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Seeds of Solutions™: An economical & efficient approach towards power engineering education

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SEEDS OF SOLUTIONS™: AN ECONOMICAL & EFFICIENT APPROACH TOWARDS POWER ENGINEERING EDUCATION

A Thesis

by

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SEEDS OF SOLUTIONS™: AN ECONOMICAL & EFFICIENT APPROACH

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ABSTRACT

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Power demands are set to increase over the next twenty years; however, research shows that there may be a shortage of power engineers due to an appreciable percentage of the current power engineer workforce retiring, insufficient enrollment in power engineering programs and a lack of emphasis in power engineering at the university level.

This thesis provides supporting research for future power demands, workforce and faculty shortages. Using temporary research in modern learning / teaching styles, student / teacher perceptions, educational trends and regional course offerings, this thesis describes a learning approach towards power engineering education. Designed specifically for universities with little to no power engineering course offerings and universities that wish to augment their existing approach, the approach incorporates an emphasis in fundamentals and engineering design making it economical and easy to implement. This thesis also includes three (3) video laboratory examples incorporating all elements of the approach.

DEDICATION

This effort is dedicated to my wife Lina, my daughter Lineli and baby Eli. Without you, I never would have experienced life. This paper is also dedicated to my mother and father, my sister and three brothers who have supported me unconditionally.

ACKNOWLEDGMENTS

I would like to acknowledge Mr. James McCann. His mentorship has had a great impact on my professional development. Mr. McCann has inspired me to do and learn things that I always believed were out of reach.

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CHAPTER I

With over 45% of the power industry's engineering work force nearing retirement eligibility by 2017 (Singh, C., 2012), the challenge of training the next generation of engineering power professionals to make immediate contributions will befall on universities and educators. Although there is an abundance of engineering curriculum approaches that have been published over the last decade, there are few publications that are recommending a combination of teaching approaches that will efficiently enhance a student's ability to design solutions to the major issues the industry is facing.

This paper, using research that spans over three decades, will formulate an approach to power engineering education that is multi-disciplined, easily implemented, economical, efficient, and specifically designed for universities that have yet to realize the immediate need for trained power professionals.

The State of Power and Power Engineering Education

Power is of paramount importance in today's digitally based world. Consequently, the integration and full-scale implementation of Smart Grid Technologies have placed the power industry and power education in a state of transition. These changes have come at a very precarious time for the power industry as labor researchers have for many years warned of the "graying" and soon-to-be retired power workforce (Meyers, D.,Ginn, J. 2010). It stands to reason that a significant amount of knowledge and power experience will be lost regardless of how effective knowledge retention programs are. This brings to light the need for educational institutions to be able to effectively train power professionals, in power systems engineering and related technologies. The questions are:

1. What studies should educational institutions focus on?
2. What methods should be used to effectively teach concepts?

The debate of these questions continues and although the majority of educational institutions agree on retention and expansion of classical power engineering concepts, research will show that there is much variance on *how* educational institutions plan to answer the questions posed in the above. Despite the variance and uncertainty, research shows that within this decade, there will be great demand for electrical engineers specializing in power. The ratio of electric power professionals needed compared to the programs available should prompt universities with existing ABET accredited programs to assume a more active role in preparing the future power workforce.

It is easy to see the challenges the industry and educational institutions will face in the coming decade in terms of the workforce training, education, replacement and retention considering the statistics such as the ones highlighting in the above paragraphs. Research will show that electrical engineers versed in many branches of the discipline will be needed to not only replace their predecessor, but also to rein in and develop the technologies that will improve the all-important concepts of power delivery and its reliability. The merging of digital and power technologies is no longer eminent: It is here.

Drivers of Change

So far, this paper has brought up the possibility that the future supply of engineering power professionals may not meet future industry demands. Also, this thesis has introduced a new paradigm in the electric power industry where the digital and electrical power technologies have merged across the industry's spectrum.

It is clear that before giving credence to the aforementioned issues, the educated reader will require proof of future demand as well as a motive for the paradigm change; thus the following questions must be addressed:

1. What is driving the change in paradigm?
2. Will it be permanent? And
3. What guarantees do universities have that the power engineer need will perpetuate and not be saturated after a few years?

There are various published papers (Chowdhury, B.H,2000; Heydt, G.T., Vittal, V, 2003; Mogridge, L., 2002; Saur, P.W., et al, 2004) that discuss low levels of power engineering majors as late as 2003. These particularly important questions are addressed elegantly in a 2008 publication. Montoya (2008) specifies four "drivers" that will increase and perpetuate opportunities in the power and energy industry.

The first of these drivers are coined Societal Drivers and are described by the public's (public or private) energy demands. New innovations in residential, commercial and industrial technologies will continue to increase the demand of electrical power. The standard of living for many will require uncompromised electrical reliability. It is for these reasons that there is much validity to this observation considering the role that electrical and electronic equipment play in the modern household and workplace.   In Montoya's words," it is man's unquenchable desire for energy that will continue its demand and new / alternative sources of it".

The second driver described are Technological Drivers. Many modern day products and services reserve some level of control / interaction for the end user. Consequently, electrical power is no exception. The wide spread integration of Smart Grid technologies such as Smart Meters have enabled and simplified energy saving programs such as time of day and instant consumption monitoring.   This paper also uses the electric industries movement from mechanical protective relaying to solid-state protective relaying as an example. In this case, the use of technology led to obsolescence of the protective relaying technician that specialized in mechanical relays. Montoya does concede it is impossible to predict changes, nevertheless, one can assume that changes will come based on trends.

The third driver discussed are Environmental Drivers, which are described as society's collective quest to reduce our dependency on dwindling levels of fossil fuels that are primarily foreign and / or to be able to exploit more abundant, cleaner burning forms of energy such as natural gas. Over the next few decades, much research will be undertaken to reduce costs of alternative generation technologies to increase the renewable resource profiles across the United States of America. Because of this research and wide scale movement, professionals will be needed to perfect manufacturing processes, improve harvesting techniques and integrate generation technically and procedurally.

A classic "Catch -22" example of a harvesting technique that requires refinement   is Hydraulic Fracturing, or "fracking", a method for releasing natural gas from rocks and shale, by drilling and injecting large amounts of a water mixture directed at rocks(Dong, L., 2013) . The practice of fracking has increased the availability of natural gas and decreased our dependency of foreign oil, however, there are several environmental concerns that are associated with the practice that include ("What is Fracking and Why is it Controversial", 2013):

1. Contamination of existing water supplies caused by the chemicals left in the ground
2. Large amounts of water used for the practice
3. Induced Earthquakes
4. Air pollution caused by open pits.

Fracking as a practice comes with extreme tradeoffs, however, the rewards are significant. The practice of fracking and other innovative harvesting and generating technologies will have to be addressed in the coming years by conscientious power and energy engineers.

Last to be discussed are Institutional drivers, which are essentially governmental entities, regulatory agencies and other institutions mandating changes to policies and competitiveness. Case in point, in June of 2007, the Federal Energy Regulatory Commission (a governmental entity of the United States) granted the North America Electric Reliability Corporation (NERC) the legal authority to enforce reliability standards with all users, owner and operators of the bulk power system in the United States ("Compliance & Enforcement", 2014). These mandatory standards have effectively changed the way utilities and industries operate and have created niches for individuals with backgrounds in computer security systems, procedure standard writing, technical writing, legal interpretations and power systems. Because Institutional drivers are extremely dynamic, changes that are mandated have significant residual impacts on power delivery.

Montoya culminates his paper by reasoning that the aforementioned drivers will collectively guarantee consistent work and opportunities to contribute, innovate and use multidisciplinary approaches to solve problems that the power industry will face.

Industry Specialization and Segmentation will also allow for

1. Specializations Areas which will lead to,
2. Interdependencies (to be discussed later) and
3. Segmentation

CHAPTER II

The Issue of Global Energy Needs

Using available references, this chapter aims to estimate just global energy needs over the next few decades. There are in fact many groups discussing “Energy Challenges” the world will face over the next two decades. Some of the notable groups that have published significant articles on the topic are the International Electro Technical Commission (IEC), the International Energy Agency (IEA) and the World Economic Forum. Of the groups mentioned, the IEA is considered the authoritative publisher of documents covering this topic, the IEA World Energy Outlook will be the primary citation.

The IEA’s World Energy Outlook (International Energy Agency, 2013) is a document that is updated annually. It is important because worldwide energy usage and needs are hard to grasp without metrics to measure the supply and demand. Many things related to power and energy, including work force needs, educational needs, generation needs to name a few, can be derived from the metrics published in the World Energy Outlook and reasonable assumptions. The IEC details (International Electro Technical Commission, 2010) a symbiotic relationship between the global economy and the population, where the economy is set to grow up to four (4) times as large over the next three decades due to a 1% growth of population over that same time period. Figure 1 summarizes the expected population increase.

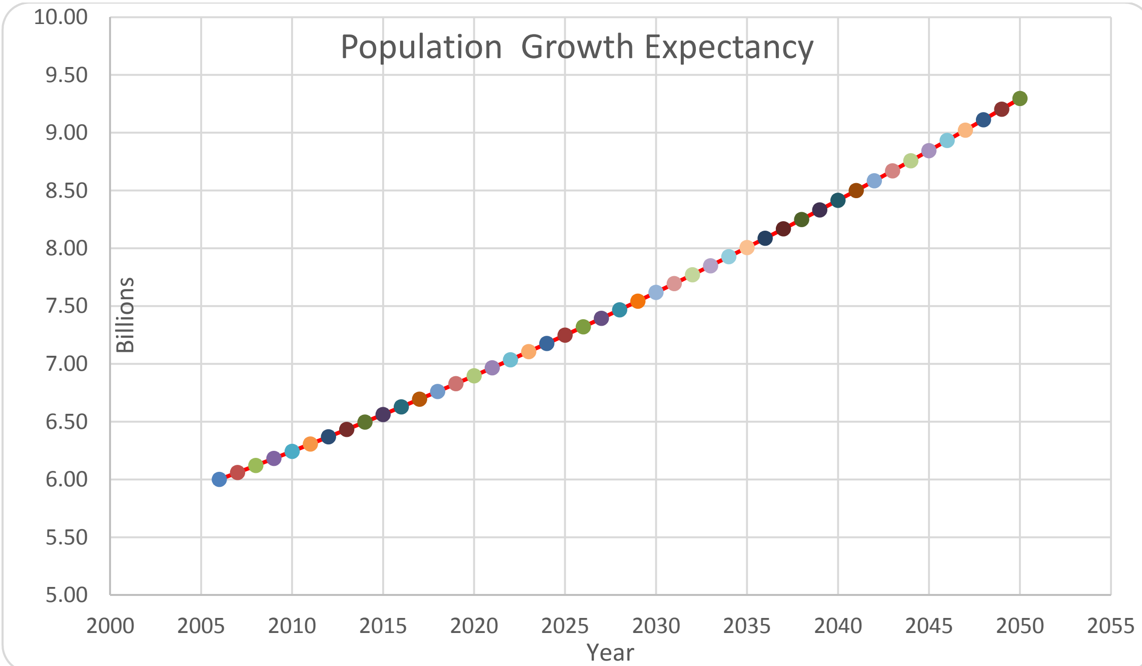

Figure 1: Population Growth Expectancy. Source: International Energy Agency, 2013

If countries adopt the business as usual model (i.e. no energy conservation programs are implemented or enforced), energy demands are expected to triple by the year 2050. Figure 2 summarizes the expected increase in energy demand.

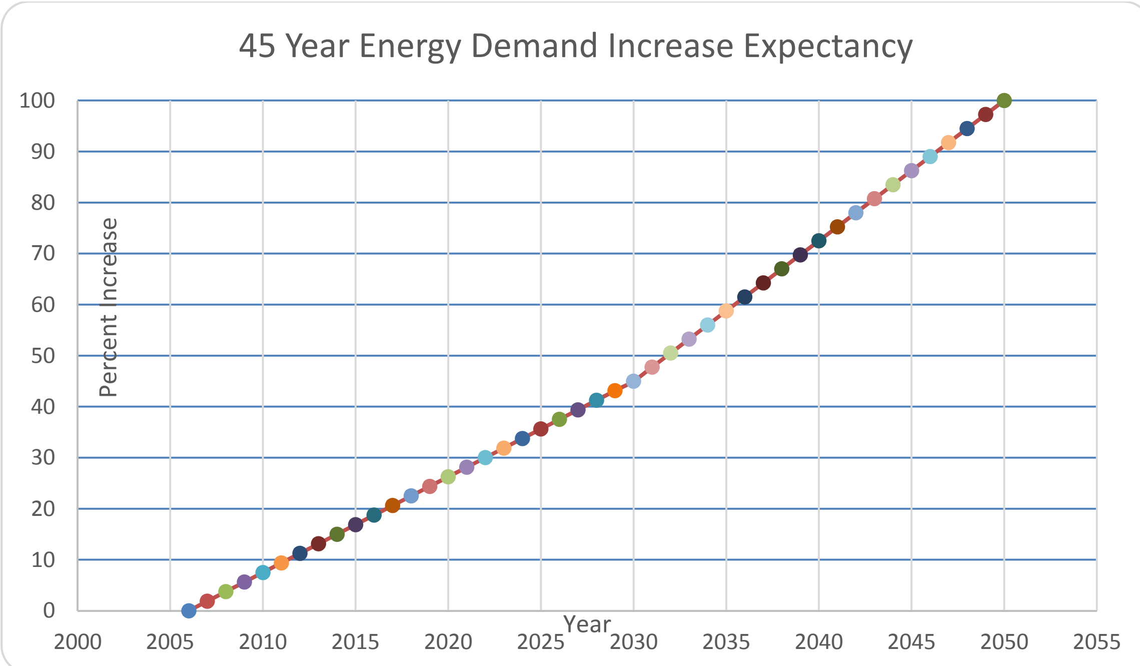

Figure 2: 45 Year Energy Demand Increase Expectancy. Source: International Energy Agency, 2013

(International Energy Agency, 2013) develops three scenarios based on key parameters affecting global energy development over the next two decades coined current policy scenario (i.e. business as usual), New policy Scenario and 450 ppm scenario. It is unlikely that the current energy policy will remain without change and just as unlikely for a full scale 450 ppm scenario will be implemented, therefore, for the sake of this section we will base the following content on the New Policy Scenario (see figures below).

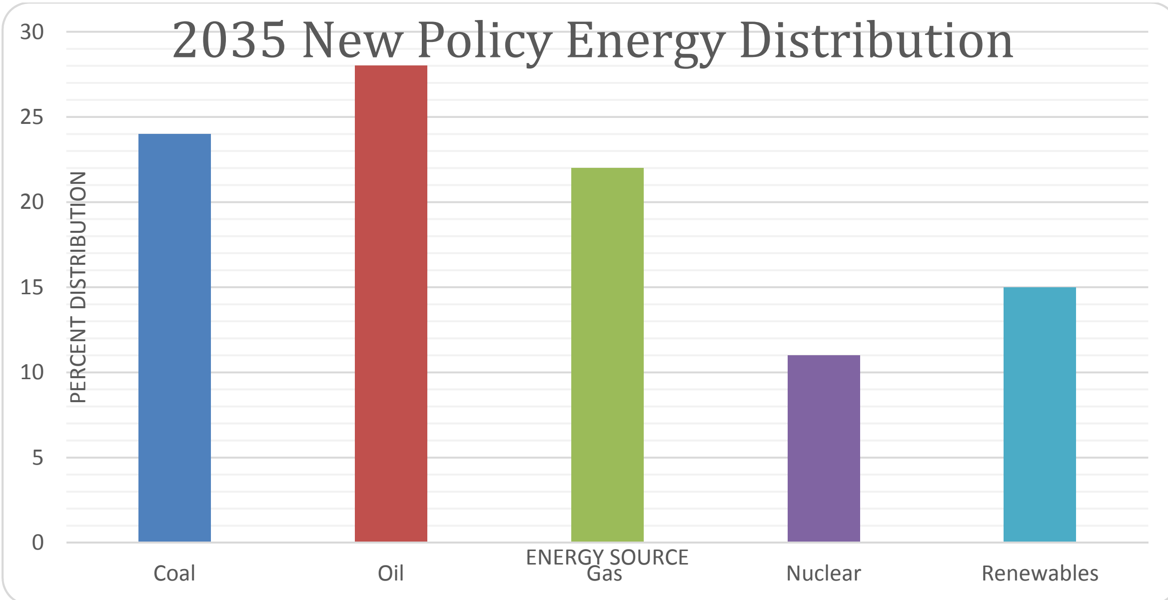

Figure 3: 2035 New Policy Energy Distribution. Source: International Energy Agency, 2013

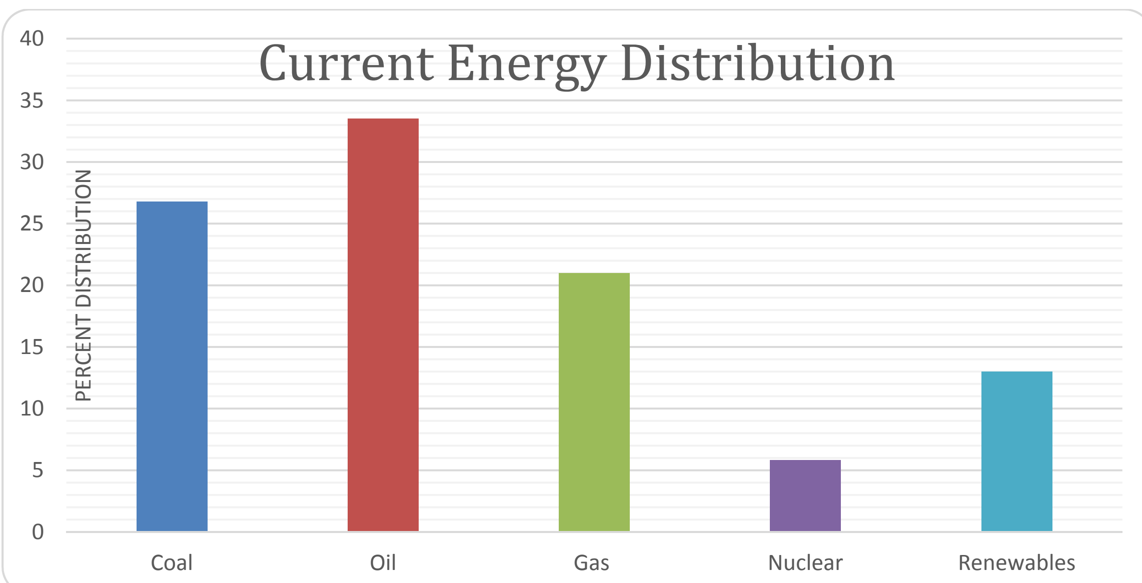

Figure 4: Current Energy Distribution. Source: International Energy Agency, 2013

By inspection, it can be seen that the current energy percentage distribution will not change much, however, the energy demands that the world will face with will require additions proportional to the energy demand increase.   For instance, Renewable generation will only need to increase 2%, however, since the energy demands will change, renewable technologies will be required to increase proportional to the energy demand increase of 45% by the year 2030.

Using the New Policy scenario projections, the energy demands for 2013 and 2030 were charted so that the reader can appreciate the energy increases by region. It can be seen by inspection that China, India, and Other non-OECD (Organization for Economic Co-operation and Development) regions will require significant energy demand increases by 2030. This is due to over 1.6 billion people in those regions that are currently without electrical energy that are expected to come on-line around 2030.

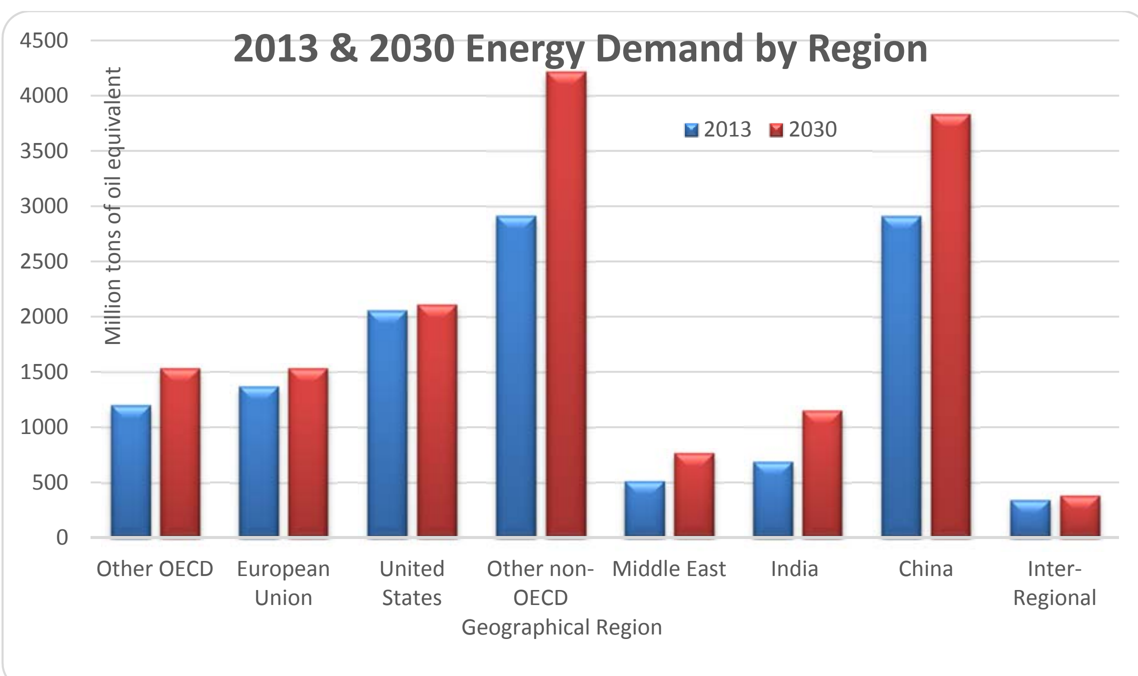

Figure 5: 2013 & 2030 Energy Demand by Region. Source: World Energy Outlook, 2013

The projected moderate energy demand increase for the United States Region does not exonerate the United States from contributing to finding solutions to tomorrow's energy demands. In fact, world wide power solutions companies such as General Electric, ABB and Seimens all base major operations in the United States. The annual sales of these companies account for approximately 433.81billion dollars. These facts coupled with the United States position as a major player in technological innovations obligates the U.S. to the forefront of the solutions towards the problems the world will face.

The following chapter will use avialable research to estimate the amount of power engineers to enter the work force over the next few decades.

CHAPTER III

Power Engineers Needed

The research results of Chapter I and II make a strong case for the future needs of the power industry. The question is, "How many engineers will be needed?" Chowdhury makes excellent points on the future need for power engineers (Chowdhury, B.H., 2000,). The first and most fundamental point is that power remains a major catalyst for success in virtually all industries. As industries evolve to satisfy the market needs, power and optimum reliability will be needed. Moving forward, new products such as hardware and software designed by power engineers will be needed to improve and increase levels of reliability. In fact, major players in power, such as Siemens, ABB and General Electric, conglomerates that account for 433 billion dollar in sales per year (forbes.com), are without question some of the most successful companies in the entire world. As those corporations grow, so will the demand for power professionals. Again the evidence points to personnel needs in design, maintenance, ancillary industries, (e.g. generator manufacturers, protective relaying, power transformer manufactures, etc.) and energy sales. All of the aforementioned sectors will require, in some form or fashion, power engineering professionals to run day to day operations. Finally, Chowdhury elaborates on previously discussed topic, that of the design and development of reliability products such as energy control systems such as Supervisory Control and Data Acquisition systems. Engineers will be needed not only to design, develop and implement these systems, but they will also be required to automate, integrate and make use of and manage the data collected from holistic system.

