AC 2007-2835: HELICAL LEARNING MODEL APPLIED IN AN INDUSTRIAL ELECTROCHEMISTRY ENGINEERING COURSE

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HELICAL Learning Model Applied in an Industrial Electrochemistry Engineering Course

Abstract

In education, a popular model employed to represent the learning process is typically portrayed as a four-stage process signified by a cycle in a two-dimensional circular path. This cycle can be repeated by revisiting topics at increasing levels of sophistication in order to produce what is known as a spiral curriculum.

In this presentation, a variation of Kolb's two-dimensional learning cycle model is offered that represents the learning cycle as if it were a three-dimensional spiral or helix, with successive turns associated with increases in Bloom's Taxonomic level. This representation is explored and developed, with a specific example from a chemical engineering course offered in Industrial Electrochemistry. This more comprehensive concept-centered model for the learning cycle explicitly includes higher order thinking skills to promote creative thinking, through the application of concepts and can be used to develop more effective curricula and course instruction. Specifically, our sample class consists of four teams, each of which is responsible for becoming expert in the concepts associated with an area of science and another of application. Transfer of content is student driven while topics are explored. Students teaching each other allows for synergistic enhanced motivation to explore, with concurrent ultimate improvement in the retention of core concepts by the entire course population.

Introduction

Engineering education is inherently a global issue[1] that compliments global engineering practice[2]. A paramount effort of engineering education is linking learning theory with recognized engineering learning goals, as illustrated by the ABET (a-k) criteria[3], while producing new models[4, 5] for instructional and learning practices. A cornerstone of modern engineering education is the stimulation of creative thinking in engineering students that requires helping the students learn how to think via idea creation and idea evaluation processes.

Using a global stage and metaphorical analogies allow one to envision the global nature of the issue. Recognition of the currents (learning pathways) within the seas of knowledge and how they influence the learning of engineering is providing new horizons for designing instruction. Traditional pathways are shored up by educators who limit the learning process when they restrict students to conventional thinking. In order to break out of this paradigm, educators need to make tentative forays into evolving learning practices. A desired outcome is the development of the student's independent problem solving skills and willingness to risk creative solutions. Exposure to, and acquaintance with, novel ideas fosters skill development and critical thinking through processes that are not fully understood. It is from wading in these uncharted waters that one develops and hones the requisite expected "navigational" skills to journey and explore what is beyond convention. We should encourage students to reach beyond national borders and faculty to reach beyond traditional teaching practices to simultaneously enhance learning and produce more creative engineers with a global perspective. Given the limited flexibility in engineering curricula, gaining a global perspective must be carefully integrated into the advancing learning models such as the spiral curriculum[6, 7] and our concept centered helical model. Specific areas of engineering could ultimately become the centers of theme based spiral curricula[8, 9]. Anticipating these simultaneous expeditions, students will need to assimilate the necessary habits, acquire the requisite skills and develop a capacity for understanding to enable a full mastery of the engineering discipline. Realizing the means will point to a proper heading in charting the best course to justify the ends of how sufficient knowledge is transferred to augment and exercise critical thinking skills. Commencing from basic concepts, we will examine the well-grounded process by which one procures the requisite skills and successfully demonstrates their application, in anticipation of endeavors towards mastery of continually more advanced topics.

Advancing Learning Models for Engineering Education

History: Throughout history, it has been demonstrated that linear knowledge is easiest to acquire, where one individual as teacher shows and tells subsequent to a student that repeats the act internally or overtly. It has been the dominant form of transmittal and accumulation in the learning process. Some is via intentional words and actions while other is through direct stimuli for example, as in today's experiential learning practices. It is in the latter that one is able to pick out pieces that may enhance creativity.

Texts from antiquity have survived and been translated which provide wonderful examples that are germane to modern circumstances. The successful Socratic methods are idealized in Plato's works as a humbling succession in prodding the mind to reflect via direct questioning inquiry. The outcome to be expected is that mental gymnastics provide the exercise that generates good habits of critical thinking. These were espoused at Plato's Academy where Aristotle, it's most famous student, developed logic, categorized the early fields of study that form the basis of many of today's disciplines, and evolved more practical uses of learning within the peripatetic school. These are many of the bricks of the foundation of Western thought that permeate our institutions today. An accumulation of all one's life experiences constitutes one's education where the richness is enhanced and molded by formal instruction. Thus education that transpires within the confines of schools and universities represents an important subset.

Intellectual autonomy was proposed by Thomas Aquinas, where the onus of education shifts to the individual as the agent provocateur for the research and discovery of ideas. This led to a model of self-education that is dramatically being enhanced by the INTERNET. This model effectively challenges the authoritative super-ordination of the learner to the instructor and is being revived today by Problem Based Learning (PBL). 19th century pragmatism expounded by John Dewey is being revisited today in Experiential Learning (EL) and Inquiry Based Learning (IBL). These latter approaches are based on constructivism[10]. Constructivism, a process in which the learner actively constructs or builds new ideas or concepts based upon current and past knowledge and experience, is the basis for numerous 20th and 21st century learning models and teaching methods. Constructivism values developmentally appropriate, teacher-supported learning that is initiated and directed by the student. More recent examples in the literature have been produced that examine the learning process at greater depths. Commencing mid-20th century, Bloom's Taxonomy[11], has been widely used to illustrate levels of learning. Nearly three decades later, Kolb[12] furthered Dewey's idea of a cyclic learning process by incorporating preferred modes for perceiving and processing information, and grounding it in experience. Teaching and learning styles have been examined with a motivation to provide a better match between these and improve engineering education[13-18].

