—One of the more effective factors forcing the change is society at large. The ever-increasing cross-cultural mobility and recognition of global dependence demand the removal of existing localized philosophy. Today's engineers are prepared not only to meet localized challenges but also towards the needs of the global village. It is also true that today's engineers are serving a society whose members are better informed and more demanding. Therefore, a greater emphasis on competitiveness and cost effectiveness will enter into the picture.

Industrial—The overall architectures of today and yesterday's industries in many respects do not conform to each otiier. In a traditional industrial organization profit was important, however, in today's industry 'profit' is always spelled in capital letters. In the past, industrial organizations have been known as insulated units working in their own spheres of interest. Today's industry, on the other hand, has to be more'competitive in a number of areas. While the hierarchical structure is a norm for the traditional industry, today's industry has a much more flat appearance. We also see a major philosophical change in 'the attitude of industry towards its employees. Traditional industry has always exhibited a parental attitude towards its employees. However, in today's corporate structure. we see a much more formal employee-emplmer relationship at every level of the organization. While traditional industry can be placed in the rich category in terms of its resources, today's industrial organizations, through its extensive restructuring efforts, surface as the ones with much leaner operations. During the last two decades, we also see that the traditional industry mat used to be thorough and perhaps a bit sluggish in its operations has assumed a much more rapid posture. In the traditional industry long-term projects were quite common, however today's industry is much more focused on current problems and issues. In consideration of all these changes, we see mat a much more hectic industrial work environment has taken over the yesterday's more stable traditional industry.

Technological—One of the more powerful winds of change is fed from the substantial technological advancements that we have been witnessing over the last two decades or so. The exponential growth in information technology, increased level of sophistication, information overload, and today's much more effective telecommunication all together place the industry on some new trajectories that were not in the radar scopes of the even most visionary organizations. The primary driver behind this forceful wind demanding changes in today's engineering curricula is the electronic explosion that we see in every facet of industry.

Measure of success—-As the societal, industrial and technological changes and developments dictate some pronounced changes in every aspect of the field of engineering, the yardsticks that are used to measure the level of success have to change as well. The perception that was used yesterday to measure the level of success has gone long and left its place to performance. Similarly, yesterday's "level growth" is replaced by "leverage" and so is the job security by employment potential. In the past the length of service was considered to be a powerful indicator of success, today, perhaps the "length of resume" is the corresponding new indicator. The degree of contentment that one was enjoying with his/her job is being changed by the degree of confidence. Perhaps, we can generalize these observations as the replacement of yesterday's romanticism with today's harsh realities.

Engineer—Whether one is graduated from the old school or the new school, there is no escape for the engineer from die effects of the forces summarized in the previous paragraphs. Yesterday's engineer who seemed to be more specialized is replaced by today's engineer who is expected to perform within a much wider spectrum of assignments. This is why today's engineer is in a more empowered status compared to the yesterday's engineer who would normally depend on his/her colleagues when the question Üıat needs to be answered is marginally out of his/her line of expertise. As a net outcome of this two statuses, we see that yesterday's comfortable engineer who felt more entitled and who is loyal to his/her company is being replaced by today's stressed engineer who is held more accountable and İn tum who has become much more loyal to himself/herself.

The question that still needs to be answered is how a new engineering curriculum can accommodate all these changes.

3.6 *Integration of research in undergraduate education*

At the present time undergraduate engineering students' exposure to research within the engineering programs across the world is quite minimal. Students who happen to gain some research exposure during their undergraduate studies are usually the ones who initiate this activity and are often the ones who are deemed most competent. There is no doubt that undergraduate students who join to a research group benefit from the experience in a number of ways including:

- developing domain expertise m science, mathematics, and engineering;
- gaining better appreciation as well as more sound understanding of the research process and the associated protocols and their implementation;
- enriching their decision making process especially at critical junctures;
- developing team member skills and appreciation for the teamwork; and
- becoming a more experienced technical communicator by writing technical reports and " making oral presentations.