Estimating Power Engineering Utility Workforce Needs for the Next Decade

Using previously reviewed statistics found in the World Energy Outlook (i.e. Figures 1 - 4), this section aims estimate just how many power engineers the workforce will demand over the coming decade. Meyers et al, using information gathered from a U.S.Power and Energy Engineering Workforce Collaborative estimate that approximately 45% of engineering power professionals working for utilities will retire from 2010-2015 (Meyers D.,Ginn, J., 2010). This percentage translates to approximately 7000 new power engineers needed to replace the retiring engineers in the utility sector. This number does not include new positions due to growth. We will use the replacement number as a basis for estimates.

In this case, the most appropriate graph to use for estimating future utility engineering needs is the 45 Year Energy Demand Increase Expectancy (labeled Figure 2). It can be seen by inspection that from year 2000 to 2030, the estimated Demand Increase Expectancy is fairly linear; therefore, a linear trend line can be derived from the following graph (Figure 6) depicting a sectionalized view of Figure 2.

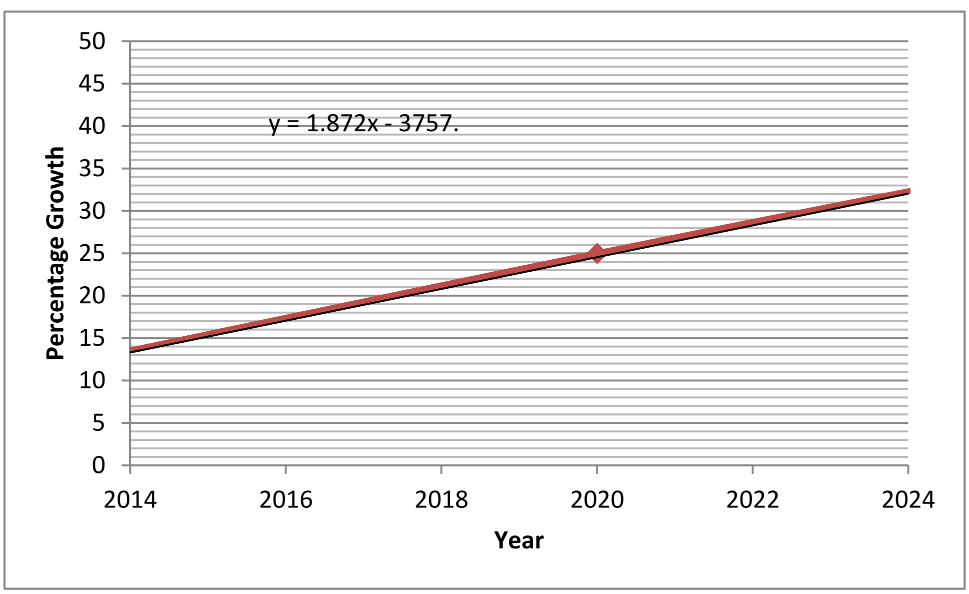

Figure 6: Sectionized view of 45 Year Energy Demand Exptancy Showing Equation of the Line

In order to be able to estimate utility power engineer workforce needs for the coming decade, a few assumptions need to be made. The first assumption is that the demand increase for utility engineering power professionals will be proportional to the energy increase. The second assumption is that the Power and Energy Engineering Workforce Collaborative estimate of 7000 utility power engineering professionals estimate is accurate. By using the equation of the line shown in Figure 6, it can be estimated that in addition to the 7000 utility power engineering professionals needed by 2019, an additional 19% of new hires can be estimated by taking the difference of the 2024 and the 2014 percentage growth. This totals to approximately 8330 new hires by 2024. This number seems reasonable, however, as of 2010, there are only about 1000 undergraduates receiving degrees that are interested in electric power annually (Meyers D.,Ginn, J., 2010). Also, one must consider that the rest of the power industry (typically with companies with larger budgets) will be competing for the services of these graduates. In 2009, The U.S. Power and Engineering Collaborative (UPEC) - a committee that consisted of industry, government and academia contributors, assembled by the Federal Electric Regulatory Commission to report on workforce challenges in electric power industry-using the Bureau of Labor Statistics, estimated that the total power engineers required for the entire power industry is approximately 14,000 to 21,000 over the coming decade (Management Steering Committee of the U.S. Power and Energy Engineering Workforce Collaborative, 2009). Another recommendation made by the UPEC is for universities to double the output of graduates trained in electric power engineering. Considering the research undertaken on the future supply of power engineering workforce, it can be argued that there is a lot of merit to idea that a lot of power engineers will be needed to sustain the growing power and energy needs of United States as well as internationally.

A Decline in Electrical Engineering Enrollment

Although there has been a *slight* increase in power engineering interest due to renewable energy and Smart Grid research, the U.S Power and Energy Engineering Workforce Collaborative reported a decrease in electrical engineering majors (U.S. Department of Energy, 2006). If the trend continues, this would not bode well for the power industry as a whole due to the decreasing pool of potential power engineers. As it will be shown in the coming chapters, slight increases in interest will not satisfy the power industries workforce needs. To compound this issue, the power engineering recruitment faces three major challenges (Chowdhury, B.H,2000; Heydt, G.T.; Mogridge, L., 2002; U.S. Department of Energy, 2006):

1. Lower average annual pay compared to other Electrical Engineering specializations.
2. Lack of power engineering faculty, course offerings and general information regarding in power engineering.
3. Students are poorly informed with regards to opportunities in power engineering. Poor perception leads to the notion that power engineering lacks the “cutting edge” aspect when compared to other specializations.

Later in Chapter 11, we will gather insight on these challenges to be able to incorporate considerations into the proposed educational approach if necessary.

Faculty Issues

Electric Power university faculty shortages may also contribute to workforce shortages if not addressed. According to the UPEC, 40% of key power engineering faculty at the university level is eligible to retire at the present time with an estimated 27% that will actually retire by 2017 (Management Steering Committee of the U.S. Power and Energy Engineering Workforce Collaborative, 2009). Over the last 2 decades, the existence of Power Engineering programs at the university level has declined (US Department of Energy, 2006). Coincidently, as universities downsized programs, or, omitted them entirely, faculty was either reassigned or the universities used those openings to hire faculty in other disciplines. To compound the issue, research shows that of the approximately 1000 students enrolled in graduate programs in power engineering, 50-75% of them are international students (US Department of Energy, 2006). This is important to note because it's likely that the international students may leave the United States once they receive their degrees. In their recommendations to the universities, UPEC recommends that they work towards doubling current faculty specializing in electrical power to offset the retiring faculty, increase enrollments and broaden educational offerings.

CHAPTER IV

Modern Teaching and Learning Styles in Engineering Education

So far, this paper has laid the ground work to be able to recommend an approach to power engineering education. In Chapter I, the author discussed the current state of power engineering and why the power industry is changing. In Chapter II, the author has shown that the future energy demands are a major concern for everyone. In Chapter III, the author using recent research has proposed the possibility of the power industry not having qualified personnel to maintain the existing power system, or, rein in new technologies due to the retiring power engineering workforce. Also in Chapter III, the author pointed out that the lack power engineering faculty is also a legitimate concern for universities and the power industry as a whole. In order to recommend an approach to power engineering education that meets all the aforementioned criteria, one must be able to understand how engineering students are being taught in the modern day engineering class room. This chapter explores learning and teaching styles in engineering education and highlights a few disconnects. Educational programs must not only know <u>what</u> to teach, but <u>how</u> to teach it in order to maximize their efforts.

Learning and Teaching Styles

Using the references available to them at the time, Felder and Silverman published “Learning and Teaching Styles in Engineering Education”, which has become the de-facto reference for understanding learning and teaching styles in engineering education (Felder, R.M., Silverman, L.K., 1988, 2002). Although many other publications exist on these topics, most reference this publication as a basis for modern implementations. Keefe (1979) defines learning styles as “characteristic cognitive, affective and psychological behavior that serves as relatively stable indicators of how learners perceive, interact with and respond to the learning environment.” The study of teaching and learning styles in engineering is essential for creating efficient teaching methods/program/course design. Over the years there have been opponents (Pashler et al, 2009) to incorporating learning styles in the design of educational approaches. The root of oppositional stance is that, from Pashler’s (2009) perspective, “there is no adequate evidence base to justify incorporating learning styles assessments into general education practice.” Before proceeding with adopting the learning style concept into an educational approach Felder recommends that the following questions must be considered (Felder, R., 2010):

1. Do students respond differently to specific forms of instruction?
2. Would Instruction that matches the students preferred instruction lead to greater learning possibilities?
3. Can Instruction be improved by taking learning styles into account?

From the author’s prospective, the answer to these questions is in the affirmative. By providing instruction based on how the student prefers to receive it is an easy observation. There is less effort needed on the part of the student to be trained according to his/her strengths rather than to force a particular approach on them. After all, the desired result for teaching is for the student to learn, retain and to further process what is being taught depending on the level of comprehension sought.

A Students Learning Style

According to Felder and Silverman (1988, 2002), a student's learning style can be determined by gaining insight to the following questions

1. How does the student perceive the world?
2. How does the student prefer to receive information?
3. How does the student organize his/her thoughts and reasoning?
4. How does the student prefer to process the information that is being taught?
5. How does the student use the information for further comprehension?

A Teachers Teaching Style

Conversely, teaching styles may be ascertained by gaining insight to the following questions according to Felder et al (1988, 2002):

1. What type of information is emphasized by the instructor during class?
2. What mode for presentation is favored during teaching sessions?
3. How are the presentations organized?
4. What mode of student participation is facilitated by the presentation?
5. What type of perspective is provided on the information presented?

The next sections will overview how one can answer some of these questions. The following table is the Felder and Silverman model of learning and teaching styles which most of this section references because of its acceptance and ease of understanding. The table listing the learning style as well as the corresponding teaching style. Each of the four "dimensions" will be discussed in detail in future paragraphs.

Preferred Learning Style	Learning Dimension	Corresponding Teaching Style	Teaching Dimension
Sensory	Perception	Concrete	Content
Intuitive		Abstract	
Visual	Input	Visual	Presentation
Auditory (Verbal)		Verbal	
Inductive	Organization	Inductive	Organization
Deductive		Deductive	
Sequential	Understanding	Sequential	Perspective
Global		Global	

Table 1: The Felder & Silverman Model of Learning and Teaching Styles. Student and Teacher Perceptions

Student / Teacher Perceptions

In 1921, Carl Jung published the groundbreaking book titled "Psychological Types". The book itself was very well received and is often considered the authoritative text in regards to the subject. The book defines two ways in people perceive the world: sensing and intuition. Jung refers to people that prefer hard facts, data and specifics as sensors. Jung names the other psychological type intuitors, or those preferring principles and theories.

Sensor Characteristics

Felder et al describes Sensors as methodical, preferring to solve problems through standard methods and algorithms. According to Felder et al, sensors are generally patient, careful and slower in their calculations. As described in the previous paragraph, sensors are more comfortable working with concrete facts and excel and memorizing this type of information.

As a consequence to their slower and methodical approach, sensors take longer translating symbols (including words) to what they represent. This presents a slight disadvantage in classical engineering courses where timed tests are given.

Studies have shown that the majority of engineering students are sensors (McCaulley, M.H, et al, 1983). This fact must be kept in mind when developing courses, laboratories and other teaching mediums.

Intuitor Characteristics

Felder and Silverman describe intuitors as one who prefers concepts and theories - quite opposite of the sensor psychological type. Where sensors thrive on details and methodologies, intuitors dislike repetitious type of tasks and thrive on the thought of innovation. Change and new ideas seem natural for the intuitors based on their propensity to innovate. In general, intuitorsmaybe quicker to finish a task compared to sensors, however, intuitors do sometimes lack the level of detail when compared to sensors. . Intuitors are actually quite comfortable with translating symbols to information, which makes them generally better suited to score well in classical engineering class style tests. Some studies have shown, that the intuitors characteristics lend to better over all grades in engineering courses (Felder, R.M., Silverman, L.K., 1988, 2002). An interesting fact is that studies have shown that the majority of engineering teachers (i.e. faculty as referred to previously) are intuitors. This fact, along with the findings in the previous section will be discussed at length in the following section.

A Disconnect in Perceptions in Engineering Education

Based on the previously sited research, there is an obvious difference in terms of how engineering student and engineering teachers perceive the world they live in. Where engineering students are focused more on the details and methodologies of the topic of study, engineering teachers are focused on the theoretical aspect of the topic of study. Generally, the focus of the course will vary greatly from the teacher compared to the typical student. For example, the teacher may spend the majority of the class deriving a formula containing numerous symbols, where the student would prefer more concrete and practical examples. The challenge, moving forward, is how to bridge this disconnect. One practical presentation skill is to know the target audience and cater teaching styles accordingly. Of course there would be many approaches; however; the most practical would be for the teacher to include a mix of facts and data along with their already existing theoretical approach to teaching.

How Students Learn

Felder and Silverman describe three (3) major ways students receive information / stimuli that ultimately leads to learning:

1. Visually
2. Audibly
3. Kinesthetic

In general, there is a correlation between a students preferred mode of learning and the way the student perceives the world (e.g. visual learners are generally sensors and audible learners are generally intuitors). Although this is generally the case, is not guaranteed to hold true in every case.

Visual Learners

Visual learners prefer to receive information that is being taught via visual format. For example, some of these formats include graphs, presentations and diagrams. Learning from a predominately audio based teaching session, such as a long lecture, is difficult for visual learners. Coincidentally, most students of college age are visual learners and fall into this category.

Auditory Learners

Auditory learners favor information that is being taught inaudible form. Lectures, discussions have a great learning impact for auditory learners. In general, there the far fewer students that prefer auditory instruction than there are students that prefer visual instruction (Felder, R.M., Silverman, L.K., 1988, 2002). An interesting fact that will be discussed in detail in another section is that most engineering courses are primarily lecture based, favoring the auditory side of the learning spectrum.

Kinesthetic Learners

Kinesthetic learners focus on tastes, touch and smell. This Thesis will not cover kinesthetic learners as there is no research suggesting that it impacts engineering education.

Discussion of Second Learning and Teaching Disconnect

As mentioned in the Visual Learning and Auditory Learning sections, students prefer to receive the information to be learned in visual format while the teachers present the information to be learned in audio format. This is a very important correlation to understand if one endeavors to maximize teaching efficiencies. The recommended course of action, when establishing a teaching approach is to include as many communication mediums in a teaching environment to be able to communicate with all learning types.

Student Thought Organization

Felder and Silverman (1988, 2002) list two categories of thought organization that students may favor:

1. Deductive Learning
2. Inductive Learning

Since the text was originally penned in 1988, the authors have updated their thoughts on specifics of both types of thought organization.

Deductive Learning

Deductive learning begins with underlying principles and culminating in to reasoning consequences of the principal. In most cases, engineering curricula is set up and designed predominately in the deductive format where freshman courses begin with fundaments and future courses are more application and design based. Because deductive learning is and foundation style approach, Felder and Silverman agree that the deductive approach makes it a natural teaching style for technical and scientific courses at the college level since each subsequent class works off the knowledge that was already taught.

Deductive style teaching, if looked at a certain perspective, may depict a principle impossible to comprehend, Felder and Silverman explain. The reasoning behind this perception is that the students do not appreciate the problem solving approach towards the principal that is being studied because the teacher has already taken the essence of the topic and concisely presented it to the class. This bodes well for most students looking to score well in the class because it tells them what they need to know in order to receive the desired grade.   The question is: Is this the most effective learning/teaching method?

Inductive Learning

The famous maxim, “Necessity is the mother of invention”, defines the principals of inductive learning. For example, often times the best designs are formulated with a person actually facing a problem that needed solving or resolution.   The problem led to the person studying, observing and testing to find solution to the problem that they were up against to find a solution or set of solutions. The aforementioned example is the most concise way to define inductive learning. Felder and Silverman (1988, 2002) explain that the Inductive learning is the natural way students learn based on the fact that humans are born with absolutely no foundational principals to rely on. Slowly, they learn that certain actions by them lead to reaction by parents. Rudimentary behavior is learned by inductive thought organization since human infancy. A summary of the benefits of inductive learning include (Swenson, E.J., 1949; Kagan, J., 1965; Lahti, A.M, 1956; Felder, R.M., Silverman, L.K., 1988, 2002):

1. Efficient / Effective Learning
2. Increased academic achievement
3. Enhanced abstract reasoning
4. Increased retention

The above list should not be overlooked when considering the benefits if applied to standard engineering education approaches.

Perceptions on Thought Organization

Felder and Silverman updated their publication in 2002 by modifying the model of learning. One modification that was made was the omission of the thought organization (i.e. inductive and deductive learning) dimension of their model. Although Felder and Silverman do believe in the idea that inductive learning would be most effective, subsequent studies have not concluded that students prefer type of instruction. Although it was omitted, the author believes that a partial inductive teaching approach could be implemented fairly easily to a pre-existing course curriculum. Again, referencing Felder and Silverman (1988, 2002), one approach would be to incorporate both deductive and inductive forms of instruction for maximum effectiveness.

The Processing of Information into Knowledge

Felder and Silverman describe the process in which perceived information is turned into knowledge can be grouped into two categories:

1. Active experimentation and
2. Reflective observation

This topic is quite essential in formulating or modifying a teaching approach, especially when considering whether or not laboratories are effective learning/teaching instruments.

Active Learning

Active leaning is described by Felder and Silverman as performing an action (i.e. discussing, explaining or experimenting) with information to gain knowledge. In general, those that are active learners are not as effective in learning situations where continuous observations or reflection is involved. A classic example of this is when the instructor lecture dominates class time. In the above example, there is very little active learning taking place and is referred to as passive learning, or, the exact opposite of active learning. One can define passive instruction when a teaching approach does not incorporate active learning nor reflective observations.

Reflective Learning

As mentioned before, reflective learning is not the antithesis of active learning but an alternate style of processing information being taught. Reflective learning is where the student is allowed to ponder what is being taught so that important learning concepts are bridged and reinforced. In general, reflective learners are theoreticians and prefer to work by themselves or in pairs (Felder, R.M., Silverman, L.K., 1988, 2002). On the surface, one can deduce that reflective learners would tend to be intuitors and active learners sensors, but there is no evidence to support this. The fact is that each person is different when it comes to learning and teaching.

A Final Thought on Information Processing

When designing a course or teaching approach, it is important to incorporate active learning and reflective learning to reach the optimum effectiveness. Many engineering students would agree that the most of the courses offered at various universities are lecture dominated, with most not involving lab work to fulfill requirements. Lecture dominated courses, without the introduction of active or reflective learning principals are largely ineffective and could lead to students choosing alternate fields of study due to poor grades or understanding.

Student Understanding

According to Felder and Silverman, there are two learning styles that lead to understanding the topic of study. The two learning styles are as follows:

1. Sequential learners and
2. Global learners

Sequential Learning

Sequential learning and teaching dominates engineering education. Essentially this learning style presents material in a logically ordered progression with a pace that is dictated by the calendar (Felder, R.M., Silverman, L.K., 1988, 2002). Consequently, most students are comfortable with this learning style since it has been incorporated since the beginning of their education. More specifically, students are presented with topics until a predetermined date where a test will be given to evaluate their mastery of the topic.

Sequential learners use a linear thought process to achieve an understanding. They are able to work on topics that they understand wholly or only partially and excel in analysis and convergent ideas (Felder, R.M., Silverman, L.K., 1988, 2002).

Global Learning

Global learners are students that do not learn in a linear sequential manner. They can be presented with the material in a sequential presentation and may not achieve understanding, until, almost suddenly (at their own pace); the global learner understands the concept wholly (it is not common for global learners to have a partial understanding of the topic). Global learners may excel in divergent thinking and syntheses and usually do better by being presented with more complex material (Felder, R.M., Silverman, L.K., 1988, 2002).

Summarizing Student Understanding

It is clear that little modifications to course presentation are needed for sequential learners because of the typical structure of modern engineering courses. However, global learners are somewhat disadvantaged because they are being forced to use the teacher's strategies rather than given the freedom to learn and devise their own. Simple devices that teachers can implement while instructing global learners is to present the learning objectives before engaging a topic, provide examples relative to the students experience and focus the relevance of the topic (Lahti, A.M, 1956). A good practice, Felder and Silverman recommend, is to engage both sequential and global learners is to ask students to consider alternative approaches to problem solving.

Summarizing Learning and Teaching Styles in Engineering Education

According to Felder and Silverman, there are 32 different combinations of learning and teaching styles in modern engineering education (reference Table 1). When considering course or topic presentation design, incorporating techniques to reach each type of learning combination could be impractical or impossible even for the most seasoned of engineering instructors. A practical approach for teachers is to be aware of the different learning types, audit their own teaching style and incorporate teaching techniques to reach all types of student learning combinations. Felder and Silverman in their 1988 publication provide Table 2 as a guide for teachers to reach a broad array of learning combinations. The idea, the authors stress, is not to incorporate all techniques, but to specifically select some based on the learning venue and the topic that is under consideration. In general, as has already been discussed, there is seemingly a disconnect in learning and teaching in engineering education based on the fact that the majority of engineering students have a learning combination of sensory and visual learning tendencies. Engineering education, conversely, is predominately presented verbally and abstractly. The key to effectively training the engineering power professionals of the future (or all engineers for that matter) is to understand and address these incompatibilities by designing courses and teaching approaches to reach all types of learning styles.

	Teaching Technique	Method	Learning Style Addressed
1	Motivate Learning	Relate material being presented to prior and future lessons	Inductive / Global
2	Provide Balance	Provide balance of concrete facts and data as well as principles and theories	sensing / intuitive
3	Balance Material	Mix practical problem solving methods with material that promotes fundamentals	sensing / intuitive/active/reflective
4	Provide Illustrations	Mix lectures with visual aids such as graphs, models and the like. Make instruction hands on if possible	sensing/visual/active

5	Use computer aided instruction	Sensors respond very well to computer aided instruction	sensing / active
6	Provide time to participate	Include time for reflection and participation during class time.	reflective/ active
7	Applaud Creative solutions	Applaud all creative solutions, even incorrect ones	intuitive/global
8	Allow Homework Participation	Allow students to collaborate with in class or homework assignments	active
9	Talk to students about learning Styles	Discuss learning styles and ask students to explain theirs	all

Table 2: Recommended teaching Techniques by Felder and Silverman. Source: Felder, R.M., Silverman, L.K., 1988, 2002

CHAPTER V

Modern Learning Models used in Power Engineering Education

In Chapter IV, learning and teaching styles in engineering education was explored. This chapter will provide overview of the various learning models used in modern day universities and will begin to address the question of exactly how engineers are being taught throughout their engineering curriculum. Later, in Chapter VI, the tools, curriculums and approaches being used to supplement these educational models throughout the university landscape will be discussed. There are various learning models in today engineering education that should be discussed, analyzed and considered in order to recommend an efficient and effective engineering education approach to power. There are various publications that specifically discuss these teaching models with respect to engineering education. One particular publication is Smith et al's (2005) explanation is that learning can be achieved in one of three different methods:

1. Competitive Learning
2. Cooperative Learning
3. Individualistic Learning

Competitive Learning

Competitive learning models have been incorporated since the late 1930's in the classroom. The basic idea of competitive learning is to use competition amongst classmates to motivate students to excel. The learning model itself, according to (Smith, K.A., et al., 2005) the competitive learning model was the de facto learning style for well over 40 years. Although this method is archaic, it is still practiced albeit on a much more limited scale.

Cooperative Learning

Beginning in the 1960's, a large number of cooperative learning research studies began to publish results that warranted additional studies as well as implementations of cooperative learning models in the classroom at all levels. Today, cooperative learning is the recommended model of learning for all levels of instruction (Smith, K.A., et al, 2005).

Individualistic Learning

Individualistic Learning is simply a learning model that does not incorporate either of the above models. The basic premise behind the model is that the student should excel, because the student should understand that the main benefactor are the students themselves (Smith, K.A., et al, 2005). Unfortunately, in engineering education, the individualistic models of learning are still being incorporated much more than one would think.

Why Cooperative Models Should Be Implemented

Smith et al. (2005) summarize that cooperative learning research is based on social interdependence theory. First developed in the early 1900's (Smith, K.A., et al, 2005), the theory of social interdependence proposes members of a group or a "dynamic whole" that are mutually dependent on one another to reach a common goal. The state of "tension" of the group members can take them toward or away from the goal. Positive interdependence (cooperation) promotes interaction among members and encourages progress while Negative interdependence (competition) promotes opposition among member and discourages progress (Smith et al, 2005). The absence of interdependence is simply individualistic efforts where no interchange of any kind takes place. Unfortunately, many teaching approaches in modern engineering education foster individualistic learning due to the traditional way of teaching engineering courses, Mills et al (2003) refer to this type of teaching approach as “chalk and talk” (Mills, J.E., Treagust, D.R., 2003). “Chalk and Talk” is described as the teacher lecturing and sharing some basic diagrams to reinforce fundamental concepts. In this model, little to no interaction is involved leading to an extremely inefficient teaching approach.

The fact is that research that spans almost three quarters of a century that individualistic approaches are the second least effective of all learning models, with competitive learning models being the least effective and cooperative models are the most effective. Just how effective can cooperative learning be if cooperative learning is implemented? A 1998 study by Johnson, Johnson and Smith (1998) provided evidence that cooperative learning can improve a student’s test scores more than 15 test points over individualistic and competitive learning models. In addition to academic improvement, Smith et al detail the following benefits of cooperative leaning models for students (Johnson, D.W., et al, 1998):

1. Quality of relationships
2. Improved psychological adjustment (i.e. adjustment to “college life”)
3. Improved attitude towards college experience.

Considering all the benefits of cooperative learning, it is difficult to understand why a professor would not feature it as an integral part of their teaching methods.

Educational Models

The following list summarizes the types of educational models that are being incorporated in modern engineering courses. The list includes the type of learning that corresponds to the teaching approach:

1. Subject Based Teaching (i.e. "Chalk and Talk") – Individualistic Learning
2. Problem Based Teaching – Cooperative Learning
3. Project Based Teaching – Cooperative Learning

Subject Based Teaching

Subject based teaching is simply the teacher defining what the students need to know and having the students learn the concept. After the student learns it, the student is given a problem that is designed to illustrate how to use the concept being taught (Mills, J.E., Treagust, D.R., 2003). This teaching method defines a large majority of courses given in engineering education. "Chalk and Talk" is primarily subject based teaching.

Problem Based Teaching / Learning

Although there have been various attempts to describe problem based learning / teaching, the following is the most accepted definition. Problem based teaching is a model that begins with the definition of a problem usually by the student; however, this varies depending on the practitioner (there are some learning institutions where the teacher formulates the question). In general, the solving of the problem takes place in small groups of students with the teacher acting as the facilitator / advisor, according to De Grave et al (1996). The problem itself is based on problems that one may encounter while working in the field of study. The detail of practicality fosters learning within the context of the field of study as promotes student motivation and comprehension (Hmelo-Silver, C.E., 2004). Some other features of problem based learning / teaching are the following:

1. Fosters Experience learning, that is the student building understanding from his or her own experience and interests.
2. Fosters Active learning thus promoting a higher level of comprehension
3. Promotes inter-disciplinary learning
4. Transfer: The ability to transfer knowledge, theory and methods from previously learning areas.
5. Cooperative learning; (benefits previously listed)

By inspection, there are various concepts listed in the list above that would translate well to a proposed educational model.

Project Based Learning

Project Base learning is very similar to problem based learning; however, there are differences that Mills et al (2003) describe that are summarized by the following list:

1. Problems in Project based learning / teaching are more authentic than problem based learning / teaching problems. The completion of the project usually takes longer than problems posed by problem based learning.
2. Project work is directed to the application of knowledge; where problem based learning / teaching is directed at the acquisition of knowledge.
3. Project based is almost always inter-disciplinary where problem based learning / teaching is not.
4. Management of time and resources is a consideration in project based learning.

5. Self –direction is emphasized in project based learning / teaching, more so than problem based.

Although there are obvious benefits that may translate well to engineering education, it is the least implemented of all models because engineering courses are driven by concepts and technology.

Implementing Project Based Learning / Teaching Models

The many facets of project based learning / teaching make it one of the most difficult and involved models to implement; however, there are obvious benefits for students if integrated into engineering curriculum. Of all the learning / teaching models that have been described, project based learning / teaching more closely resembles reality that other models. The fact that the problem is more authentic in project based learning, multiple disciplines are usually involved in order to solve the problem and interdependence is more of a factor. A true project based learning / teaching model is present in all courses of a particular program, therefore; there are very few examples of a full-fledged project teaching model in engineering education at the university level. The nature of the model would require an existing program to be fully revamped to incorporate all aspects of project based learning. Although most modern day engineering programs do incorporate at least a few courses that are project based (e.g. senior design), the author does not believe partial implementation of project based incorporations would be difficult or unreasonable to implement to pre-establish courses. The next chapter will discuss trends in Power Engineering Education.

CHAPTER VI

Current Trends in Power Engineering Education

Chapter IV discussed how students learn and how engineering educators teach (reference Table 1) and details two (2) important disconnects:

1. Typically, engineering students prefer visual instruction, while engineering educators prefer to give auditory instruction.
2. Engineering students prefer practicality, while engineering educators prefer theoretical approaches towards teaching.

Chapter V discusses the competitive, cooperative and individualistic teaching / learning models. Also, Chapter V details Subject Based Learning, Problem Based Learning and Project Based Learning, all which are prominent in modern day universities. The following chapter provides examples of trends in power engineering education that have been implemented at universities. Essentially, they are the university's response to the questions posed in Chapter I:

1. What studies should educational institutions focus on?
2. What methods should be used to effectively teach concepts?

For this chapter, the author chose to include examples from universities worldwide. A lot of the literature available is redundant; therefore, the author tried to capture the essence of the trend with one example.

What Power Engineering Topics and Teaching Approaches Should Universities Focus On?

Most scholars agree that current power engineering programs need to be modified to incorporate a multi-disciplined approach to train tomorrow's work force due to the fact that the solutions to modern day problems involve many disciplines of study. The debate is on exactly what topics should be taught and what teaching methods / approaches should be utilized to thoroughly prepare graduates to <u>immediately</u> contribute to the power workforce. Leading authors (Joos, G., 2008; Wollenberg, B., Mohan, N., 2010;Singh, C., 2012; Kezunovic, M, 2010) in research of this kind agree that curriculum rich in classical power system education, power electronics and electric drives should be considered when planning a learning curriculum for the modern power engineer. In addition, it is important to note that authors offer significant variance on recommended courses that enrich the understanding of the power fundamentals. It is the author's observation, given the breadth of the field that most of the suggested courses translate well to the power industry based on how they relate to data integration and "smart grid" technologies.

Power education research leader, Karady, recommends that a more practical hands on approach to power education should be taken, specifically in hardware knowledge (Karady, G.G, et al, 2000). Karady's point is clear: Field related knowledge is what hiring companies and utilities expect their entry-level power professionals to know. It is the author's opinion that most hiring companies would agree with this statement. For example, the intricacies of electrical substation design would be difficult to teach without the student understanding how large most equipment is, yet, research shows that field related education is not a typical university tool (Karady, G.G, et al, 2000).

Another power education research leader, Kezunovic, details that a program already installed at the Texas A&M University is emphasizing slightly unconventional power topics, namely, power market education, protective relaying and state estimator education (Kezunovic, M., et al, 2004). This approach does address a particular niche in power engineering that is somewhat less established (save for protective relaying), however, the recommended courses are designed to offer students a working knowledge of the topics. Although this is helpful, it may not lead to significant industry contributions until further in student's career.

Albuyeh details another interesting approach by making a case for emphasizing the following in addition to a strong science, physics and mathematical foundation (Albuyeh, F., 2010):

1. Generation technologies
2. Transmission and distribution studies
3. Operations studies
4. Market studies
5. Soft skills / Impersonal skills

Up to this point, scholars had not recommended a non-science course of study, however, the author does see some value in investing some time in studying Soft Skills /Impersonal Skills. The reason is clear once it is understood that the power industry, in both the private and the public sector, is changing. From the research referenced in this section, it is clear that the trend moving forward will include a multi-disciplined approach to prepare the future power professional to understand the relationships of the systems they are trying to improve and / or integrate. The power industry and education of power professionals is in flux; therefore, power professionals will have to work alongside a highly diversified and multi-disciplined work force.

Summarizing Supplemental Courses and Skill Sets

Louis Blackburn, a leading researcher and author in protective relaying principals and other power related topics, describes the factor that contributes to protective relay engineers when they design their protection system as “personality factor” (Blackburn, J. L., Domin, T.J.,2007). The same personality factor can be used when analyzing a teacher’s point of emphasis and educational approach. Ultimately, the educational designer will refer to their specialty, experiences, philosophy, training, and funding sources when designing an educational approach. That said, the authors referenced in this section are not proposing major changes to the standard power curriculums. They do, however; emphasize a different set of support courses and skill sets that will be required when they enter the workforce. It is the author’s opinion that there is no set of correct answers to the question of course work.

Modeling and Simulation in Power Education

The recent trend in Power Engineering education is the increased utilization of modeling and simulation of electrical machines, operations and phenomena. It is important to understand the similarities and differences of simulation and modeling.

Modeling is the process of creating a suitable description that emulates the performance or characteristics of the actual item being modeled while simulation uses sets of computer programs that allows one to model the important aspects of the behavior of the specific system under study (Laplante, P, 1999). Although modeling and simulation seem to be new trends, the fact is that these two teaching devices, in one form or another, have been serving students for more than 3 decades (Karady, G.G, et al, 2000).

Power education predominantly uses simulators and models in the area of protective device courses, load flow analysis and rotating machines (Karady, G.G, et al, 2000; Kezunovic, M., et al,2004).

Kezunovic et al (2004) points out that models and simulators are not commercially available, forcing educational institutions to create and maintain specifically designed models and simulators to match the teaching objectives of a course they feel is important to offer. Therefore, it can be said that there is no de-facto standard as it relates to modeling and simulation in power engineering.

Some addition questions for universities to ponder are:

1. Is modeling and simulation beneficial to our teaching objectives?
2. If so, what should we invest our resources in to capture the benefits of modeling and simulations?

The following section will detail examples of modeling and simulation currently in educational curriculums.

Examples of Models

It is difficult to easily find many examples of modeling in power engineering. The author assumes that this is due to space constraints in universities as well as safety aspects of working with electricity. Models mostly reside in real space, as opposed to simulators that can be contained within a computer. A major benefit of modeling is that the researcher is modeling actual phenomenon, more realistic observations could be attained. As mentioned previously, simulator success relies heavily the input data and exhaustive knowledge of the systems behavior. Being able to model phenomena would introduce a tremendous amount efficient learning opportunities to sensor and visual learners based on the multi-media nature of modeling.

This section begins by detailing the most advanced incorporations of modeling in the area of power education. Kesonovic et al (2004) detail the various courses at Texas A& M University that prominently incorporate models and simulators. Kesonovic prefaces the discussion by roviding a quick primer on how models and simulators concisely describe complicated mathematical formulas. Another interesting observation is that the author describes is that the sensitivity in the input / output relationships is a difficult and time-consuming process with accuracy relying heavily on utility participation. Although, he discusses the importance of utility participation, interestingly enough, Kesonovic does not affirm if his program works with a utility.

In perhaps the most used application, educators at the Texas A & M University have created models to assist in teaching Load Flow Studies. More specifically, students can systematically model up to a 1000A bus. Finally, in perhaps the most sophisticated model at the school, students and educators used the MATLABand Simulink to create models of various protective relays to be able to model and study behavior in a faulted situation (Ren, J., Kezunovic, M., 2010). The genesis of the development of Merit 2000, which the protective relay model is called, was based on the fact that models (and simulators) are not available via the current market. To be clear, most of the models incorporated at Texas A&M work require simulators and therefore must be created and maintained.

Lee et al (2001) describe an interesting approach to modeling is in where they have designed and elaborated, a scaled down model of an actual distribution system . The system itself includes miniature motors, generators, switching devices and other university made devices that are designed to enhance freshman engineering students appreciation for these devices. The model itself allows Senior design and graduate students to perform simulations using these devices.

Karady (2008) affirms that large models were built in the 1960's for power engineering students to explore concepts and phenomena in his discussion of changes in power engineering instruction . The primary reason for doing away with them, he explains, is basically the floor space they took up. Realizing the instruction power of such models, schools such as Drexel University incorporated scaled down version of the type of model described by Lee et al (Carullo, S.P., et al, 1996). Drexel, as early as 1996, have constructed and maintained a laboratory that houses a model of a distribution system called Interconnected Power Systems Laboratory (IPSL). The model also incorporates simulators that assist with emulating events that an electrical operator would encounter. Since its inception, many documents have been published describing the research and experiments that have been performed in the lab. Based on the research performed throughout the years, there is no question that students have benefited from the reimplementation of scale models.

There are many more examples of modeling that have been published throughout the years, many of them similar in nature. The author has incorporated examples of models that represent subsystems, scaled down systems and mid scale systems (Carullo, S.P, et al, 1996; Lee, C.H., et al, 2001; Ren, J., Kezunovic, M, 2010), all of which could be effective depending on the course and teaching objective.

Examples of Simulators

Similar to modeling, the market availability for simulators is scarce, however, there are interesting and creative examples of simulators that have been published which will be discussed later in this section. There are popular simulation tools available that allow students to easily create their own simulations (and models). For example, the area of Power there is PSCAD, developed by Manitoba Labs. PSCAD allows students to model electric machines and incorporate them in a simulation of their design. Similar to PSPICE, PSCAD is object oriented fairly easy to attain some level of proficiency. University professors at the University of Texas-Austin are using PSCAD and some additional add on programs to simulate renewable generators. The simulator is used as a teaching mechanism for an undergraduate renewable generation course. Another popular simulation tool that is universally recognized in many science related areas of study as a standard is MATLAB. As discussed in the previous section, students used MATLAB to create Merit 2000, a complicated simulator that aides in protective relaying education at Texas A&M University. ASPEN, developed by Advanced Systems for Power Engineering, Inc. is another popular tool used by various educational institutions. If used properly, ASPEN could be extremely powerful. ASPEN can model and simulate large power systems and incorporate a large amount of buses, power transformers, generators, protection devices and transmission lines. Simulation libraries are also available via the manufacture for some protective devices and high scale electric machines. With its powerful capabilities comes a relatively considerable price tag that can be a deterrent for smaller schools on a restricted budget. The considerable costs of the ready-made simulators have lead to the development of simulators for specific and general purposes. In addition to the cost savings, the development and maintenance of a simulator in house, explains Kezunovic et al (2004), assists with the student understanding the phenomenon under consideration. Furthermore, the authors cautions that the solutions to the problem should be the creation of the simulator and not necessarily be a "programming issue" (this is actually a benefit of purchasing site licenses of programs such as PSCAD and ASPEN: i.e. little to no programming is needed to use the applications). Kezunoic et al (2004) explain, that engineering concepts and not programming should be studied in power related courses. Kezunovic describes a digital simulator that simulates a power system. The power system output, is connected to a series of instruments and signals that are ultimately processed by a digital device that serves as a model for a Substation Process bus. Similarly, students use a digital simulator connected to actual protective relay modules to test the behavior of relays under consideration.

Another subsystem model is Xianshu's et al (1996) work, which was a generator simulator used to train power plant operators. The simulator itself simulated a generator in steady state, as well as a generator in transient state. The simulator was created using standard mathematical models. Power Market education is a dynamic topic of study, therefore, various examples of simulations have been created to increase the understanding of real-time and day ahead markets. One such example was an internet based power market simulator the developers dubbed NetPMS (Internet Power Market Simulator; AbaeeKopaee, M.B., et al, 2012). In the NetPMS environment, users can create the power markets based on various case studies and learn the various facets of power market education via the seller, buyers and managers of the Power Market perspective. The authenticity and maintenance of the case studies used to simulate the power market are the keys to the accuracy of the simulators.

As stated before, there are many more examples of simulators being used in power education. The author again, tried to list examples that mimic subsystems, scaled systems and full-scale system.

Field-programmable Gate Array / Specialty Boards

Although many universities have incorporated Field Programmable Gate Arrays (FPGA) in digital laboratories over the last decade, Wollenberg and Mohan (2010) from the University of Minnesota, developed specialty board called the Power Pole Board in addition to a FPGA controller board. The Power Pole board was designed to study power electronics and drives, and the FPGA controller board was designed to interact with the Power Pole board. It has a bevy of components suitable to construct any of the dc-dc converters including buck, boost, buck-boost, fly –back and forward converters and can help students perform analysis for their own project drives (Wollenberg, B., Mohan, N., 2010). To maximize its usage potential, the University of Minnesota has published a repository of laboratories that can be performed with this board at no cost to universities. The Power Pole Board is available via the open market at a substantial price of $1,250 per unit (http://www.hirelsystems.com/shop/Power-Pole-Board.html).

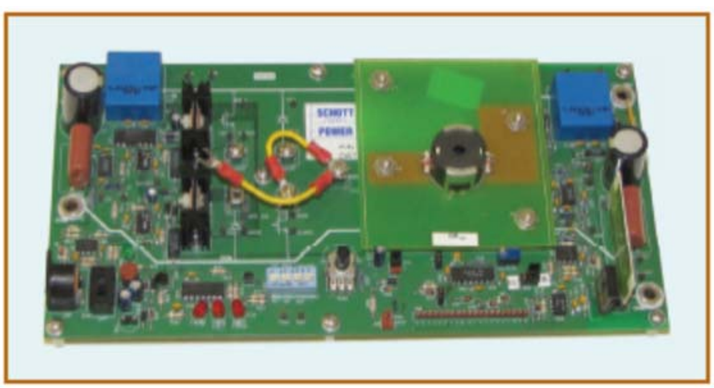

Figure 7: Pole Board. Source: Wollenberg, B., Mohan, N., 2010

The Utilization of laboratories in Modern Power Engineering Education

In the early 2000's, researches began to closer observe the state of the power engineering work force. The general consensus was that simply replacing retiring power professionals would not be enough due to the expected increase in global power demand. The publications authored by Chowdhury (2000), Heydt and Vittal (2003), and Mogridge (2002), all published in the early 2000's, served as a reminder to researchers that recruitment is key to the future of power related industries.

Chowdhury (2000) reasoned that one of the obstacles that the power engineering profession was faced with, is that power technology plateaued for some time; reducing the amount of specialty courses in power that universities were offering. The lure of cutting edge technology that was available in fields such as solid state engineering had led students away from power engineering. Heydt et al (2003), add that one of the reasons for weak student enrollments in power engineering is simply due to the fact that universities do not offer it as alternative. With the problem clearly identified, researches began evaluating the power engineering educational process. The questions were (Karady, G.G, et al, 2000)

1. What is the state of power engineering education?
2. What is being done at the undergraduate level?
3. What is being done at the graduate level?
4. What is role of the laboratory in power engineering education?
5. What are future expectations?

Karady et al (2000) published "Role of laboratory education in power engineering: is the virtual laboratory feasible?", which was essentially a call for university white papers to submit the level of lab usage for their particular program in addition to answering the questions listed above.

Karady, et al (2000), explained the mindset behind the importance of Laboratory in Power Engineering Education by pointing out that one of the major problems of electric power education is the lack of hardware knowledge students have when they graduate. Since the industry expects recent graduates to have a working knowledge of hardware and their general application, it's imperative that educational institutions provide the means and location where this learning could take place: The Laboratory. This logic seems reasonable and fundamental, however, studies have shown that educational institutions are not incorporating extensive laboratory sessions as course requirements. As a follow up to the transaction publications on uses of labs in power engineering education, Wallenberg and Mohan(2010) included results of a survey taken across the Universities of the United States that showed 1058 power courses offered at 118 schools (approx. average 9 courses per school), only 132 (approx. 12%) of the courses require extensive lab work .   Another result of note is that 26 of the 118 (22%) school surveyed do not even offer labs. Prior to the publication of the survey results there were various white paper publications by Joos and Karady(2008) respectively detailing the programs that they assisted in developing .

The Benefits of Laboratories in Power Engineering Education

Gathering from the research in the above, laboratories, if used intelligently and creatively, can be effective teaching tools. Besides bringing engineering to life there are various other educational benefits for the modern day engineering student.

Because most students prefer sensory and visual instruction, as such, the laboratory is a tailor made learning environment for the majority of engineering students. The reason is quite simple, considering the typical laboratory experiment: The input being the modeling or simulation of a realistic event, and the output being the observed phenomena under the student's control. Essentially, the learning possibilities for sensory and visual learners are only limited to the design of the laboratory because the cause and effect nature of most laboratories is practical and predictable.   Another arguable benefit of laboratories is that they support the building block approach when coupled with lecture (Wollenberg, B., Mohan, N., 2010), i.e. the deductive learning approach prominent in engineering education ("tell me what I need to know and I will learn it").   Perhaps the best benefit is described eloquently in Feisel and Rosa's (2005) quote: "The overall goal of engineering education is to prepare students to practice engineering. Applying science to everyday life requires both theory and hands-on practicum. While the former lends itself to classroom learning, the latter can only be learned and practiced in the physical laboratory". In short, laboratories effectively merge practicality with hard science and create learning opportunities via the students own experiences.

Summarizing the Use of Laboratories in Power Engineering Education

The impacts the laboratory as it relates to power engineering education, is captured in Ben Franklin's famous quote: "Tell me and I forget, teach me and I may remember, but involve me and I learn" (Heydt, G.T., Vittal, V., 2003).   The "involvement" in this quote could be linked to laboratories, where students put concepts to test. Heydt et al. (2003) ends his publication by stating that real engineering brought to the classroom is one of the most effective pedagogical tools available. In all publications surveyed, the use of laboratories in Power engineering essentially point to the laboratory's ability to indelibly teach fundamental concepts.

CHAPTER VII

Undergraduate Power Engineering Courses at Texas Universities

For this thesis, a study was performed on ABET credited universities in Texas with electrical engineering programs. Although there are 100's of stellar ABET accredited electrical engineering programs on a national level, the author chose Texas based universities to limit the scope and consider programs regionally. Although only Texas based programs will be discusses, the author cautions that preparing for world class energy situation is a job for universities worldwide.