There are several challenges in increasing the number of undergraduate research participants. First of all, funding is an issue for both research advisors and students. The rigid nature of the undergraduate engineering curricula also does not'permit for the student's participation in the research program for an extended period of time. Therefore, the mentor's investment on the student during the time the research program is initiated may be lost if the student does not have the flexibility to continue with the program for several consecutive semesters.

In consideration of the difficulties outlined above and the expected added values to the student's educational experience, faculty in their respective courses should provide ample opportunities to equip their students with some research experience. Engineers seek optimal solutions to problems. In making decisions analogical reasoning is at the heart of engineering thinking. By participating in research projects engineering students will receive training and be able to enhance their engineering skills in the use of analogy. This is a critical component of engineering education that should not be overlooked.

3.7 *e-Learning and engineering curricula*

Most of the e-learning is done at the graduate level education. This statement is also true for engineering education. By any measure e-leaming is booming, as it is becoming one of the fastest moving trends in higher education. Faculty members in different programs are putting their course materials in an electronic format and experimenting with various forms of interactive teaching forums such as web based learning and real time chat-room discussion groups. It is not a far-fetched imagination that within a decade or so all courses taught on-site will also be available on-line.

The burning question is whether the students learn as well on-line as they do on-site. Although only some relatively limited data (due to the relatively young nature of e-learning) have been collected, all of the data indicate that teaching and learning on-line does not dilute the educational experience of the students. However, it is also recognized that on-line learning requires more discipline and maturity than conventional on-site learning.

One of the questions that still needs to be answered in e-education is the question on the ownership of the intellectual property. Who owns the course taught on-line? The professor who designed it? or the school who helped putting it on-line by providing servers and/or courseware designers? While answers to questions like this are still being discussed, e-leaming will continue to become an increasingly attractive alternative to students both at the undergraduate and graduate levels. The engineering curricula should also be ready for this most significant transformation in the higher education institutions.

3.8 *Fully integrated engineering curricula*

A fully integrated engineering curriculum will respond to the external forces that demand significant changes in different components of the undergraduate engineering education. These changes will include (Everett *et al.* 2000):

- integration of basic sciences and mathematics into problem solving and engineering design;
- an increased emphasis on teaming and collaborative learning;
- use of computers to improve design and problem solving throughout the curriculum; and
- continuous outcome based assessment and evaluation methods.

Curriculum integration can be defined as the establishment of an educational protocol in which individual courses become integral components of a whole, while at the same time they are ensured to be interdependent with each other and are bound by a common thread of knowledge. Figure 5 schematically describes this educational protocol, One can visualize Figure 5 as a number of bowl-shaped water fountains that are concentrically placed within each odier. Water from the innermost fountain representing the basic sciences and mathematics cascades into the next fountain when it is filled up. The second fountain, engineering sciences in this case, while filled up from a direct connection to the main water line, İt also receives the cascading water from the first fountain. This process in a similar manner continues as the water from the innermost fountains reaches the outermost fountains.

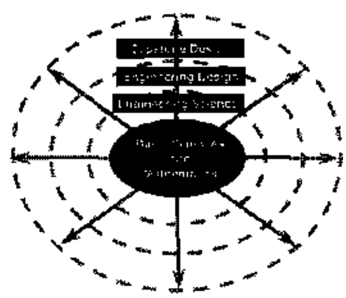

Figure 5. A possible structure for a fully integrated engineering curriculum.

In this process, it is important to note that water from the innermost fountain will reach the outermost fountain and will help having that portion of the fountain filled up. In this metaphor of cascading water fountains water represents the knowledge and information that are imparted to and utilized in the subsequent modules of the curriculum.