Research shows that there are 19 universities with an ABET accredited Electrical Engineering programs in Texas ("Accredited Program Search", 2013). Table 3 summarizes the schools and the undergraduate courses in power engineering they currently offer.

There are observations worth noting when studying Table 2 as well as other details of the each universities catalog (see Bibliography for references).

Observation 1

Of the 19 universities researched, 15 universities currently offer at least one course in power engineering; therefore; the average for all 19 universities is 2.6 power engineering course offerings per university. This is an important finding for this study and will have a significant impact on recommendations made in future sections of this paper.

Observation 2

Of the 15 schools with power engineering course offerings, 14 of the universities offer power engineering courses as electives. The only school that requires a power engineering course as a requirement for graduation is University of Texas at Tyler ("2012-2014 Undergraduate & Graduate Catalog", 2014). This is also an important finding that will have an effect on the recommendations made in future sections.

Observation 3

11 of the 15 universities that offer power engineering courses offer Power Engineering Fundamentals / Analysis (or a derivative of) as a course offering.

Observation 4

Of the 15 universities that offer power engineering courses, 5 of the schools offer power engineering laboratories and a supplement to lecture based courses offered. The 66% that do not offer labs far surpasses Wollenberg and Mohan's 2010 study where the authors reported an estimated 22% (26 out of 118 schools) of schools they surveyed did not offer supplemental laboratories for power courses offered (Wollenberg, B., Mohan, N, 2010).

Observation 5

The average Power Engineering Faculty for all schools surveyed is approximately 2.3 faculty members. This number may be biased when considering Texas A&M University (10) faculty members specializing in power engineering.

Summarizing Table 3 Observations

Most of the undergraduate courses listed in the table can be described as fundamental courses or “survey courses”. Course offerings, it seems, are also a function of proximity in relation to industry such as UT Tyler and UT Austin, which are both near ERCOT headquarters in their respective cities. Each of these observations can be used to design an educational approach to power engineering considering that, to do so, one must know the exactly what is currently being done at the various universities.

ABET Accredited Texas School Name	Total Undergraduate Courses	Electric Power Faculty	Power Systems Analysis /	Power Electronics	Power Laboratory	Power Quality	Protective Relav s	Renewable Related	Reliability Analysis	Electric Drives /	Power System Control	Pulsed Power	Energy Conversion Lab	Energy Conversion
Baylor University	3	1	x	x				x						
Lamar University	1	1	x											
Prairie View A&M University	4	4	x	x	x				x					
Rice University	0	0												
Southern Methodist University	1	1	x											
St. Mary's University	2	1	x		x									
Texas A&M University	5	10	x	x			x			x	x			
Texas A&M University - Kingsville	2	1	x	x										
Texas State University	0	0												
Texas Tech University	6	4	x	xx						x		x	x	
The University of Texas - Pan American	3	1	x	x						x				
The University of Texas at San Antonio	5	3	x	x	x			x		x				x
University of Houston	2	2											x	x

University of North Texas	0	0												
University of Texas at Arlington	2	5	x								x			
University of Texas at Austin	8	6	xx	x	x	x	x	x		x				
University of Texas at Dallas	0	0												
University of Texas at El Paso	1	1												x
University of Texas at Tyler	4	3	x	x	x						x			

Table 3: ABET Accredited Universities in Texas with EE Programs and Power Engineering Course Offerings and Electrical Power Faculty. Sources: See Bibliography

Select Texas Universities Emphasis in Power Education

Major universities in the state of Texas have maintained a strong presence in power engineering education for a considerable amount of time. ABET approved universities in Texas, such as University of Texas-Austin, Texas A & M University, and Texas Tech University have invested considerable resources throughout the last two or three decades to be able to effectively and efficiently educate the next generation of power engineers.

Texas A & M University, as previously mentioned, has led the way in protective relaying education. Supplemental to their educational philosophy, they incorporate modeling, simulations, utility interaction and classical power courses (Kezunovic, M., 2010). At the undergraduate level, they offer more 5 courses in power, covering topics such as power electronics, power engineering analysis and protective relaying. Texas Tech University, with a strong tradition in power education, has established a niche in power electronics (ttu.edu) having secured various government grants in the research area of Pulsed Power. The University of Texas- Austin (UT) continues their four decade long contribution to power engineering education by having power engineering program formalized in 1978. UT has almost 300 faculty members involved in energy research projects with an approximate budget of 105 million dollars (utexas.edu). Unlike other universities, UT conducts research in niche sectors of power education such as Policy and Law, Economics and Society, Demand/ End Use, Environmental Impact Analysis and Storage and distribution ("Undergraduate Catalog 2012-2014", 2014). Basically, no other university in Texas invests more in power education and research than UT.

Although the University of Texas at Arlington only offers 2 undergraduate power engineering courses, UTA is the home of the Electric Power Research Institution or EPRI (uta.edu). In addition, UTA offers more than 5 power engineering courses at the graduate level ("Course List", 2014*)*.

The University of Texas at San Antonio (UTSA) also has a well-established power engineering undergraduate course selection. To teach the 5 undergraduate courses in power engineering, they have 3 faculty members with specializing in power electronics, power systems and smart grid implementations (utsa.edu). UTSA is also the home of the Power Electronics and Electrical Power Research Laboratory (PEEPRL;"Power Electronics and Electrical Power Research Laboratory", 2013). The PEEPRL concentrates their research on:

1. Medium and High Voltage Power Electronics
2. Transportation Electrification
3. Renewable resource integration
4. More efficient Semi-conductors
5. Power Grid Support.

Some notable sponsors for the PEEPRL are Boeing Company, CPS Energy, CSR, National Science Foundation and Huavei.

In summary, all Texas universities surveyed in the above have identified the need and incorporated various learning tools to their power education curriculum. Learning tools such as modeling and simulation, utility collaboration and extensive lab work have all played a role in establishing premiere power educational programs.

CHAPTER VIII

Formulating an Approach to Power Education

As in most products or concepts, it is rarely the case that the first generation release is the most effective generation. As history proves, hindsight is a beneficial tool when creating more efficient and effective approaches to products or concepts, therefore; for this thesis contemporary research is to be used as a basis for recommending a power engineering educational program to universities that wish to establish a low cost and effective power engineering educational class or program at the undergraduate level.

As discussed in Chapter II, energy growth will continue to climb in a linear fashion for the next 20 years. Chapter III details the large amounts of power engineering professionals planning to retire within that time, in addition to the dwindling emphasis in power engineering education from a faculty and course offering standpoint. Also, Chapter III details the possibility, based on the current graduation expectancy, that the supply for power engineers may not meet the demand.

Chapters IV – VII were explored to be able to design an educational approach using best practices from all resources surveyed. More specifically, the author will use the research in the below list to formulate a low cost, easily implemented and effective power engineering educational approach.

1. How Students Learn (Chapter IV)
2. Learning Models (Chapter V)
3. Educational Trends (Chapter VI)

4. Current Course offerings in Texas Universities (Chapter VII)

Recommended Elements of the Proposed Educational Approach

The following is list of elements that the author is recommending to universities looking to improve or create power engineering courses of study at the undergraduate level. Collectively, the five elements are named Seeds of Solutions™ by the author:

1. Add Fundamentals of Power Engineering to required undergraduate curriculum instead of a junior level elective. The course should reinforce that Power Engineering is a professional option. The goal here is to double the current interest in electrical power engineering.
2. A laboratory course requirement should be added to the course for a total of 4 required hours. The laboratory will mandate active learning and incorporate the following:
    a. Every laboratory will incorporate a model or simulation for the electrical phenomenon under consideration.
    b. Each laboratory will be designed by instructor with the assistance of the industry / utility contact to add authenticity to the laboratory.
    c. All laboratories will require a multi-disciplined approach in order to complete.
    d. Project Based Learning model will be used for each laboratory.
    e. To the extent possible, laboratory will incorporate an inductive learning element for each laboratory
    f. Reflective learning exercises at the end of each laboratory.
    g. All laboratories, to the extent possible, will use open source hardware and readily available software. Open source hardware will offer portability and availability so that students can experiment at their convenience.

3. In addition to the previously recommend course, offer some or all of the following courses as electives at the undergraduate level:
   a. Power Electronics
   b. Electric Machines / Drives
   c. Wireless Communication
   d. Renewable Generation

   University administrators can hold course place markers such as “Topics for Electrical Engineering” and monitor student interest in taking additional power engineering courses.
4. Establish industry or utility relationships to be able to form a collaborative, attain sponsorships and enhance authenticity to teaching content.
5. When selecting future faculty, consider hiring a professor with experience in power related sciences; or, provide training to current professors to able to teach power engineering related courses. Another option is to hire lectures (rather than assistant professors) to assist with content development.

Seeds of Solutions: An Augmented Undergraduate Approach to Power Education

The Seeds of Solutions (SOS) name was developed to highlight the approaches emphasis on electrical power engineering fundamentals stressed early in the undergraduate curriculum. The idea is to introduce the power engineering profession early on, inspire students to choose the power as their chosen profession via authentic class / laboratory content and professor mentorship. Because the SOS approach incorporates a required course, a small increase in recruitment is almost guaranteed. So in effect the approach is planting and nurturing the “Seed” for “Solutions” to the future issues the electrical power industry will face.

Although the author does believe that second year engineering students could potentially have the necessary educational skills to take the Fundamentals of Power Engineering course and have success, the class is most appropriate at the junior undergraduate level after most of the required foundational courses (i.e. physics, math and fundamental engineering courses have been taken.

The author arrived at the undergraduate approach considering the following factors:

1. Level of comprehension needed to meet future supply of power engineering professionals.
2. Type and Availability of existing power courses used in today's electrical engineering curriculum.
3. The most optimal way to impress on students that power engineering is an option.

Level of Comprehension

Before discussing why the emphasis was not targeted at graduate university curriculum, the author believes it is important to provide a quick introduction on Bloom's Taxonomy (Bloom, B.S., et al, 1956).

Primer on Bloom's Taxonomy

In 1956, Benjamin Bloom and a group of scientists and psychologists published *Taxonomy of educational objectives: The classification of educational goals* which introduced the fundamentals of what is commonly known as Bloom's taxonomy (Bloom, B.S., et al, 1956). The first of three publications released describing the specifics of the taxonomy was called *Hand*

Book 1: The Cognitive (i.e. relating to thinking and understanding) *Domain* (Bloom, B.S., et al, 1956). The publication to this day is widely regarded as the seminal publication of its time with regards to cognitive study. Essentially, Bloom's taxonomy introduced the levels or degrees of understanding that a student can attain depending on their level of comprehension in the topic of study. Table 4 shows blooms level of understanding hierarchy. The lowest level of understanding in Bloom's taxonomy is Knowledge. Bloom defines Knowledge as the comprehensive ability to recite facts and figures. Understanding is defined by being able to rationalize why something works or doesn't. Application is being able to apply principals to achieve an outcome. The Analysis level of comprehension, the student would be able to identify new conditions the topic would be subjected to and be able to recommend a solution.

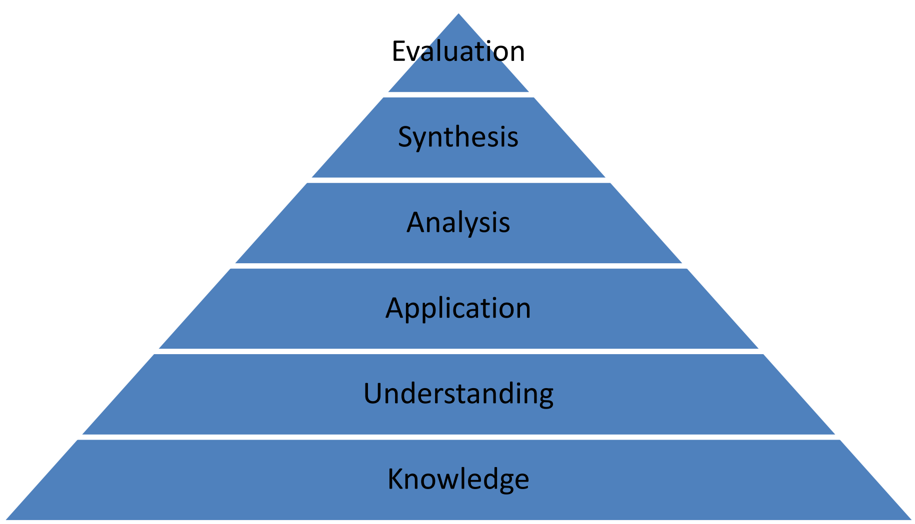

Figure 8: Bloom's Depth of Understanding and Hierarchy. Source: Bloom, B.S., et al, 1956

The Synthesis level of comprehension is believed to be able to arrange and realize engineering designs. The last comprehension level is evaluation. Students reaching the Evaluation level of comprehension are believed to be capable of evaluation of arguments and alternative policies.

In educational circles, there are various opinions on whether students that receive a degree attain a certain level of understanding according to Bloom's Hierarchy. For example, it is widely regarded that students that receive an undergraduate degree have reached the level of Application and students that receive a Master's degree has reached the level of Analysis (Kezunovic, M., 2010). In evaluating Bloom et al's description of each level of understanding, the author would agree with Kezunovic's correlation between Bloom's level of understanding and degree received. Further use of this correlation will follow in future sections.

Bloom's Depth of Understanding Example

To add substance to Bloom's Depth of understanding concept, the author will correlate the level of comprehension necessary to perform standard electrical utility position duties. The discussion will begin with the position of an Apprentice lineworker (an employee who requires supervision when installing or maintaining high voltage equipment). Even the best Apprentice Lineworkers only require **knowledge** of power systems to perform their duties, considering the fact that they are under constant supervision. The extent of the work they perform are routine tasks with **limited necessity to deviate from standard procedures**. A lineworker (an employee that installs or maintains high voltage equipment unsupervised), on the other hand, must **understand** why an operation must be performed a certain way in order to **prevent major injuries** to him / herself and crew. Electrical distribution design engineers must be able to **apply** engineering concepts to **meet the established design criteria**. Transmission Planners must attain an **analysis level of comprehension** to be able to **forecast future load growth and**

<u>recommend economically viable solutions to the future load reliably</u>. Senior Substation Design Engineers (one that designs special protection schemes, designs component layout according to standards, etc.) must attain a **<u>synthesis level of compression</u>** due to the need of **<u>incorporating various considerations</u>** to reliably deliver power under various system conditions. Electrical Standards Committee members must attain an **<u>evaluation level of comprehension</u>**, to **<u>consider various solutions and recommend the safest and most economical approach</u>**.

Undergraduate or Graduate Emphasis

There is much debate at what level of education and what degree of understanding engineers will need to be able to replace the retiring power engineering workforce. Researchers like Kezunovic, believe that the ideal replacement for the retiring engineering workforce would be a student that has attained a master's degree in his/ her area of study and has achieved the Analysis level of comprehension (Kezunovic, M., 2010). Kezunovic emphasizes innovation in the area of power engineering and smart grid technology implementation, however, the author has a different perspective. Although it is extremely important to innovate and rein in new technologies, not all engineers have the capacity or "want" to do so. As such, the author believes that the current level of graduate students entering the workforce that have attained the Analysis level of Bloom's taxonomy is sufficient. The sheer number of replacement and new hires needed over the next 5- 10 years makes it unrealistic to have every graduate of the power engineering work force contribute to their profession by innovation; therefore, the author's recommended approach would be to hire recruits right out of college to contribute the power engineering workforce. Thus, the undergraduate emphasis of SOS approach.

Type and Availability of Power Courses

In Chapter VII a study was performed on all ABET accredited Electrical Engineering Schools in Texas after determining the level of understanding / education the ideal candidate will need. The study consisted of evaluating the undergraduate course offerings in power engineering education. It was determined that most schools do not require power engineering courses as part of the undergraduate curriculum, thus, the recommendation to require a foundational course with a laboratory in power engineering. For a university looking to create or enhance interest in power engineering education, an augmented approach such as the SOS requires the least risk. For one, most universities will only be making a minor change to their catalog considering that most universities are already offering a power engineering foundational course. A second advantage is that university will likely not have to hire specialty faculty considering that the recommended class and laboratory is foundational in nature and that part of the SOS approach is to create an industry contact list.

Why a Foundational course?

Considering the researched detailed in Chapter VI, there three reasons for recommending a foundational course:

1. Using an existing or easily implemented foundational course requires less planning and start-up requirements for university administration.
2. There is no agreed upon power engineering specialty course or emphasis. It is widely believed by many that the future of power engineering will be invariably multi-disciplined.
3. A foundational course would be the most effective way of reaching potential power engineers compared to more advanced courses.

Why a Laboratory?

Teaching styles in engineering classrooms are predominantly lecture driven with little active or cooperative learning. Since the reasons for this approach are what some researchers say "inherent" based on the nature of engineering, a laboratory is the ideal venue to include active learning and explore alternative teaching styles. Again, the foremost objective is to create interest in power engineering. The only way meet this objective is to connect with the students based their learning preferences and highlight the multi-disciplined nature of today's power engineering via laboratories.

As detailed in earlier sections, laboratories offer the following benefits:

1. Real world engineering is brought into a place of learning.
2. Students familiarize themselves with electrical machines and how they are used.
3. Fundamental concepts that were calculated can be observed.
4. The bridge between concepts and realization is gapped.

The next chapter discusses how to implement the SOS approach.

CHAPTER IX

Implementing the Seeds of Solutions Approach

Overall, the Seeds of Solutions approach is relatively easy to implement considering it was designed to be installed with limited investment for universities; however, the administrative portion of the approach could possibly take a significant time to approve and launch. Recall that there are five elements of the SOS approach to consider:

1. Including and Fundamentals of Power Engineering course as part of a required curriculum. The course itself may or may not exist.
2. Include a supplemental laboratory for the above mentioned required course.
3. Add additional classes as interest in power engineering grows. Again, courses should be foundational.
4. Establish industry contacts to authenticate the laboratories and classroom examples. Also contacts may be able to arrange field trips.
5. When hiring faculty, consider hiring professors with power engineering experience. Or, if not hiring, cross train existing faculty in power engineering related sciences.

Classroom Approach

Besides the curriculum requirement aspect, and for some the addition of the Fundamentals of Power Engineering course, there are little recommended changes to the teaching style emphasis in the classroom. A major paradigm shift in engineering teaching styles can potentially take decades to change. When one considers the circumstances, an endeavor to change styles that are so deep rooted in tradition may not be practical. There are some conscientious techniques professors can use to be able to increase efficiency, interest and learning retention. A simple technique would be for the professor to increase the use of diagrams and photographs used during lecture. This effort will take planning and organization time for the professor.

Another technique deserving inclusion is cooperative learning time during classroom lectures. A combinational approach would be to group students in small groups to discuss alternative designs and approaches to a given problem (i.e. problem-based learning and reflective learning). Class time can also be supplemented by site visits organized by the professor along with the industry or local utility contact. The site visit will add interest, scale and highlight the opportunities of the power industry if it is supplemented with a research assignment on the various niches in power engineering along with general information such as pay and leading employers. These small changes can possibly make a great impact on class time teaching efficiency and virtually come with little or no monetary investments.

Laboratory Approach

In the author's opinion, the most critical portion of the SOS approach is the design of the supplemental laboratory. The laboratory element has multiple purposes: Not only is it required to educate effectively, it is also required to be a source of inspiration.

The research undertaken in this thesis has identified the most effective techniques and tools being used in engineering education to be able to incorporate them into the laboratory.

Typically in a traditional engineering laboratory, a standard laboratory instruction sheet is given to the students that they can systematically assemble the experiment and measure fundamental values generated from the laboratory assembly. Of course, there is absolutely great value in this type of instruction for 1st or 2nd year engineering students; however, there are a few important learning opportunities that are glazed over if this technique is used in 3rd and 4th year students that would add substance to the learning objectives. In order to tap into all of the laboratory teaching and learning potential, the author proposed the previously mentioned incorporations. The following is a list of steps used by the instructor to create SOS laboratories:

1. Select topic and or engineering concept to be studied. Based on time constraints in a undergraduate level course, the topic must be common with significant research available. To the extent possible, the model must be akin to the topic of study being lectured, however, not identical. This will allow for inductive learning.
2. While still planning the laboratory, use local utility contact to discuss equipment used in utility that functions off of the engineering concept to be studied. For instance, if the instructor is studying voltage regulation, capacitor banks and voltage regulators could be discussed.
3. Instructor is to discuss real world examples of situations where the utility, based on the situation, was required to incorporate particular equipment that works off the engineering concept of interest. Similarly, Instructor can also discuss particular examples of when it is necessary for the customer/end user to incorporate equipment.
4. Once enough background information is attained, the instructor can begin designing the laboratory.
5. In all SOS laboratories, there will be equipment constants that will model and or simulate the phenomena of interest. This may take additional testing from instructor and support staff to be able to model the phenomena accurately. For the sake of uniformity,

the author will simply refer to the equipment constant as the Model. The Model design itself can be laboratory requirement for the students.

6. Once the Model is established, the instructor will be required to design the teaching objective and ancillary concepts. For instance, in the voltage regulation example, the fundamental concept to be taught is the capacitors ability to offset line inductance. Simply sizing the capacitor bank and measuring the voltage behavior would not be enough for an SOS laboratory. Of equal importance to the fundamental engineering concept is "how" and "why" equipment designs are incorporated in practical power engineering. The lab will be successfully completed not only sizing the bank correctly, but to also incorporate all of the multidiscipline design parameters the instructor specifies.
7. The equipment used for the Model and laboratory solutions will utilize, to the extent possible, open source hardware. This will allow students to work on solutions away from lab.
8. With the model complete and the teaching objective(s) established, the instructor can set design parameters as difficult or easy as he/she sees fit. The design parameters will require the student to research technology methods, programming languages and equipment to **incorporate** concepts making this a multi-disciplinary learning experience. Continuing with the voltage regulation example, the ancillary example could be simply a remote switch or a more sophisticated logic controller that completes a closed loop system.
9. Because project based learning can closely mimic industry projects, SOS laboratories will incorporate project based learning aspects. Each team will be separated into groups no

larger than 4 students. The students will sub group themselves into "resources" to complete various parts of the laboratory so that a timely completion time is achieved. The sub grouping of teams further authentic the learning experience because students will invariably be subjected to conflict during the project build up as well as the main program as due dates draw near (Meredith, J.R., Mantel, S.J., 2011). The goal is to cultivate positive interdependence amongst teams to facilitate completion of laboratories. Some key aspects of the project process is for teams to:

a. Plan and organize tasks
b. Set achievable timelines and goals
c. Use tools like Gantt charts and financial analysis tools
d. Create performance criteria (if possible)

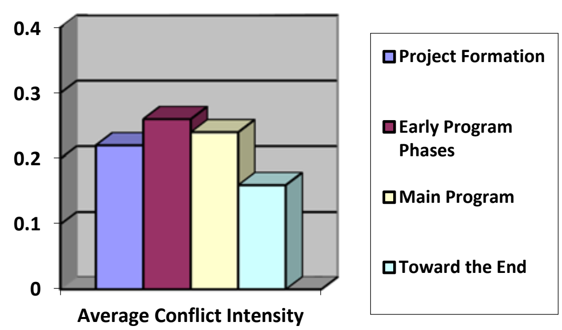

Figure 9: Average Conflict Intensity Over the Project Life Cycle. Source: Thamhain et al., 1975

10. The student completes the lab based on the established design criteria. Key points are emphasized using Bloom's Taxonomy Action Verbs associated with Application level (or desired comprehension level), which is the targeted level of concept retention.

11. A write up is completed with design specifics and evidence supporting generalizations observed during the lab. In every lab, a reflective learning exercise is to be completed by each individual student.

12. Steps are summarized below.

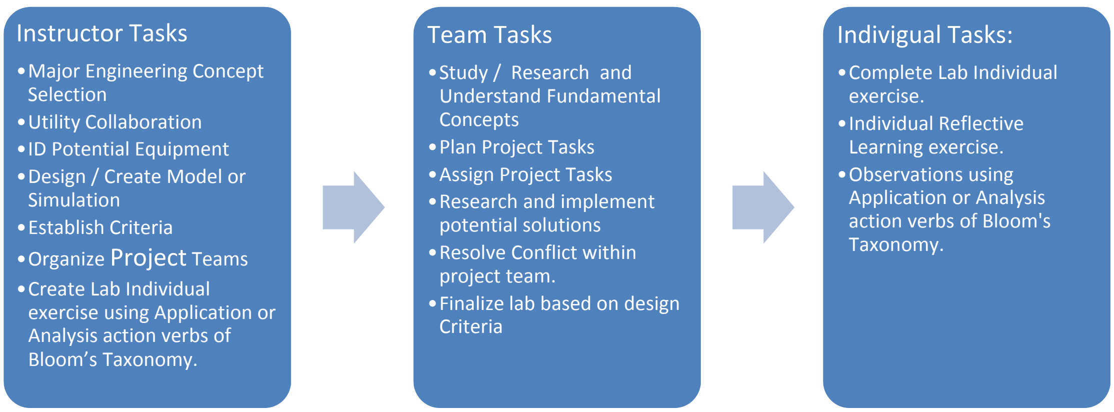

Figure 10: List of Instructor, Team and Individual tasks for SOS Approach

Action Words for Bloom's Taxonomy				
Knowledge	**Understand**	**Apply**	**Analyze**	**Evaluate**
define	explain	solve	analyze	reframe
identify	describe	apply	compare	criticize
describe	interpret	illustrate	classify	evaluate
label	paraphrase	modify	contrast	order
List	summarize	use	distinguish	appraise
name	classify	calculate	infer	judge
state	compare	change	separate	support
match	differentiate	choose	explain	compare
recognize	discuss	demonstrate	select	decide
select	distinguish	discover	categorize	discriminate
examine	extend	experiment	connect	recommend
locate	predict	relate	differentiate	summarize
memorize	associate	show	discriminate	assess
quote	contrast	sketch	divide	choose
recall	convert	complete	order	convince
reproduce	demonstrate	construct	point out	defend
tabulate	estimate	dramatize	prioritize	estimate
Tell	express	interpret	subdivide	find errors
Copy	identify	manipulate	survey	grade
discover	indicate	paint	advertise	measure
duplicate	infer	prepare	appraise	predict
enumerate	relate	produce	break down	rank
listen	restate	report	calculate	score
observe	select	teach	conclude	select
Omit	translate	act	correlate	test
Read	ask	administer	criticize	argue
Recite	cite	articulate	deduce	conclude
Record	discover	chart	devise	consider
Repeat	generalize	collect	diagram	critique
Retell	give examples	compute	dissect	debate
visualize	group	determine	estimate	distinguish
	illustrate	develop	evaluate	editorialize
	judge	employ	experiment	justify
	observe	establish	focus	persuade
	order	examine	illustrate	rate
	report	explain	organize	weigh
	represent	interview	outline	
	research	judge	plan	
	review	list	question	
	rewrite	operate	test	
	show	practice		
	trace	predict		

	transform	record schedule simulate transfer write			

Table 4: Action Words for Bloom's Taxonomy. Source: Bloom, B.S., et al, 1956

Equipment Needed to implement a Solutions Based Laboratory

After much research on low cost equipment, the author is proposing the following equipment so that educational institutions can implement SOS based laboratory or classroom without a burdensome financial investment. Selection criteria are based upon the following:

1. Price
2. Educational effectiveness / Criticality
3. Availability
4. Ease of Use
5. Portability / Flexibility

Standard / Classical Electrical Test Equipment

It is important to include a formidable test kit that includes most of the standard electrical test equipment used in classical electrical circuit analysis. Some of equipment includes the oscilloscope, the multi-meter, AC / DC power supply and personal computer. Most of this equipment is already available to students enrolled in ABET certified programs; however, a detailed explanation of the importance will follow.

Oscilloscope

The oscilloscope is fundamental to power engineering education based on the simple fact that it can show, via testing, the circuit behavior when subjected to frequency anomalies. More and more, frequency anomalies are topics of interest for various reliability entities as they study frequency stability and the part in plays in reliability. Properly adjusted oscilloscopes can also capture electric characteristic behavior based on instantaneous events. Instantaneous events are extremely important in power system analysis.

AC and DC Variable Voltage Power Supplies

AC and DC variable power supplies are needed for nearly all power related laboratories. They are essential when subjecting a design to voltages that other than nominal. They also provide nominal input voltage to equipment in the laboratory.

Function Generator

A function generator is an essential tool for electrical power laboratories for its ability to produce low voltage sine waves. Students can safely test output wave forms of a particular circuit and compare them to the input wave form. Fundamental concept of induction and capacitance of a circuit can be explored with a function generator and oscilloscope.

Bench or Handheld Digital Multimeter

The multimeter is another essential tool needed to measure voltage and currents for nearly all power related projects. The multimeter will not only be used to verify electrical characteristics, but also in troubleshooting equipment.

Labview Student Edition

Labview is a graphical development environment built specifically for applications in engineering and science (Bishop, R.H.,2007). The full version is considered by many to be *the*de-facto program to design, test, measure, automate and control scientific experiments. The Student Edition offers the same functionality of the full version save for some printing capabilities. The Student Edition is available to students with proof of university enrollment via the National Instruments website at a modest cost of under $40 (Ni.com, 2014). Having access to the program will allow the students to be able complete laboratory assignment at their convenience and pace (an especially good feature for global learners).

Various Electrical Machines

Electrical machine models will be needed to authentically test machine types when they are subjected to mechanical or electrical inputs. For universities just beginning their programs, it is recommended to create a list of laboratories before purchasing equipment then gradually add equipment as the repository of laboratories grows bigger.

Current and Voltage Transducers / Transformers

Current and voltage transducers are needed because the measuring of electrical characteristics will be done at a personal computer or standalone microcontroller. The transducers will represent nominal electrical characteristics within equipment parameters. Transduction and transformation is done at all levels of academia and industry**.**

Data Acquisition Cards and Logic Controllers

Data acquisition Cards (DAQ) and logic controllers are a main stay in power engineering education because students need to acquire data in order to interpret it. The DAQs work with programs such as Labview, Matlab and Visual Basic to acquire the input or output of a circuit or system. Once data has been acquired, the logic controllers can be programmed to carry out various tasks such as closing or opening a circuit. Many commercially available DAQ also have Logic controller functionality and vice versa.

Arduino

The Arduino is an open source microcontroller that if correctly programmed and configured can also double as a DAQ in the Labview environment ("Arduino", 2014). The Arduino does not require a computer to function as it can operate as a single board computer, however; the user does require a computer to program to the Arduino. The Arduino is extremely powerful as it can be programmed to control circuits using open source software (free), write programs and create interface circuits to operate switches and other sensors, control motors with only general knowledge of C++. All software needed to program the Arduino is free and there is a significant amount of free information and samples available online. Make no mistake, the Arduino is more than a toy, in fact universities such as the University of Minnesota have incorporated into the mechanical engineering curriculum (Durfee, W., 2011). Perhaps the Arduino's best fearture is its availability and relatively inexpensive price (amazon.com, 2014: $29.00). The Arduino's price point makes it feasible for all students to be able to purchase one as part of the laboratory requirement. Example laboratories in this thesis will incorporate the Arduino.

Figure 11: The Arduino Uno. Source: www. Arduino.cc

CHAPTER X

Example Laboratories

The following chapter introduces a sample set of laboratories using the elements of the SOS approach. Each sample lab will include a discussion and solution of the teaching / learning principals utilized. Before going into the examples, it is important to discuss inductive learning and project-based more in detail so that the laboratory objective can be better understood.

Designing Laboratories with Inductive and Project Based Learning Principals

Project-based learning is inherently inductive in nature (Prince, M., Felder, R., 2006); however, there are techniques that should be incorporated by the educator to increase the efficacy of the instruction. Prince and Felder (2006) offer the following:

1. Instruction should begin with content and experiences likely to be familiar to the students so that they can make connections to their existing knowledge structures.

2. New Material should be presented in the context of its intended real work application.

3. Material should not be presented in a manner that requires students to alter their cognitive modes abruptly.

4. Instruction should require students to fill in gaps and extrapolate material presented by the instructor. This helps with the student's ability to be self-learners.

5. Instruction should involve students working together in small groups which supports the used of cooperative learning.

By inspection, it can be seen that project-based learning, by definition, incorporates many of the above.

Project-based learning will require students to incorporate the Engineering Design Process. More specifically, students will:

1. Define or consider a problem
2. Specify or consider Requirements
3. Consider Solution Tradeoffs and develop solution based on research
4. Build and test Prototype
5. Redesign if necessary
6. Communicate results.

It differs significantly from the Scientific Method as the Engineering Method uses science to design a product or service for a specific need. The Scientific Method on the other hand is used to understand (and witness and interpret) phenomena. In general, most laboratories use the Scientific Method over the Engineering Method; however, the Engineering Method is crucial to the Seeds of Solutions approach.

The following labs will incorporate all the elements of the Seeds of Solutions approach. After each sample lab, a discussion will follow that identifies each element of the teaching / learning principals utilized.

Scientific Method	Engineering Method
State a question of Problem	Define or consider a problem
Gather Background information	Gather Background information
Formulate hypothesis	Specify or consider Requirements
Design Experiment; Establish Procedure	Consider Solution Tradeoffs and develop solution based on research
Test hypothesis by doing experiment	Build and test Prototype
Analyze Result; Conclude	Redesign if necessary
Communicate results.	Communicate results.

Table 5: Scientific Method vs. Engineering Method. Source: "Comparing the Engineering Design Process to the Scientific Method", 2002-2014.

Lab 1: Design and Build of a Transformer

Objective:

The objectives of this laboratory are as follows:

1. Research IEEE STD C57.12.91-2011and understand the importance.
2. Understand the functionality of a transformer, Faraday's Law, the corresponding formulas including how they are used in a practical engineering design scenario.
3. Design and build a single phase transformer according to the design and performance specifications.
4. Understand the tradeoffs associated with transformer design.
5. Create a project management plan to identify and track tasks. Create a research and development plan that includes a per-unit cost for the transformer design. Assume that company will invest in winding machines.
6. Construct a product specification sheet that includes an equivalent circuit drawn in PSPICE.

Background:

The electronics design/manufacturing company that you work for is looking into establishing a line of small, dry type transformers for data acquisition systems. The interest stems from an unsolicited Request for Proposal (RFP) the procurement manger received for a certain dry type transformer with a rare primary side voltage specification (12V). Since your company has no pre-established market share in this area, and the RFP is due in 21 calendar days, the company has authorized 14 calendar days for your project team to design a transformer that meets the following specifications:

1. 12V Primary
2. 5V Secondary

3. .1-.11 Amp (output current)
4. >.80% Efficiency
5. <1 5% Voltage Regulation

In addition to the fully functional transformer prototype for management's review, your team has been tasked to formulate a per-unit estimate for the particular transformer your team designs. If the award is given to your company, the purchasing company requires a test certificate that lists all the transformer losses and performance information based on the results of the ratio test, open circuit test and short circuit test. The test certificate must also include a CAD generated (i.e. PSPICE, PS-CAD or AutoCAD) diagram of the equivalent circuit. In order to do this, your team is to research the associated IEEE Standard to find the methods to perform baseline tests listed above.

Research Hints:

There is no shortage of transformer design information available in books as well as web based periodicals. It is recommended that each team first research IEEE STD C57.12.91-2011 and any other pertinent standards, then; reference a well respected text in Electrical Machines to research transformer and transformer testing theory.

Project Guidelines:

The electrical specifications for the transformer to be built were selected with safety and material availability in mind, therefore, no latitude is given for altering the primary or secondary voltages selected. However, the rated secondary current can be altered to satisfy the safety confidence level of the student or instructor.

Required Equipment:

Transformer Core

Power Meter (capable of measuring mW) or Oscilloscope with delay measuring function

Magnetic Wire

Soldering Iron and Soldering supplies

PC with previously listed CAD program

Multi-meter

Proto Board with assorted lengths of wire

Current Transformer or other current measuring device

<u>Project Deliverables:</u>

- A fully function prototype of the transformer. The Transformer must meet most or all the performance criteria / specifications. If the transformer does not meet the performance specifications, the team is required to submit a scientific explanation of why it did not meet criteria.
- Considering the cost of labor (the average electronics tech is paid a wage of 17 dollars an hour) formulate a per-transformer cost. Make sure to include line items for all equipment (consider researching cost of winding machines), labor, and materials and overhead required to construct the transformer. In a team report, include the following:
    - Work Break-down structure.
    - Gantt chart.
    - Project Summary that includes
        - Introduction
        - Problem Statement
        - A list and discussion of publications researched
        - Discussion of chosen solution(s)

        - Specification Sheet
        - PSPICE drawing of Equivalent Circuit
        - Phase Diagram
        - Procedure used to complete project.
        - Limitations you might have observed during the design phase of the laboratory
        - Conclusions

Individual Student Submittal:

- Each student is to submit a report that addresses the following:
    - In one page or less, each student must explain Faraday's Law in their own words.
    - In one page or less, each student must submit an explanation of what considerations must be made to the design and build a 3-phase transformer.
        - Each student must include a list of formulas
        - A block diagram of the 3 phase transformer that shows:
            - the core geometry
            - winding locations
            - primary terminals
            - secondary terminals
    - In one page or less, each student is to summarize the importance IEEE STD C57.12.91-2011 from a purchaser's perspective
    - In one page or less, each student is to summarize the importance IEEE STD C57.12.91-2011 from a design manufacturer's perspective

Discussion of Laboratory I:

Laboratory I –The Design and Build of a Transformer is a laboratory designed to expose students to the theoretical operation of a transformer as well as practical tradeoffs involved in transformer design. The students will need a fundamental understanding of Ohms law (in all forms), a mastery of Faraday's Law and the Universal Transformer EMF Equation. Students will also reference ANSI/IEEE standards to design acceptable methods for testing transformers to complete this laboratory. From a technical perspective, the design and construction of a transformer that meets the criteria selected requires an Application level understanding of the operation of a transformer. As mentioned previously, a documentary of a completed transformer is included with this thesis submittal, therefore, only a brief procedure in included here (please see Laboratory I.WMV).

Discipline Incorporations:

Electrical Power Fundamentals

Electro Magnetic Theory

Practical Engineering Manufacturing Design

Electrical Measurement Equipment

Electric Circuit Fundamentals

Recommended Length of time allotted for Laboratory I:

This laboratory will require significant research for each project team (no more than 2 to 3 project team members) if the students do not have prior experience in transformer or electrical power calculations. All things considered, the author recommends three (3) weeks for completion of the Laboratory I.

Key Formulas for Laboratory I:

1.0 Transformer Ratio Relationship $a = \frac{N_P}{N_s}$

1.1 Transformer Voltage Relationship $a = \frac{V_P}{V_s}$

1.2 Transformer Current Relationship $a = \frac{I_s}{I_p}$

1.3 Transformer Turns Ratio $a = \frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_P}{N_S}$

1.4 Universal Trans. EMF Equation $V_{\max\_in} = 4.44 \times A_e \times \beta_{\max} \times N$

1.5 Ohm's Law (Power) $P = \frac{V^2}{R}(Watt)$

1.6 Ohm's Law (Power) $P = i^2 \times R(Watt)$

1.7 Ohm's Law (Reactive Power) $Q = I^2 \times X(VAR)$

1.8 Apparent Power Formula $S = I^2 \times Z(Var)$

1.9 Alt. Apparent Power Formula $S = V_{rms} \times i_{rms}(VA)$

1.10 Power Factor Formula $pf = \frac{P}{S}$

General Procedure:

1. Research possible solutions using the references provided (ANSI / IEEE Standards) and any other references available to students.
2. Formulate the Gantt chart for this laboratory and work break down structure.

3. After research is completed, calculate the design turns ratio, the number of turns for each winding, saturation voltage using a design optimizing spreadsheet. The spreadsheet must be created by each team during the research phase of this laboratory.
4. Based on various design models, choose the pertinent design features of the transformer, and procure materials in order to build the transformer.
5. Build the transformer according to design specifications.
6. Once the transformer has been built, perform the following tests:
    a. Ratio Test
    b. Open Circuit Test
    c. Short circuit Test
    d. Efficiency Test
    e. Voltage Regulation Test (purely resistive load)
7. Based on results of test, draw the transformer's equivalent circuit in PSPICE (or other CAD program)
8. Create a phase diagram of the transformer built.
9. Finalize and submit team laboratory submittal
10. Submit individual submittal.

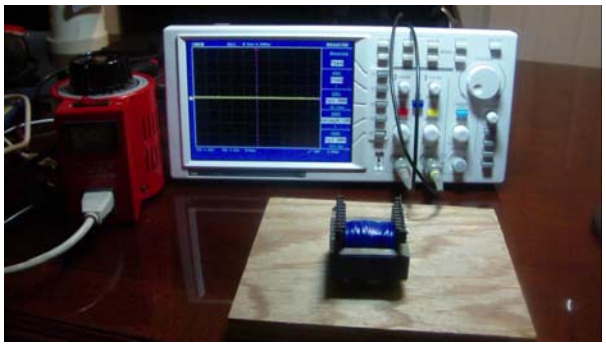

Figure 12: Completed Transformer with Test Equipment

Figure 13: Transformer prepared for Short Circuit Test

Lab 2: Designing and Build of a Power Meter

Objective:

The objectives of this laboratory are as follows:

1. Research existing ANSI / IEEE Standards and understand the importance.
2. Understand the functionality of power meters, the corresponding formulas and how they are used in a practical engineering scenario.
3. Create a project management plan to identify and track tasks and create a research and development budget.
4. Design and implement single phase power meter that can be monitored on a personal computer.

Background:

The operations manager of an auto parts manufacturing company has contacted your engineering firm to discuss electric metering for their manufacturing plant. The operations manager goes on to explain that their corporate office concerned about their latest bill. The operations manager explained that they had contacted their electric utility to inquire about "tapping off" the utility's meter, however, the utility explained that was not an option as of yet. After a review of the aftermarket products that do not offer a complete solution, he contacted your firm to see how much it would cost for your firm to design a custom personal computer based single phase power meter to measure the following:

1. RMS Current
2. RMS Voltage
3. Apparent Power
4. Real Power

5. Reactive Power
6. Power Factor

The president of your engineering firm has authorized 14 calendar days for your project team to research and develop (R & D) a solution. Part of the R & D task is to create estimate for the customer.

Research Hints:

There are several ways of measuring the values the customer is requesting. There are numerous sensors, transducers and meters that designers can use to attain accurate values. Each team is to begin researching pertinent ANSI / IEEE standards for guidance – namely IEEE Std. 1459-2010 and ANSI/IEEE C37.26-1972.

Project Guidelines:

For this Project, each team is to use a function generator to produce the sinusoidal voltage signal. This will allow teams to explore electrical signals and the corresponding formulas at low voltages without the need of sensors. The use of special sensors that directly measure Real Power or Active Power is strictly prohibited for this Laboratory.

Required Equipment:

For Voltage Source:

Variable inductor in the 500mH range.

Resistor

Proto Board with assorted lengths of wire

Function Generator

RCL Meter

Oscilloscope

For Data Acquisition:

Data Acquisition Device, preferably with simultaneous sampling.

Personal Computer

Labview

Project Deliverables:

- A working Labview© Virtual Instrument (VI) that measures or calculates previously listed electrical values.
- Considering the cost of labor (the client is charged $90 dollars an hour for each project member) put together a formal proposal for the customer. Make sure to include line items for piece of equipment, unit of work and necessary software. Recall that this is a fully functional meter that is being implemented, therefore, you must include specific instrumentation.
- In a team report, include the following:
    - Work Break-down structure.
    - Gantt chart.
    - Project Summary that includes
        - Introduction
        - Problem Statement
        - A list and discussion of publications researched
        - Discussion of chosen solution(s)
        - Procedure used to complete project.
        - Limitations you might have observed during operation of your design.

        - Conclusions
        - Screen Shot of the Front Panel and block diagram of the VI.

Individual Student Submittal:

- Each student is to submit a report that addresses the following:
    - A detailed explanation of a method of directly measuring Reactive Power.
    - A detailed explanation of what changes must be made to VI to be able to measure 3-phase power values.
        - Each student must include a list of formulas
        - A block diagram of the 3 phase power meter
    - In one page or less, each student is to summarize the importance of IEEE Std. 1459-2010 from a design engineer's perspective.
    - In one page or less, each student is to summarize the importance ANSI/IEEE C37.26-1972 from a design engineer's perspective.

Discussion of Laboratory II:

Laboratory II –The Design and Build of a Power Meter, is designed to expose students to all fundamental electrical values, their associated formulas and the industry accepted (i.e. ANSI/IEEE standards) way of calculating each value. In order to extract each electrical value, the student must understand the signals under consideration and how to process them to attain the values sought. From a technical perspective, the inclusion of Labview for the creation of functional instrument such as a single phase power meter assures Application level understanding of the following key formulas. As mentioned previously, a documentary of a completed power meter is included with this thesis submittal, therefore, only a brief procedure in included here (please see Laboratory II.WMV).

Discipline Incorporations:

Electrical Power Fundamentals

Signal Processing

Programming (Labview)

Electric Circuit Fundamentals

Recommended Length of time allotted for Laboratory II:

This laboratory will require significant research for each project team (no more than 3 project team members) if the students do not have prior experience in electrical power calculations. All things considered, the author recommends two (2) to two and a half course weeks for completion of the Laboratory II.

Key Formulas for Laboratory II:

2.0 Voltage RMS $v_{rms} = \sqrt{\frac{1}{T}\int V_{\max}{}^{2}(t)dt} = \frac{V_{\max}}{\sqrt{2}}$

2.1 Current RMS $i_{rms} = \sqrt{\frac{1}{T}\int i_{\max}{}^{2}(t)dt} = \frac{I_{\max}}{\sqrt{2}}$

2.2 Apparent Power (VA) $S = v_{rms} \times i_{rms}(VA)$

2.3 Sinusoidal Voltage Signal $v(t) = V_{\max} \sin \omega t(V)$

2.4 Sinusoidal Current Signal $i(t) = I_{\max} \sin \omega t - \theta(A)$

2.5 Average Power Formula $P = \frac{1}{T}\int v(t)i(t-\theta)dt(Watt)$

2.6 Reactive Power Formula $Q = \frac{1}{T}\int v(t)i(t-90°)dt(Var)$

2.7 Alt. Average Power Formula $P = I^2 \times R(Watt)$

2.8 Alt. Reactive Power Formula $Q = I^2 \times X(Var)$

2.9 Alt. Apparent Power Formula $S = \sqrt{P^2 + Q^2}(VA)$

2.10 Power Factor Formula $pf = \frac{P}{S}$

General Procedure:

11. Research possible solutions using the references provided (ANSI / IEEE Standards) and any other references available to students.
12. Design and build the circuit model.
13. Calculate expected values such as real power, apparent power, reactive power and power factor by measuring RMS Voltage, RMS Current, resistance and inductance of the circuit model. Students must use the oscilloscope to cross check calculations.
14. After selecting measurement approach for each value, each team is to program a single phase Power Meter using the specifications and guidelines previously provided in Labview.