An integrated engineering curriculum as described here is expected to provide motivation for meaningful learning. It becomes more readily obvious to the student that mathematics and science are critically important to engineering as concepts learned during the freshman year are utilized in the first engineering course and the last capstone design course at an equal rate. A second advantage of an integrated curriculum lies in its inherent capacity for providing better control of the curriculum. In other words, concepts are taught İn a much more umform manner and duplicative effort in teaching is minimized.

It is reasonable to conclude that a fully integrated engineering curriculum ensures that technical complexities are handled efficiently, and good problem analysis and problem solving skills are instilled to the students in an effective manner. Although these aspects of an integrated curriculum are necessary, are they sufficient to educate the engineer who is sought by the today's society and industry? Some of the missing links of an integrated curriculum as depicted in Figure 5 will include:

- flexibility in choosing courses from other disciplines;
- team experience and collaborative learning;
- written and oral communication skills;
- contextual perspective—can the engineer look at a problem İn the context of a much larger problem?
- engineering ethics and professionalism;

- industrial safety and health;
- continuous learning;
- adaptability to broader spectrum of engineering problems; and
- decisiveness and judgment.

These aforementioned elements of an integrated engineering curriculum should be interjected into the curriculum at each level of the student's learning experience. In other words, our so called cascading water fountains should also be connected to other auxiliary water lines through which these equally important components öf the curriculum are introduced.

In the next and final section of tins paper, under the umbrella of integrated engineering curriculum, we will develop an inter-engineering disciplinary program.

4 SUBSURFACE ENGINEERING: AN ENGINEERING CURRICULUM FOR ACHIEVING SYNERGY

The concept of establishing an integrated undergraduate curriculum stems on the coexistence of Mining Engineering, Petroleum and Natural Gas Engineering, Geo-Environmental Engineering, and Mineral Process Engineering degree granting academic programs under administrative structure of the Department of Energy and Geo-Environmental Engineering (formerly known as the Department of Mineral Engineering) at the Pennsylvania State University.

4.1 *Motivation and driving force*

The shear diversity and complexity of the spatial domain called *earth* and of the potential for use of this domain for fulfilling human needs demand a broad-based view of the pertinent engineering activities anchored on a strong scientific foundation. This, no doubt, requires a broad and integrated multi-disciplinary approach. However, the present scientific culture for studying the earth and its resources is highly fragmented. While a number of disciplines focus on the very same spatial domain, they do not provide a coherent and integrated engineering education and research experience. The result of this fragmentation and rigid compartmentalization is a crop of young engineers and scientists with relatively narrow focus.

The approach being proposed under the umbrella *of subsurface engineering* takes a global view of the earth realizing that extracting mineral and other resources from it is only a subset of much broader set of activities all of which are interconnected. This is not only a radical philosophical shift in the way we think of the earth but also one which requires a new approach in the way we train engineers to think of it. If we treat the earth as a uniquely valuable resource that needs to be preserved and enhanced instead of being degraded by uncoordinated engineering activities, then optimal utilization of the earth can be achieved. It is envisaged that the engineers and scientists trained on this platform will be better equipped with broader and integrated thought processes and skills that will enable them to devise and build better engineering systems that satisfy a much wider spectrum of societal needs.

The driving force has three salient components whose resultant is the prime mover for tie new integrated engineering program proposed here.

These are:

- energy balance and society;
- environmental imperatives; and
- inter-/multi-disciplinary nature of the issues involved.

Whereas traditionally different groups of engineers focus on each of these forces without due cognizance by the others, the proposed approach will attempt to integrate all of them together with the eye on the prime mover. This is essential because the earth only recognizes the prime mover bufnot each of the components independently.

4.2 *Justification*

The fact that all human scientific and engineering activities are anchored by the earth is indisputable. The earth sustains the human being. However, uncoordinated human activities, whether on or in the earth, can only lead to a greater momentum towards non-substance of the earth. The challenge for the scientific and engineering community is to take an integrated view of the earth and its resources in such a manner that the parts will be greater than the whole. Although various disciplines are anchored on the earth, they tend to be compartmentalized as if there is no coupling between the various interest and activities. Since the sub-systems involved are physically coupled, it follows that the studies of these subsystems should take into account the interactions between them. This can only be achieved through a multi-disciplinary integrated approach.