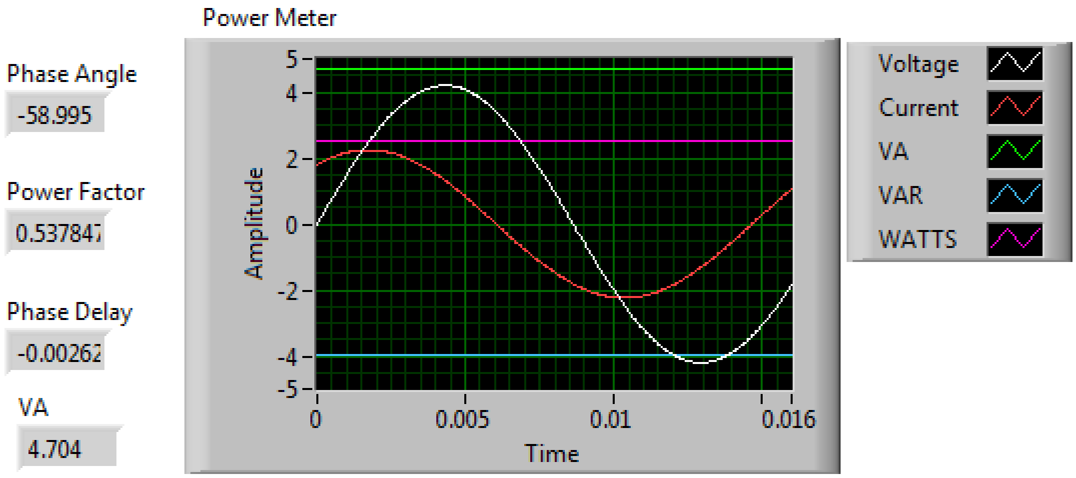

Figure 14: Labview Screen Shot of Power Meter

Lab 3: Design and Build a SCADA System with an Automatic / Remote Capacitor Bank

Objective:

The objectives of this laboratory are as follows:

1. Research IEEE PC37.1™/D1.9 Standard for SCADA and Automation Systems and understand the importance.
2. Understand the elements of a SCADA system and how / why it used in industry.
3. Understand why / how / where capacitor banks are installed and apply formulas to size a capacitor bank.
4. Design and build a fully functional SCADA system with remotely activated capacitor bank.
5. Design and implement hardware based solutions to measure electrical values.
6. Create a project management plan to identify and track tasks.

Background:

A small Municipal Utility District (MUD) has contacted your engineering firm to inquire about your firm's ability to design a SCADA system for a single phase lift station that serves a local subdivision and small clinic with an ICU. The MUD Manager has mentioned that they originally considered commercially available SCADA packages; however, the cost of the systems considered surpassed the grant funds awarded for pump and control upgrades. The grant was awarded to the MUD due to the lift station's criticality (i.e. serves the clinic with the ICU). Because of its criticality, the lift station has dual electrical feeds and a back- up generator. Your firm is tasked with building an AD-HOC SCADA System that provides all elements of a SCADA system without compromising functionality.

Given the fact that the MUD Manager has no prior experience with SCADA systems, he is not sure what the exact requirements for one are; however, the grant officer confirmed that AD-HOC designs are acceptable under the grant terms and conditions “just so long the SCADA System meets IEEE / ANSI Standards”.

Also discussed was the electric bill for several lift stations that the MUD maintains. Apparently, the electric service provider has been charging a Power Factor Penalty Charge for the last two years for the four (4) lift stations that they own / maintain. The cost is substantial and the MUD Manager would like your firm to incorporate an automatic reactive support solution into the SCADA system you design.

Because there are no spare conduits and the most of the lift station is paved in concrete, it makes economic sense to control the capacitor bank remotely (due to the cost of a directional bore); therefore, your team will have to research wireless solutions that will able to reliably activate a capacitor at least 10-20ft from the control room.

Power factor correction would allow the MUD to save significantly on their electric bill; therefore, the extra cost should be justified. To assist with the Design, the MUD Manager has furnished you with a utility plan (included as part of this handout).

Research Hints:

Project teams will have to reference IEEE PC37.1™/D1.9 Standard for SCADA and Automation Systems to research the key elements of a SCADA system. Also, Projects teams will have to research industry standard wireless communication protocols to activate and control the capacitor bank.

Project Guidelines:

In Lab 2, we explored methods of measuring reactive power using software signal processing techniques. Lab 3 will require your team to explore a hardware based methods of measuring the components of the power triangle (i.e. apparent power, average power & reactive power). For example, project teams can design a measurement controller that can measure reactive power without the need to process the signals via software. Teams are encouraged to use Labview, however standalone systems and alternative control software like Simulink are acceptable as well.

In order to test your solutions, each team will have to construct a distribution model that incorporates a high enough X/R ratio to be able to model a power factor of ≈.80.

The construction of the distribution model is meant to emulate a single phase load to be able to calibrate the SCADA system will consist of:

1. 24-120 V AC voltage source (teams can use any voltage within this range)
2. A variable resistance
3. Variable inductor.
4. >.5A current

One of the SCADA standard requirements is the ability to measure electrical values. Using a combination of hardware and software techniques, your team must develop a method of monitoring:

1. Voltage
2. Current

3. Average Power

4. Reactive Power

5. Apparent Power

6. Power Factor

Since the remote capacitor bank needs to support any source (i.e. Utility ABC, XYZ), part of the assignment is to designate the location of the capacitor bank. Your project team is use the utility drawing of the lift station included with this handout to designate the location of the following:

1. SCADA Computer

2. Location of the instrument transformers.

3. Location of the Capacitor Bank

Required Equipment:

Lab View

Personal Computer

Auto Transformer

Proto Board with assorted lengths of wire

Data Acquisition Cards

Voltage Transducer / Transformer or other current measuring device

Current Transducer / Transformer or other current measuring device

Wireless Communication Devices

Recommended Equipment:

Stand alone microcontroller

CAD program

PSPICE

Project Deliverables:

- A fully functional SCADA system with remote capacitor bank.
- An Engineer's Cost Estimate (teams need to research this term) of how much it would cost for an Electrical / Mechanical company to install your design. Make sure to include the cost for the design (your firm's design charge). The Engineer's Cost Estimate must list assumptions and/or basis for costs.
- A list of readily available SCADA SYSTEMS (i.e. name of company as well as price range)
- In a team report, include the following:
    - Work Break-down structure.
    - Gantt chart
    - Project Summary that includes
        - Introduction
        - Problem Statement
        - A list and discussion of publications researched
        - Discussion of chosen solution(s)
        - All notes and Calculations
        - Circuit diagram of the distribution model. Include:
            - Points of measurements
            - Location of Capacitor
            - Location of Resistor

        - Location of Inductor
        - Type of conductor used.
    - PSPICE drawings of circuit designs
    - Fully functional SCADA.VI
    - Screenshot(s) of Front Panel.
    - Procedure used to complete project.
    - Limitations you might have observed during the design phase of the laboratory
    - Conclusions

Individual Student Submittal:

- Each student is to submit a report that addresses the following:
    - In one page or less, each student is to explain why lift stations are critical to the health and safety of the public. What could happen if the lift stations are left without power? Besides adding backup circuits and generators, how do utilities reduce the possibility of lift station failure?
    - Research and draw a block diagram of a lift station float / switch circuit.
    - In one page or less, each student must explain why reactive support is important for customers.
    - In one page or less, each student must submit an explanation of why reactive support is important for utilities.
    - Each student must include a list of formulas used to complete the laboratory.
    - Each student is to include a list of key elements of a SCADA System.

- A block diagram of the SCADA System that was designed for the Laboratory.
- Some Consulting firms provide energy savings designs free of charge. Payment is determined by the savings in the bill over a period of time. For example, the company pays 50% of the energy savings to the consulting firm for a period of 5 years. In one page or less, each student is to give their opinion on whether or not this is a good option for companies. Does the company or consulting firm benefit (financially) more from such a practice? Each student must provide solid reasoning in their explanation that includes sample calculations.
- In one page or less, each student is to explain if installing capacitors in a residential electrical service will save on energy costs if a utility does not have a power factor penalty. Each Student is to include sample calculation to back their responses.

<u>Discussion of Laboratory III:</u>

Laboratory III is a laboratory designed to expose students to reactive support via a systems approach (i.e. the SCADA SYSTEM to be designed). The students will need a fundamental understanding of Ohms law (in all forms), a mastery of the power triangle and basic analog and digital circuits. Students will also reference ANSI/IEEE standards to research the elements of a fully function SCADA SYSTEM. From a technical perspective, the design and construction of SCADA System with reactive support requires an Application level various sub-systems. As mentioned previously, a documentary of a completed SCADA system is included with this thesis submittal, therefore, only a brief procedure in included here (please see Laboratory III.WMV).

<u>Discipline Incorporations:</u>

Electrical Power Fundamentals

Transformer Operation Theory

Digital Electronics

Electrical Instrumentation

Electrical Measurement Equipment

Electric Circuit Fundamentals

Micro Controller Programming

Signal Processing

Recommended Length of time allotted for Laboratory III:

This laboratory will require significant research for each project team (no more than 3 - 4 project team members) if the students do not have prior studies signal processing, electrical power calculations. All things considered, the author recommends three (3) to four (4) weeks for completion of the Laboratory III.

Key Formulas for Laboratory III:

Laboratory III utilizes all of the formulas previously used in Laboratories I & II

3.0 Transformer Ratio Relationship $a = \frac{N_P}{N_s}$

3.1 Transformer Voltage Relationship $a = \frac{V_P}{V_s}$

3.2 Transformer Current Relationship $a = \frac{I_s}{I_p}$

3.3 Transformer Turns Ratio $a = \frac{I_s}{I_p} = \frac{V_p}{V_s} = \frac{N_P}{N_S}$

3.4 Ohm’s Law (Power) $P = \frac{V^2}{R} (Watt)$

3.5 Ohm's Law (Power) $P = i^2 \times R(Watt)$

3.6 Ohm's Law (Reactive Power) $Q = I^2 \times X(VAR)$

3.7 Apparent Power Formula $S = I^2 \times Z(Var)$

3.8 Alt. Apparent Power Formula $S = V_{rms} \times i_{rms}(VA)$

3.9 Power Factor Formula $pf = \frac{P}{S}$

3.10 Voltage RMS $v_{rms} = \sqrt{\frac{1}{T}\int V_{\max}{}^2(t)dt} = \frac{V_{\max}}{\sqrt{2}}$

3.11 Current RMS $i_{rms} = \sqrt{\frac{1}{T}\int i_{\max}{}^2(t)dt} = \frac{I_{\max}}{\sqrt{2}}$

3.12 Apparent Power (VA) $S = v_{rms} \times i_{rms}(VA)$

3.13 Sinusoidal Voltage Signal $v(t) = V_{\max} \sin \omega t(V)$

3.14 Sinusoidal Current Signal $i(t) = I_{\max} \sin \omega t - \theta(A)$

3.15 Average Power Formula $P = \frac{1}{T}\int v(t)i(t-\theta)dt(Watt)$

3.16 Reactive Power Formula $Q = \frac{1}{T}\int v(t)i(t-90°)dt(Var)$

3.17 Alt. Average Power Formula $P = I^2 \times R(Watt)$

3.18 Alt. Reactive Power Formula $Q = I^2 \times X(Var)$

3.19 Alt. Apparent Power Formula $S = \sqrt{P^2 + Q^2}(VA)$

3.20 Impedance Formula $Z = \sqrt{R^2 + X^2}(Ohms)$

3.21 Frequency Cut Off Formula $f_c = \frac{1}{2\pi RC}$ (Hz)

3.22 Voltage Divider Formula $$V_2 = V_1 (\frac{R_2}{R_2 + R_1})$$

3.23 Non-Inverting Op Amp Gain $$A_v = 1 + (\frac{R_2}{R_1})$$

3.24 Voltage Gain (db) $$db = 20\log(\frac{V_2}{V_1})$$

General Procedure:

1. Research possible (ANSI / IEEE Standards) and any other references available to students to determine SCADA SYSTEM elements.
2. Formulate the Gantt chart for this laboratory and work break down structure.
3. After research is completed, discuss possible solutions for each SCADA Element that includes a solution for wireless control of the capacitor bank.
4. Decide on hardware solutions for measuring each power triangle value.
5. Design and construct the Distribution Model.
6. Design and construct hardware based measurement solutions.
7. Begin implementation of the SCADA SYSTEM including the wireless capacitor bank.
8. Test SCADA SYSTEM performance, adjust as necessary.
9. Begin preparation of team submittal.
10. Finalize and submit team laboratory submittal
11. Submit individual submittal.

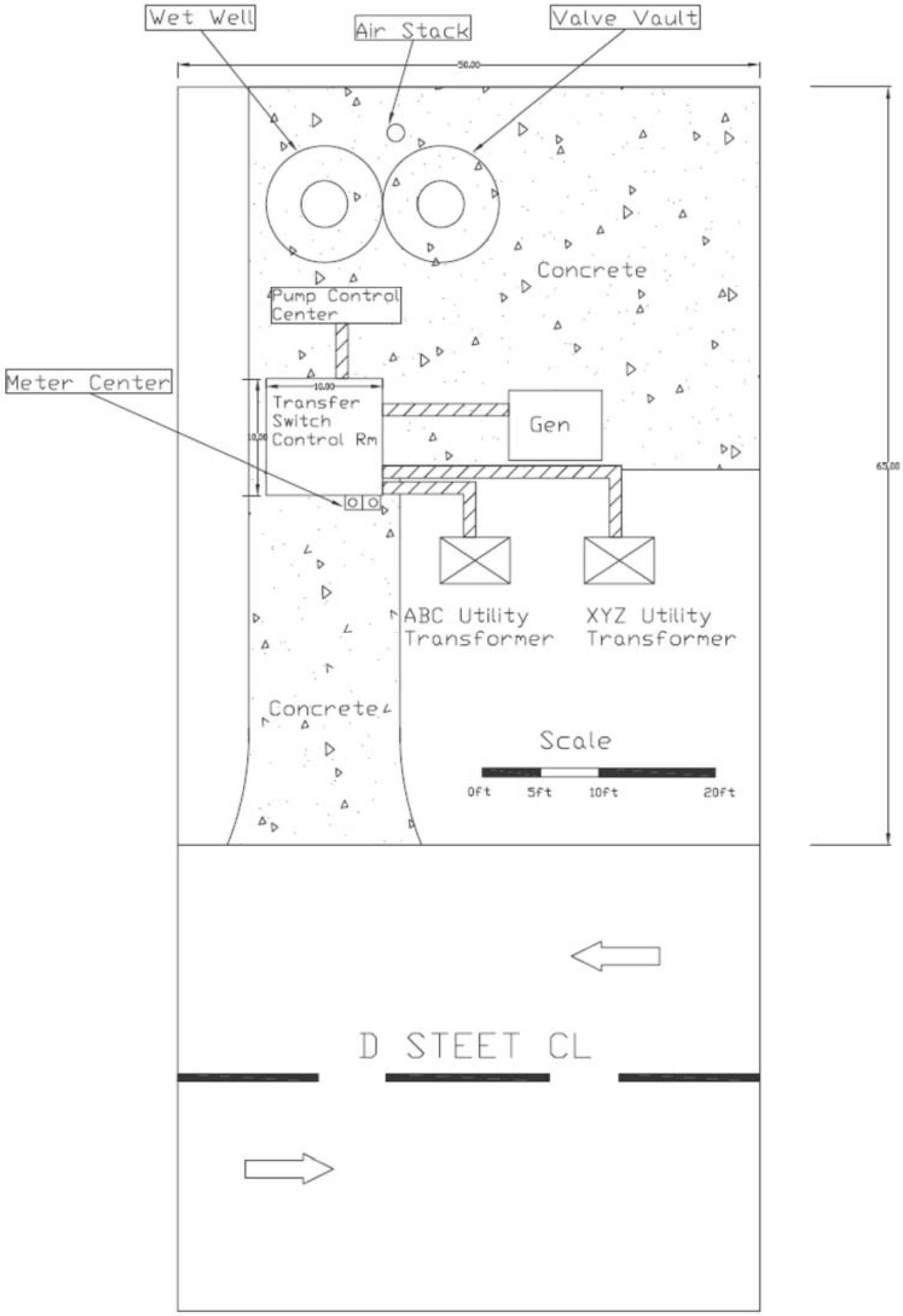

Figure 15: Utility Drawing for Lab. III

CHAPTER XI

Survey

The survey was designed to test the various assumptions and hypotheses that the author considered throughout the educational design process. An arbitrarily organized list of 18 questions was grouped in the form of a survey to test the elements of the Seeds of Solutions approach to gauge student response and reception. A copy of the survey can be referenced in Appendix A of this thesis (Engineering Course Survey).

Preferred Industry, Awareness & Professor / Class Impacts

Question 1 addressed the career direction of the students taking the survey. This survey question was included to get a general idea of what industry students preferred and discover any trends that may exist. The results are shown in Figure 13.

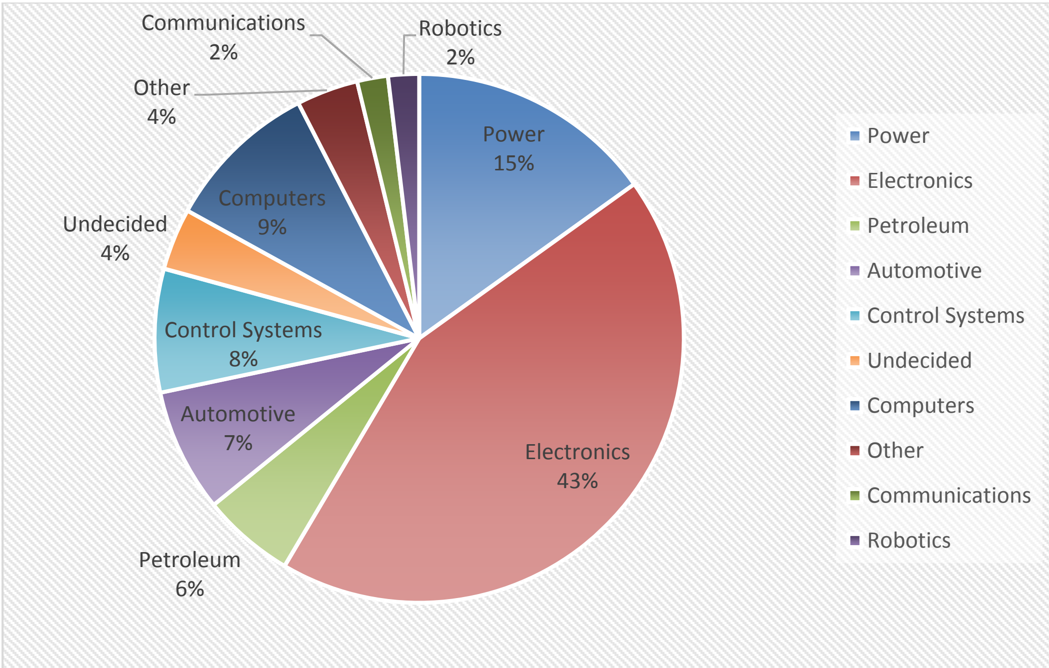

Figure 16: Q1 –Student career industry preferences

The results of the survey question show that 43% of the students surveyed prefer a career in Electronics. Another point of note is that Power comes in a distant second in industry preferences. It can be assumed that the *slight* increase discussed in brief in Chapter V shows up in this result.

Question 2 dealt with whether or not students were aware that power engineering was a career option as an electrical engineering major. The results of question 2are summarized in Figure 14. Surprisingly, 25% of the students surveyed were not aware that power engineering was even a possibility.

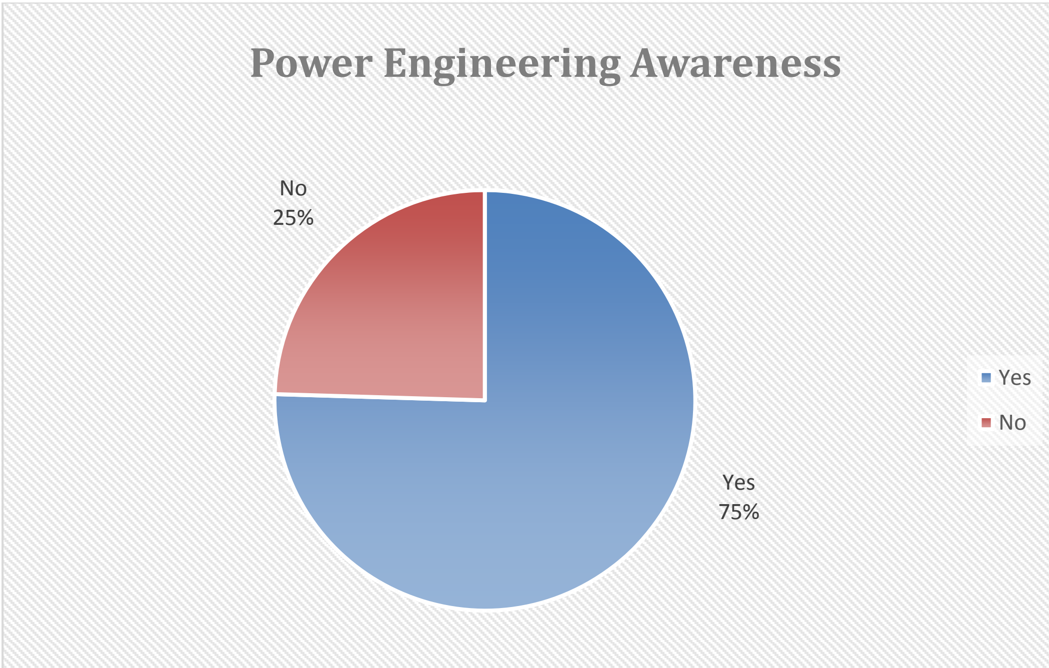

Figure 17: Q2-Power Engineering Awareness

Questions 3 & 4 - Important aspects of the Seeds of Solutions Approach hinge on professor career guidance as well as class inspiration / impact. Questions 3 & 4 were to test whether or not this approach and assumption is even possible. Based on the survey, Figure 15 shows that 96% of the students believe that professors can shape the industry preference and Figure 16 shows that 75% of the students surveyed believe that a class could inspire them to change their industry preference.

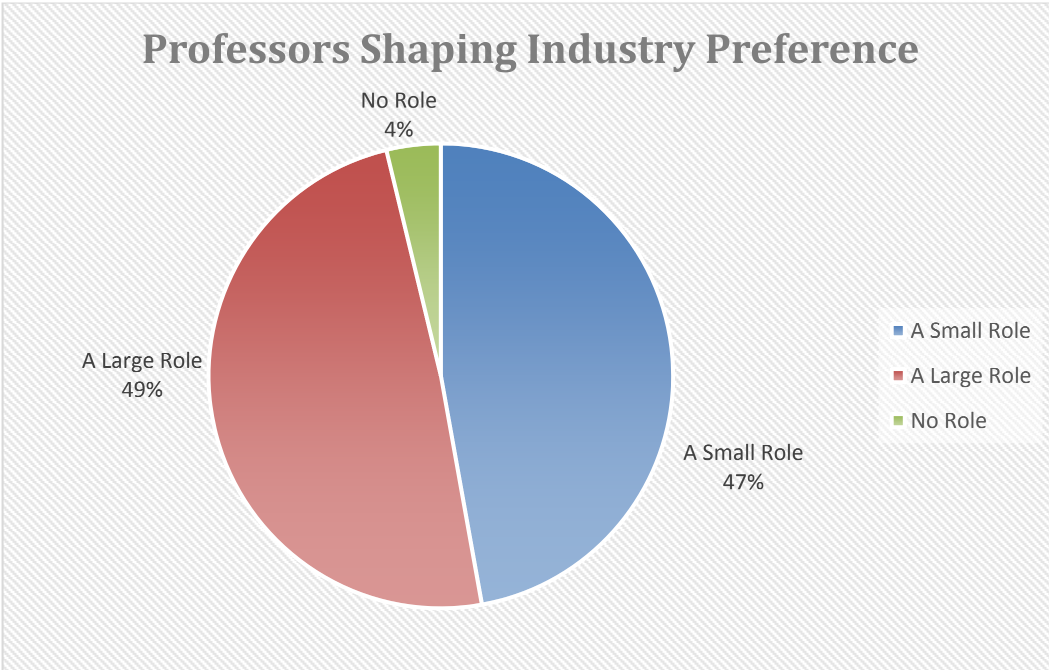

Figure 18: Q3 - Professor Influence

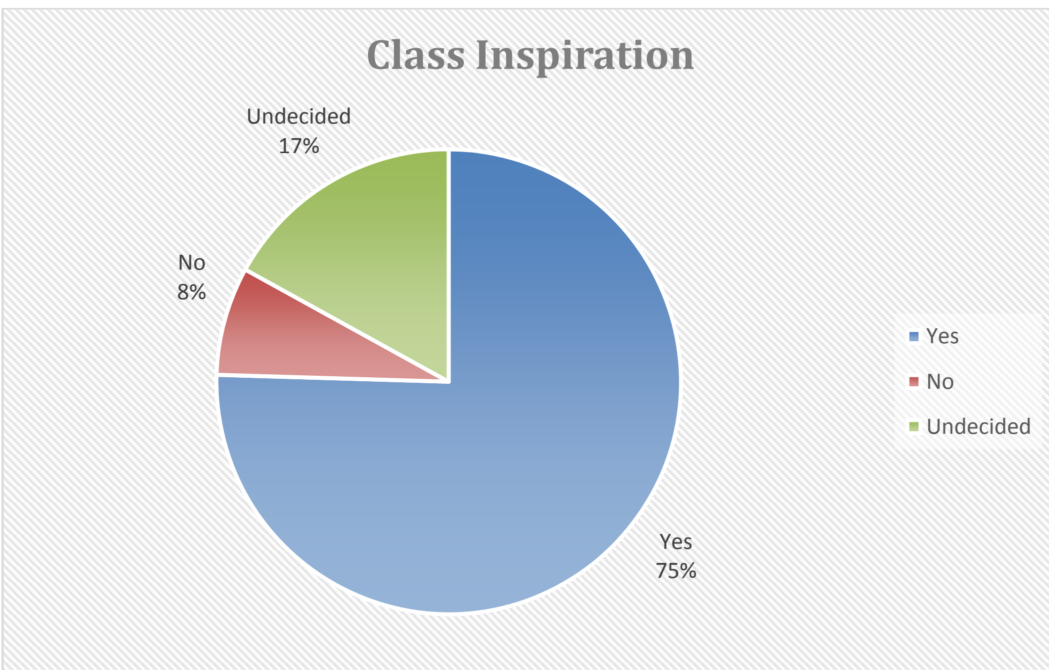

Figure 19: Q4 - Class Inspiration

Ranking Job Characteristics

Question five was included to explore how students rank job characteristics and to provide insight on recruitment Challenge 1 listed in Chapter V. The weighted average was taken with their most important characteristic accounting for 5 points, and the least important characteristic accounting for 1 point. The totals for each characteristic were totaled and divided by the total amount of surveys. Figure 17 details the weighted average ranking of all surveys. Based on the results of this survey, pay ranks as the second highest job characteristic students consider when selecting a job (3.3), however, it is not much higher than job security (2.9). Therefore, it is conceivable to believe that less pay may not necessarily be a major "deal breaker" for recruitment; however, it would behoove hiring companies to adjust their pay for the sake of their own prosperity.

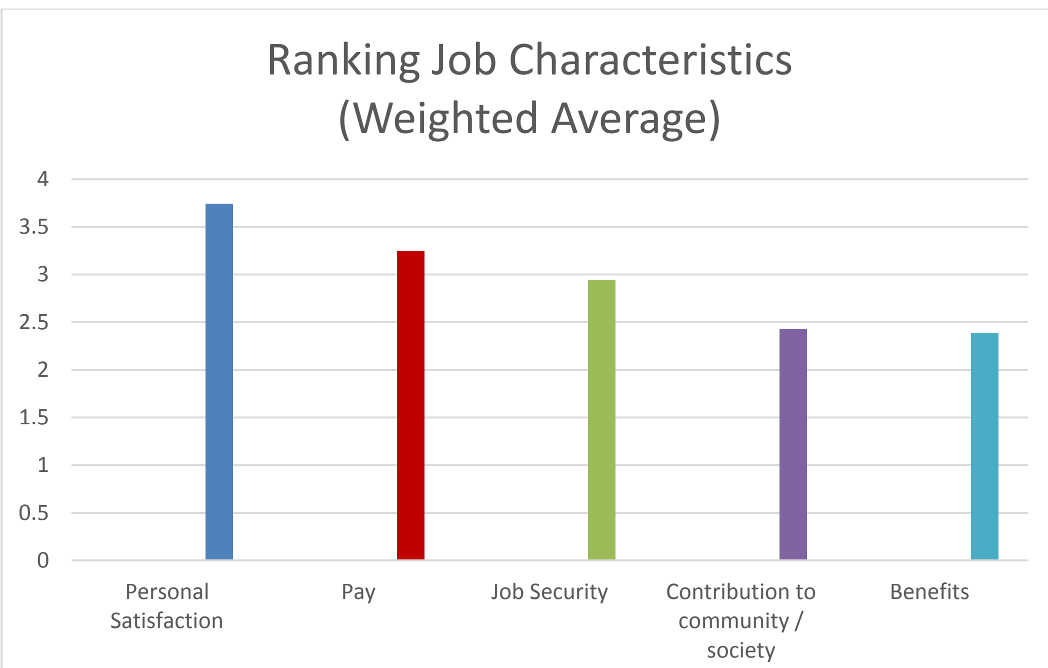

Figure 20: Q5 - Ranking Job Characteristics

Student Perceptions and Learning/Instruction Preference

Questions 6, 9 & 11 provide insight on how the respondents perceive the world as discussed in Chapter IV (i.e. sensors or intuitors), how they prefer to be taught and how they prefer to learn new subjects. It also provides a gauge on how effective the first two elements of the SOS approach (i.e. incorporate creative and authentic labs to enhance lectures) could be. As Figure 18 shows, 60 % of respondents prefer to learn new subjects using a combination of facts and figures and theoretical approaches. It must be noted that 36% of the respondents prefer instruction to be dominantly sensory in nature. Figure 19 shows that 68% of the survey respondents prefer to receive instruction visually. Both of these results are predictable considering the engineering students preferences discussed in Chapter IV.

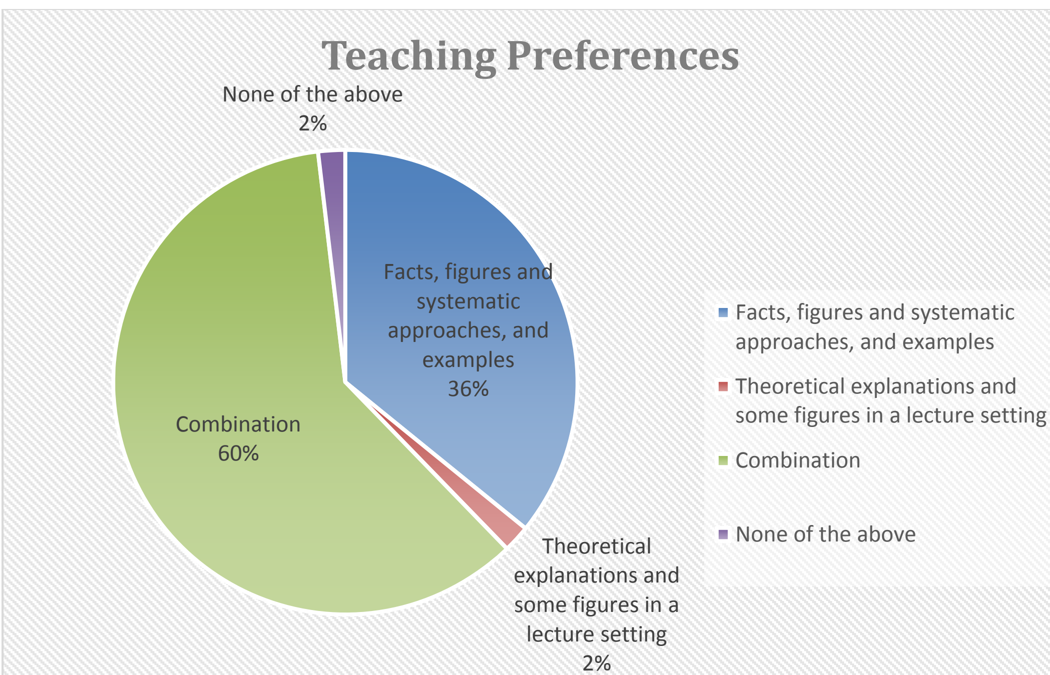

Figure 21: Q6 – Teaching Preferences

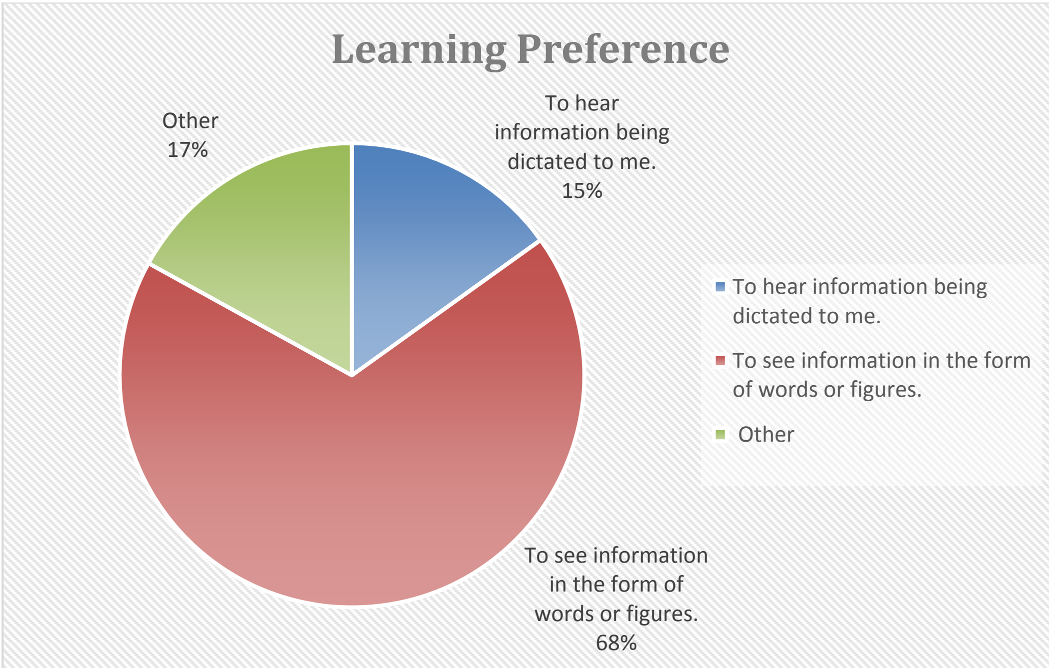

Figure 22: Q9 – Learning Preferences

Cooperative Learning

Questions 7 & 11 were added to gain insight on the student's perceived benefits of cooperative learning. For Question 7, 47% of the respondents believe they learn best in small groups while 34% of the respondents believe they learn best on their own. For Question 11, 79% of the respondents believe that they would benefit from cooperative learning exercises during class time.

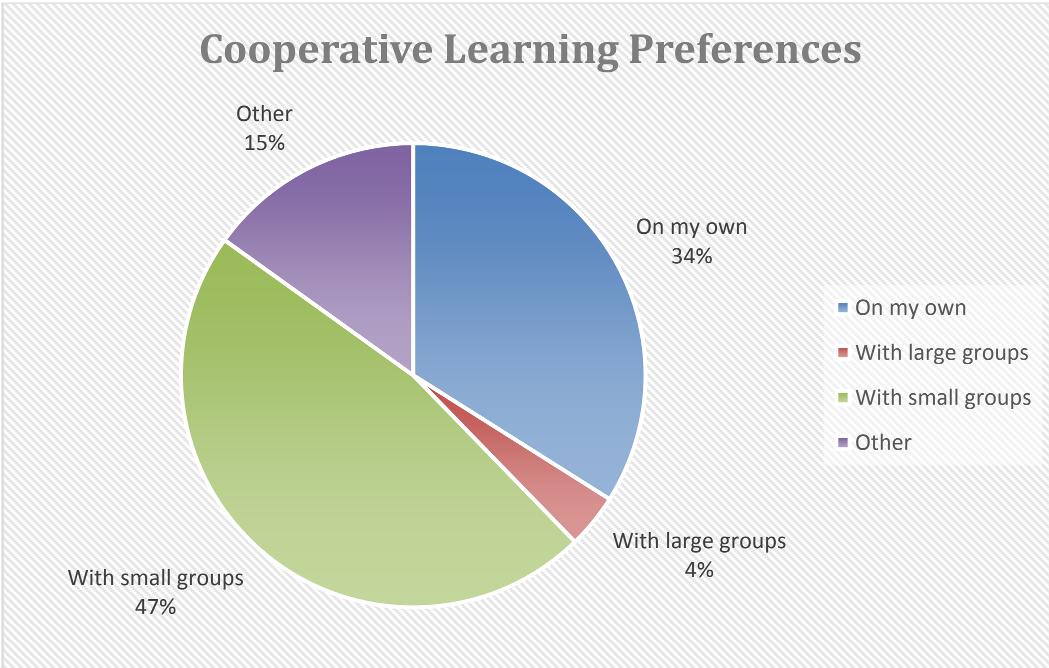

Figure 23: Q7 –Cooperative Learning Preferences

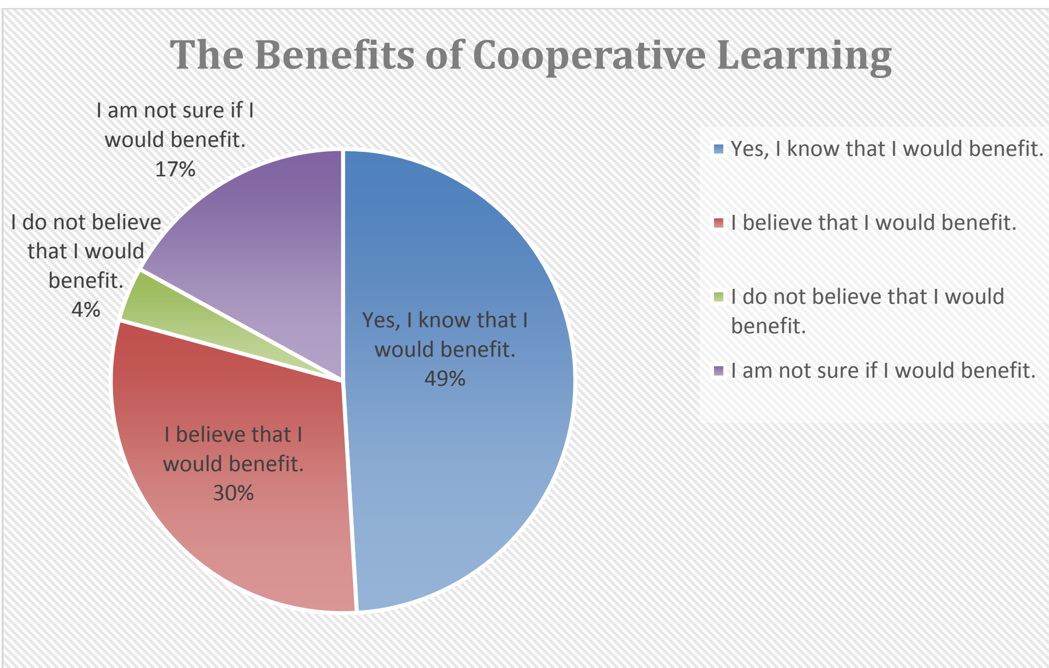

Figure 24: Q11 – Benefits of Cooperative Learning

Industry Collaboration

Question 8 focuses on the student's perceived benefit of field trips or industry participant discussions, which is a part of the element 4 of the SOS approach. An impressive 94% feel that they would benefit from field trips and or discussion sessions with industry professionals.

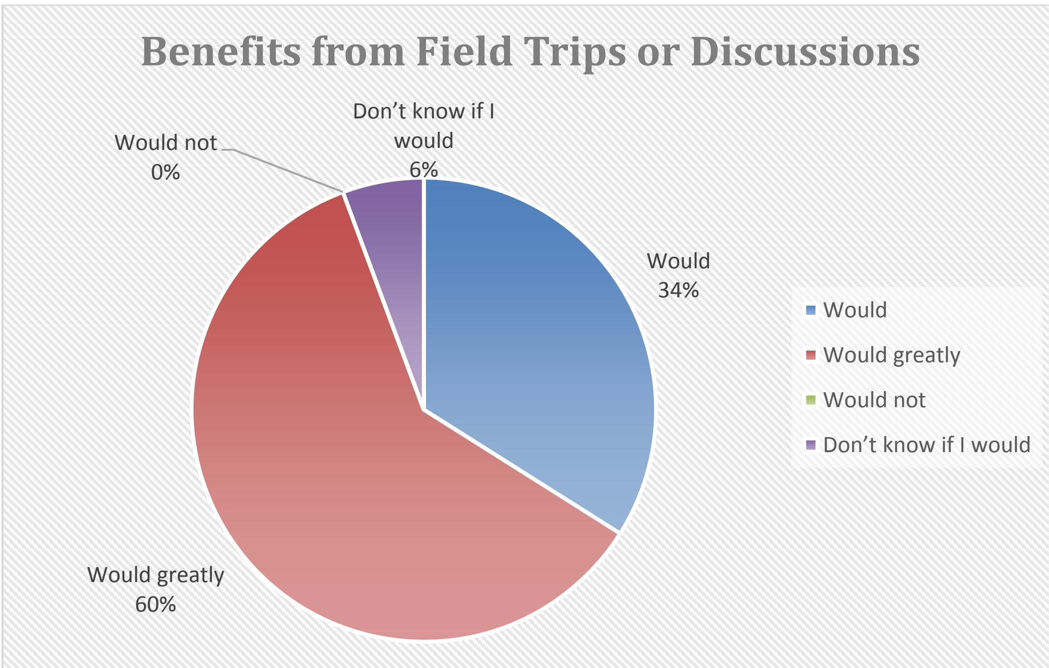

Figure 25: Q8 – Benefits from Field Trips or Discussions

The result of this question gives great insight on how impactful industry collaboration could be to enhance learning curricula.

Laboratory Importance, Difficulty and Design Experience

Question 10 was included to test the how well received the active learning component of the SOS laboratory would be for students. Figure 23 shows that 96% of the respondents prefer active learning while in the laboratory.

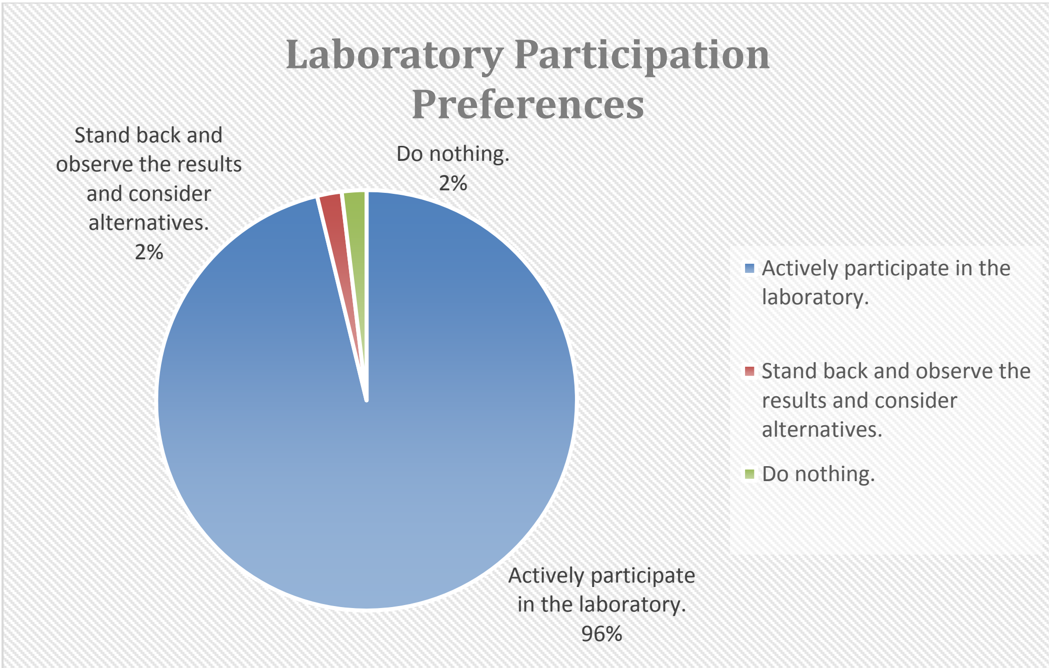

Figure 26: Q10 – Laboratory Participation Preference

Question 12 was included to gain student insight on how important they believe the laboratory is on mastering engineering concepts. Figure 24 shows that 58% of the respondents believe that laboratory is required in order to master engineering concepts.