4.3 *Vision, goal and objective*

<u>*Vision*</u>—-The proposed integrated curriculum aspires to shape future undergraduate and graduate education in earth related engineering through carefully orchestrated and fully integrated programs in subsurface engineering. This vision is anchored on the following premises:

- an engineered system that is based on a full understanding of the coupling with the other subsystems within the earth guarantees harmony between people and her environment; and
- engineers and scientists whose training and thought process emanate from an integrative approach to problem solving will become fully aware of the transportability of their knowledge based skills to a broad spectrum of problems.

Goal—The subsurface engineering curriculum focuses on the system of educating, training and research whose goal is to achieve optimal utilization of earth resources while preserving the pristine nature of the earth. Through creative and enlightening educational and research opportunities the program will promote the intellectual development of its students to improve the portability of their knowledge and skills. Along these lines, the specific goals are:

- to promote a full intellectual awareness of the interconnectivity between earth's subsystems and the corresponding engineered systems; and
- to produce a new breed of subsurface scientists and engineers whose understanding of the interconnectivity of the sub-surface sub-systems and the universality of the governing principles make them versatile and portable

Objective—The primary objective of the proposed integrated academic program is to construct a sound platform which will serve as a springboard from where the proposed integrative educational and research training programs İn subsurface engineering can be launched.

4.4 *Barriers envisaged and catalyst needed*

It is certain that an ambitious initiative of this type will require a certain amount of activation energy to overcome the inherent energy barrier. As shown in Figure 6, it is quite probable that a high level of activation energy which includes:

- fear of moving away from traditions;
- uncertainty of success;
- threat to disciplinary individualism;
- unwillingness to share resources; and
- adapting to new realities

will be encountered.

It is strongly believed that the single most potent catalyst is the robust atmosphere of academic freedom. After all, the essence of academic freedom is to challenge established thought and traditions, and expand the knowledge envelope. It should not be forgotten that the primary motivation mat will propel this concept to a logical end for achieving the necessary synergy is the commonality of the parameters and the similarity of die systems currently being addressed within various disciplines.

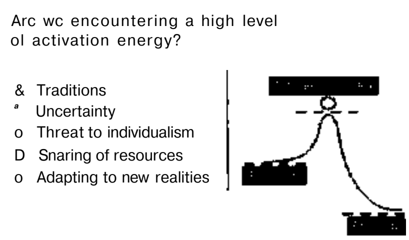

Figure 6. Potential barriers in structuring a new program.

4.5 *Framework/or the proposed multidisciplinary curriculum*

The practice of designing sub-surface engineered systems differs significantiy from that of traditional engineering systems. When designing sub-surface engineered systems one is invariably faced with far more unknowns than the number of relationships available. The challenge is always that the subsurface engineer is educated to work in any area in which all the answers are never known. That is why the subsurface engineer's education and logical minking must always be tempered with sound engineering judgments. In many cases, such judgments are emphasized. Perhaps, one of the reasons why the practice of subsurface engineering is partially shrouded mystery is a lack of understanding and accountability of interactions between the systems in question with other sub-surface systems. The framework of the proposed curriculum should be established on the aim of removing this shroud of mystery through integrated training and creative research.