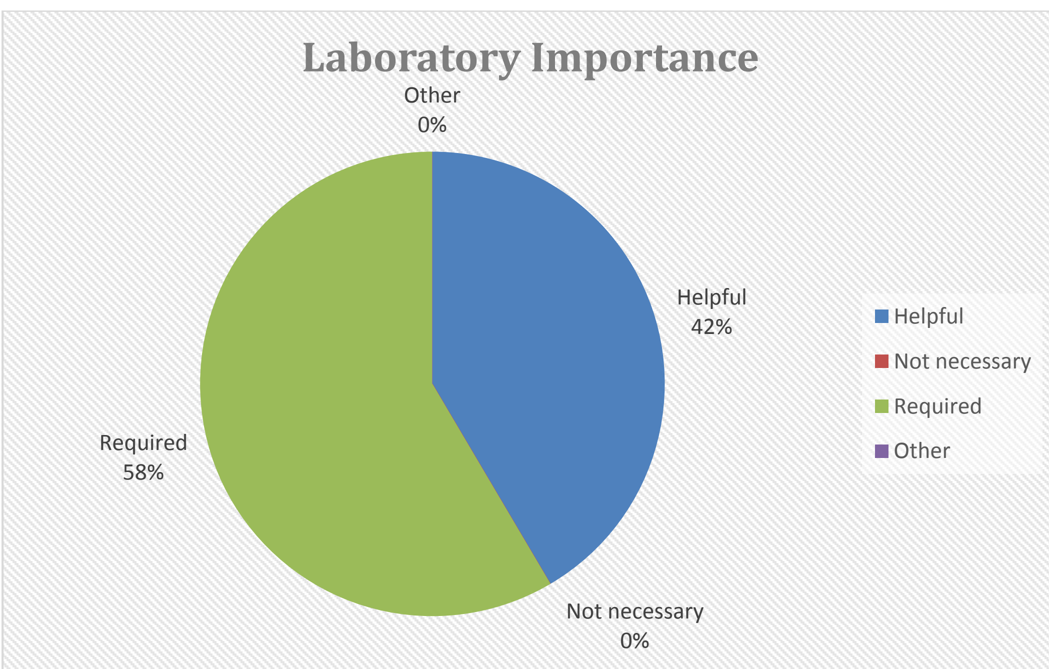

Figure 27: Q12- Laboratory Importance

Question 13 & 15 were added to gain insight on the student's laboratory and design experience thus far. Figure 25 will show that 84% of the students would describe their laboratory work as "challenging". Figure 26will show that 74% of the students feel their design experience is "adequate". The results of these two questions speak well of the electrical engineering program at the University of Texas Pan American and no additional conclusions can be drawn.

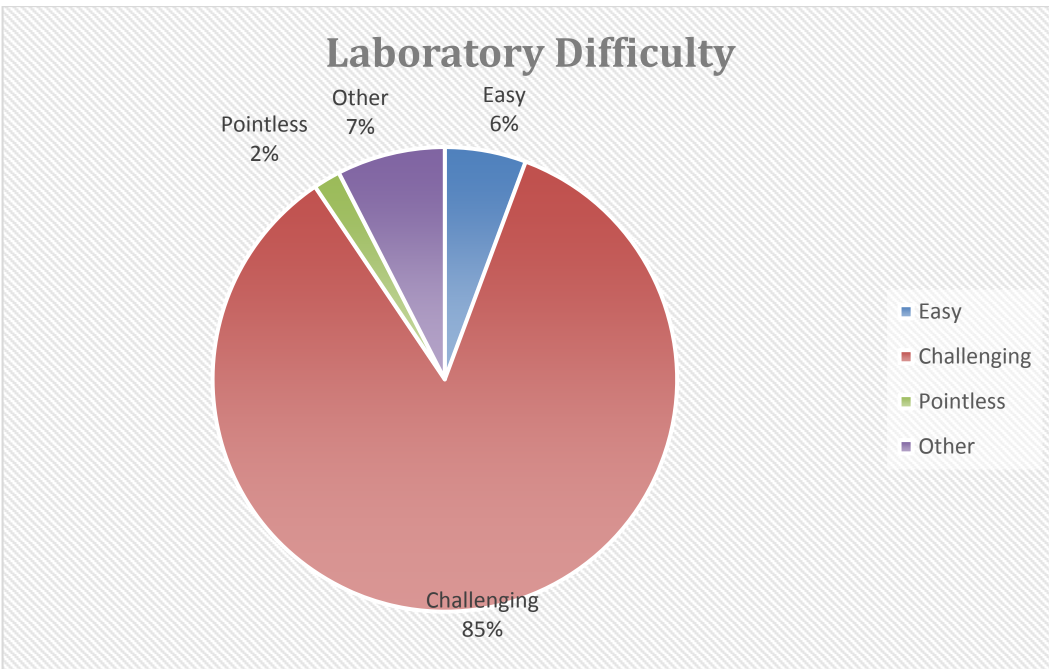

Figure 28: Q13 – Laboratory Difficulty

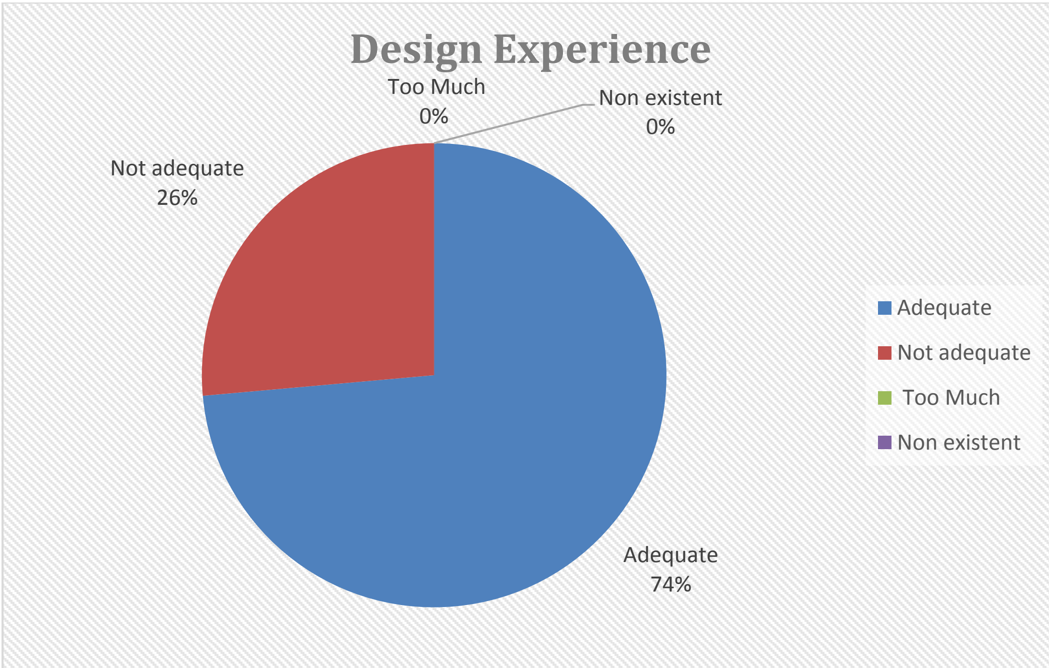

Figure 29: Q15 – Design Experience

Gauging Reception and Effectiveness of the SOS Laboratory

Questions 14, 16-18 were included to gauge student reception of prominent features of an SOS Laboratory. For Question 14, 91% of the respondents preferred industry examples to be featured in laboratories (see Figure 27).Similar to Question 14, Question 18 asked whether or not practical laboratories would help them in mastering engineering concepts. Figure 28 shows that 92% of the respondents believe they would. The responses to Question 14 & 18 confirm why it is critical to have industry collaboration assisting with forming curricula.

The results of Question 16 are shown in Figure 29. Essentially, 77% of the respondents believe that they would benefit from incorporating project management principals in laboratories. Lastly, 77% of affirm that a research laboratory would appeal to them (Figure 30).

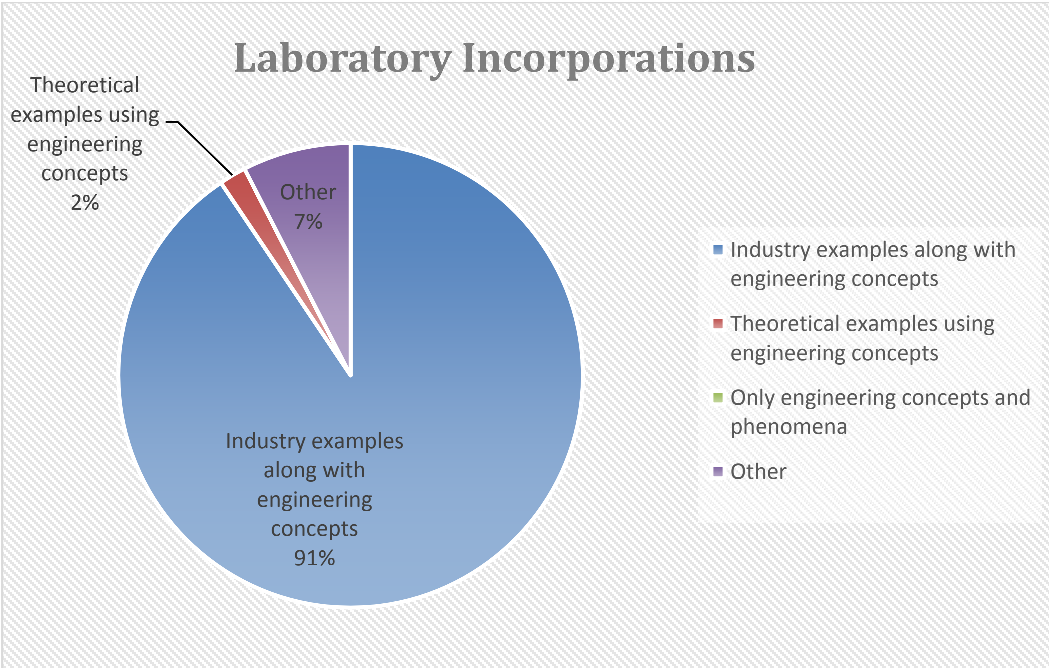

Figure 30: Q14 – Laboratory Incorporations

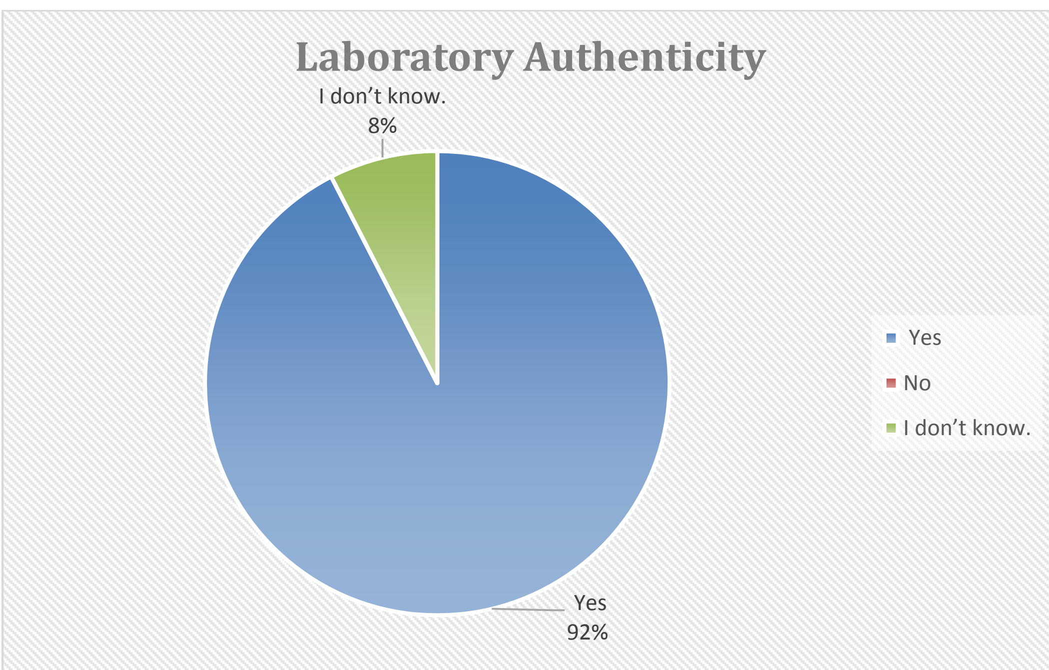

Figure 31: Q18 – Laboratory Authenticity

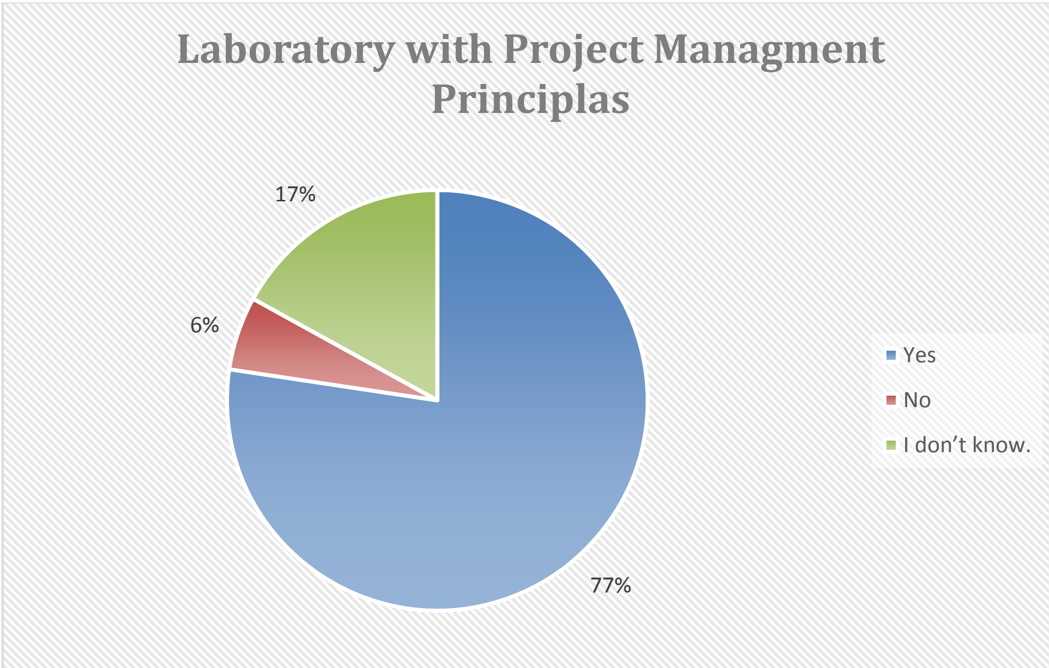

Figure 32: Q16 – Laboratory with Project Management Principals

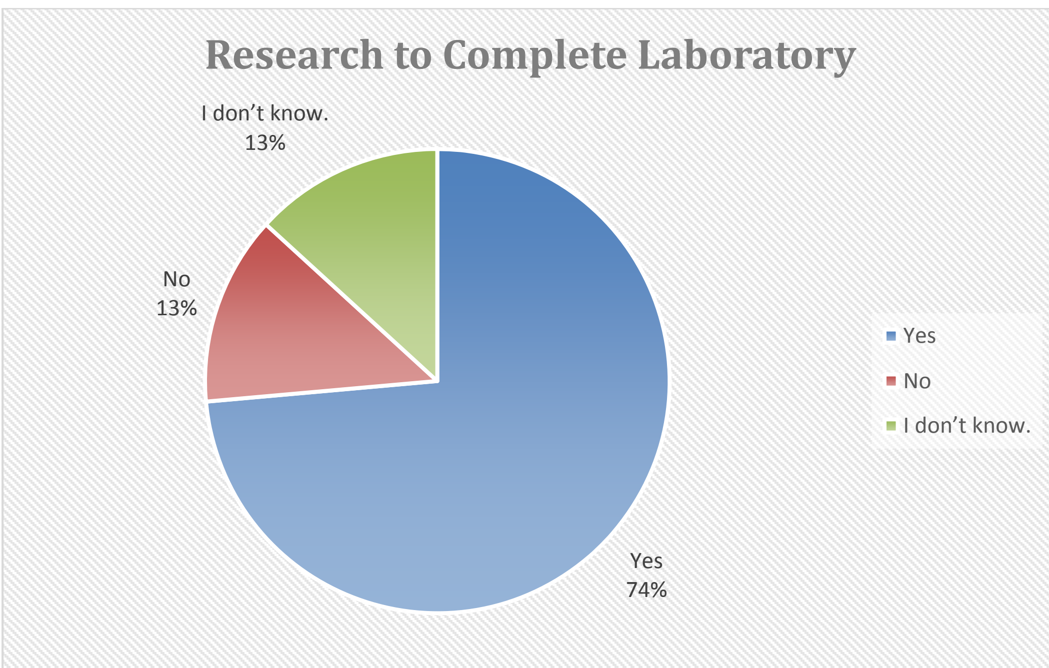

Figure 33: Q17– Research Laboratory

Summarizing Results of Survey

The results of the survey can be summarized by the following bullet points:

1. The career preference for this sample set is fairly typical as a large percentage prefers electronics over other industries.
2. Theoretically, classes and professors can have an impact on student's career choices.
3. According to this sample set, pay is not the main reason candidates select one job over another. A larger sample set is needed to gain more insight.
4. The perceptions of this sample set are highly sensory in nature, however, students still prefer a mixture of theoretical and concrete facts when learning new material.
5. Most students are open to cooperative learning in small groups.
6. According to sample set, UTPA electrical engineering laboratories are challenging and provide adequate design experience.
7. Elements of a SOS Laboratory appeal to a large percentage of respondents.
8. Industry collaboration can have a great impact on existing curriculum and possibly recruitment.

CHAPTER XII

Conclusion

This thesis researched the state and future of power needs from a physical and technological prospective. With future power demand expected to increase steadily over the next 20 years, research evidence shows that there could be a shortage of trained power engineers if the recruitment remains at the status quo.

The focus of this thesis was to design an educational approach towards power engineering that would:

1. Attract students to power engineering.
2. Provide authentic design experience that would supplement class time, thus allowing students to contribute to the power engineering industry upon graduation.
3. Expose students to the power engineering profession via class and laboratories.
4. Inspire students to choose power engineering as their chosen field of study via creative and authentic class content and laboratories.

In order to design the approach towards power engineering, this thesis included extensive research in the following:

1. How Students Learn (Chapter IV)
2. Learning Models (Chapter V)
3. Educational Trends (Chapter VI)
4. Current Course offerings in Texas Universities (Chapter VII)

Based on research results, an educational approach named the “Seeds of Solutions” was formulized that consisted of following five educational (5) elements:

1. Include a Fundamentals of Power Engineering course as part of a required curriculum.
2. Include a supplemental laboratory for the above mentioned required course.
3. Add additional classes as interest in power engineering grows. Courses should be foundational.
4. Establish industry contacts to authenticate the laboratories and classroom examples.
5. When hiring faculty, consider hiring professors with power engineering experience, cross train existing faculty or hire lectures.

The elements of the approach were reviewed by a survey group of 53 current UTPA students. The highlights of the survey indicated several facts that were favorable to the proposed educational approach:

1. 96% of the students believe that instructors at least have a small role in shaping their industry preference.
2. 75% of the students state that a class could inspire them to change their focus of study.
3. 77% of students believe that they would benefit from a laboratory with project management principals.
4. 74% of students would appeal to a class or laboratory that required research in order to solve.
5. 92% of the students would prefer authentic laboratories.
6. Students ranked job characteristics as follows:

a. Personal Satisfaction
b. Pay
c. Job Security
d. Community Contribution
e. Benefits.

To refine and define the Seeds of Solutions approach, the author created a series of laboratories that incorporate all aspects of the second element (Provide authentic design experience that would supplement class time . . . etc) of the Seeds of Solutions Approach. These example laboratories are foundational in nature, research based, industry based (authentic) and design heavy. The laboratories are documented in DVD and AVI formats for easy dissemination. Regardless of the exact number of the power engineers needed, it is clear that there will be vast opportunities in the coming decade for professionals specializing in electric power and associated technologies to reign in, improve and maintain current and future electric power related technologies. The contributions associated with this thesis (research, thesis, and Laboratory documentaries) are designed to offer solutions to issues the power industry is facing from an educational prospective. Although it is not all inclusive, the Seeds of Solutions approach towards power engineering is scientific based and, from the author's perspective, will provide the educator an easily installed educational approach towards power engineering education that is both efficient, effective and economical.

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APPENDIX A

APPENDIX A

ENGINEERING COURSE SURVEY

Industry Preference:

1. Upon graduating, what industry would you prefer to work in? (e.g. computers, digital electronics, etc.)

   Write in your Industry Preference.

   ____

2. Are you aware that Power Engineering is a career option for Electrical Engineers?
   a. Yes
   b. No

3. What role do your professors have in shaping your industry preferences?
   a. A small role.
   b. A large role.
   c. No role.

4. Theoretically, would interest in a class inspire you to change your industry preference?
   a. Yes
   b. No
   c. Undecided

5. Rank the importance of the following job characteristics (1 being the most important and 5 being the least important).

   ___ Personal Satisfaction
   ___ Pay
   ___ Job Security
   ___ Benefits (medical, fringe, dental, etc)
   ___ Contribution to community / society

Learning Preferences:

6. When learning new subjects, I prefer for professors to use:
    a. facts, figures and systematic approaches, and examples
    b. theoretical explanations and some figures in a lecture setting
    c. both A & B
    d. None of the above

7. I learn best _________.
    a. On my own
    b. With large groups
    c. With small groups
    d. Other ____________________

8. I ________ benefit from field trips and or discussions with industry professionals as a part of my engineering education:
    a. Would
    b. Would greatly
    c. Would not
    d. don't know if I would

9. When learning, I prefer _____________________.
    a. To hear information being dictated to me.
    b. To see information in the form of words or figures.
    c. Other ____________________________________

10. When in a laboratory, I prefer to ______________.
    a. Actively participate in the laboratory.
    b. Stand back and observe the results and consider alternatives.
    c. Do nothing.

11. During class, do you feel that you would benefit from the professor providing time to collaborate with other students when considering questions, problems or alternatives?
    a. Yes, I know that I would benefit.
    b. I believe that I would benefit.
    c. I do not believe that I would benefit.
    d. I am not sure if I would benefit.

Laboratory Preferences:

12. Laboratories are _________ when attempting to master engineering concepts.
    a. helpful
    b. not necessary
    c. required
    d. Other _______________
13. The engineering laboratories that I have taken in my engineering education have been ________.
    a. Easy
    b. Challenging
    c. Pointless
    d. Other ___________________

14. I would prefer laboratories that incorporate___________.
    a. Industry examples along with engineering concepts
    b. Theoretical examples using engineering concepts
    c. Only engineering concepts and phenomena
    d. Other ____
15. The level of design experience I have had in my engineering education is__________.
    a. Adequate
    b. Not adequate
    c. Too Much
    d. Non existent

16. As an electrical engineering student, would you benefit in a laboratory that incorporates project management principles as part of the learning curriculum?
    a. Yes
    b. No
    c. I don't know.
17. Would a laboratory that would allow you to research solutions appeal to you?
    a. Yes
    b. No
    c. I don't know.

18. Would practical laboratory projects help you in mastering engineering concepts?
    a. Yes
    b. No
    c. I don't know.

BIOGRAPHICAL SKETCH

Eli Alvarez was born in Brownsville, TX where he and his family currently reside. In 2003, Mr. Alvarez graduated with a Degree in Mechanical Engineering from the University of Texas - Pan American. Upon graduating, he began his career with the Brownsville Public Utilities Board where he is currently employed as an Electric Operations Manager. In 2008, Mr. Alvarez became licensed in Texas to practice engineering and specializes in electrical distribution construction design, load forecasting and reliability statistics.

Mr. Alvarez' research preferences include digital signal processing, power engineering education, numeric methods and general electronic design. In his spare time, Mr. Alvarez enjoys studying music, reading, wood crafts and quality time with his family.

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