Historically, the various disciplines that deal with some aspects of sub-surface engineered systems have operated within non-intersecting and non-interacting spheres, even when İt is apparent that they may be addressing similar problems. This invariably translates into the training of their graduates to be narrowly focused. The proposed subsurface engineering curriculum is an attempt to redefine the needed intersections between the expertises of these various disciplines and map out the synergy needed to address the complex subsurface problems that must be solved. Inevitably, one realizes that the nature of interactions is strongly dictated by the problem at hand The major ingredients for the "dynamic positioning" needed to firmly anchor the new integrative education in subsurface engineering are subsurface domain characterization, the kinetics of the chemical activities, transport phenomena and geomechanics, economic risk factor considerations, impact of sub-surface operations on the environment and public policies. This *interdisciplinary synergy* and *intellectual cohesiveness* will shape the *modus operandi* of the subsurface engineering curriculum as shown in Figure 7.

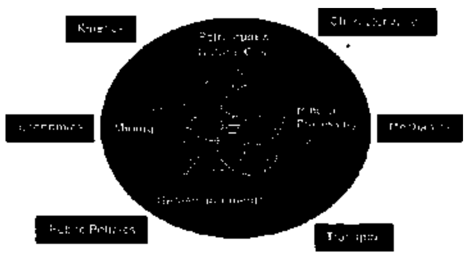

Figure 7. Intellectual cohesiveness and ingredients for a dynamic positioning.

4.6 *Typical thematic areas*

Within the framework of the subsurface engineering curriculum proposed, it is expected that engineers graduating from this integrated multidisciplinary program will be able to address problems and work on projects that span a wide variety of disciplines. A number of thematic areas is identified, examples include:

- groundwater resource management;
- solution mining;
- contaminant transport and control;
- waste storage and disposal
- coalbed methane recovery and containment;
- carbon dioxide sequestration;
- geothermal energy resource recovery;
- underground gas storage; and
- slurry transport.

The examples listed above to a certain extent epitomize the diverse and multi-faceted nature of sub-surface engineering issues. The cross-disciplinary challenge of addressing any of these issues is obvious. The subsurface engineer is not the one who is able to address one of these thematic areas in isolation but the one who is comfortable in addressing many of them and at the same time cognizant of the intricacies of their interconnectivity. Figure 8 schematically shows the thematic positioning of various engineering disciplines and their intersection on solution mining and coalbed methane recovery.

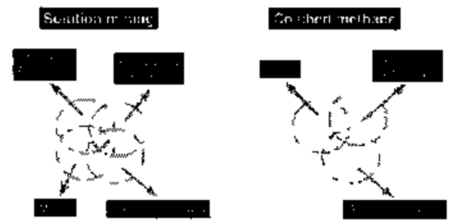

Figure 8. Intersection of traditional engineering programs on two interdisciplinary thematic areas.

4.7 *Process crystallization*

A broad-based engineering education for the subsurface engineer of the 21st century is necessitated by a need for skill mobility, flexibility and versatility. This is particularly important for the engineer to be well positioned in order to guarantee the continual marketability in the world's rapidly changing economical structure.

The colleges and universities who are best positioned to nucleate the subsurface engineering curriculum are the ones that have educational programs in petroleum engineering, mining engineering, geo-environmental engineering, geological engineering, mineral process engineering, and mineral economics. The necessary intellectual cohesiveness that emanates from these various disciplines will provide the scientific bedrock in the areas of exploration, characterization, mechanics, kinetics, economics, and public policies. In developing a new academic program in subsurface engineenng it is expected that the relevant faculty members from these various disciplines will form the core of this inter-disciplinary program so that no significant new faculty resources will be needed. Along the same lines, the existing instructional laboratories in these disciplines should provide the necessary infrastructure in fostering the objectives and goals of the subsurface engineering academic degree program as described earlier.

5 CONCLUDING REMARKS

In educating engineers we have come a long way and it has been a very successful journey. However, we should realize that we have come to a crossroad. It is now high time that we make a decision at this crossroad whether we should proceed on the same trajectory or make a departure. With the challenges of today, change is necessary to enable us to harness the opportunities of the future. An integrated engmeenng education anchored on strong scientific bedrock with an understanding of the social, cultural, geo-political context of our society and the globalization of the world economy provides the best competitive advantage for future engineers

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