The upshot today is to make available more content in our curricula to which access is guided by interlinked multidimensional concepts[19]. Concept mapping, developed by Novak[20] at Cornell University in the 1960s, as being expanded by our European colleagues[21] has demonstrated directly and indirectly how interdependent our knowledge base has become in a global context. One can expect to provide best practices with common bases for international exchange based on science, math and engineering concepts. Global experiences must link these life experiences directly to formal engineering educational practices. Uniting commonalities across borders and societies will better allow each party to deal with engineering and cultural differences that exist and provide value to a global outlook. Nurturing this universal view may best be facilitated by recognizing and exploiting the various learning styles. Non-inclusive examples may be presentations that are textual, audio-visual, lectures by guests from beyond a nation's boundaries, and exchange visits.

Concept Mapping, Analysis and Other Best Practices: Concept mapping has been well practiced in nursing[22,23]. It will be a key to engineering education, being done for several purposes[24]:

- to generate ideas (brain storming, group communications, etc.);
- to design a complex structure (long texts, hypermedia, large web sites, etc.);
- to communicate complex ideas;
- to aid learning by explicitly integrating new and old knowledge;
- to assess understanding or diagnose misunderstanding.

In addition it is being used to design engineering curricula and courses as demonstrated for example in the chemical[25] and mechanical[26] engineering fields.

Concept analysis is a relatively new applied mathematical practice to represent, analyze, and construct conceptual structures based on concept hierarchy[27]. As pointed out by Arthur Stutt[28], it offers the opportunity to create constructivist's epistemologies and ontologisms, explicit specifications of conceptualization that describe concepts and relations that exist in a knowledge domain and are necessary for knowledge representation and exchange.

Helical Concept Centered Model: Kolb's experiential learning theory is one of the major educational theories being used in both research and practice in higher education[12,29]. It is based on the four-stage learning cycle shown in Figure 1: concrete experience, reflective observation, abstract conceptualization, and active experimentation. Learners can go through the cycle numerous times resulting in a spiral of cycles. Kolb further suggests that students have preferential ways of learning and can be classified as divergers (using brainstorming and generation of ideas), assimilators (using inductive reasoning and creation of models), convergers (using hypothetical-deductive reasoning), and accommodators (plans, experiments and immediate circumstances to learn). In addition, Bloom's taxonomy[11] provides the expected learning levels for the stages. It has six levels for the cognitive domain: knowledge, comprehension, application, analysis, synthesis and evaluation.

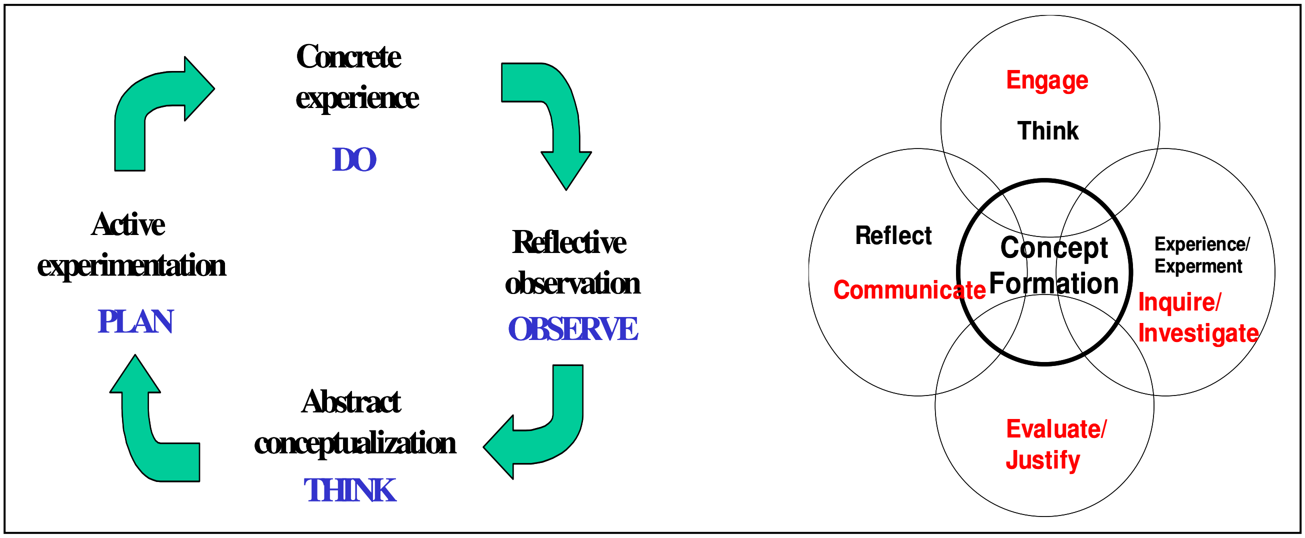

Figure 1. Combining Kolb's learning cycle with PBL, and our concept centered process, results in a new model that lends itself to spiral and helical course and curriculum development around Concept Centered Learning (CCL).

A combination of the Kolb and Bloom methodologies were employed by Cocke et al[4] to provide a content interactive strategy for PBL in an Atmospheric Chemical Engineering course. Environmental Chemistry is the study of the sources, reactions, transport and fate of chemical species in the environment[30]. First and foremost, the student needs to be reminded that chemistry is the unifying theme in an atmospheric chemical engineering course. Chemistry is reaction based science. Reactions need to be the catalysts of concepts and the central issue visited and revisited as the student's progress around learning cycles. As one develops the problems in the concept centered PBL, the examination of photochemistry, acid-base chemistry, free radical chemistry, and homogeneous and heterogeneous catalytic cycles is revisited many times during

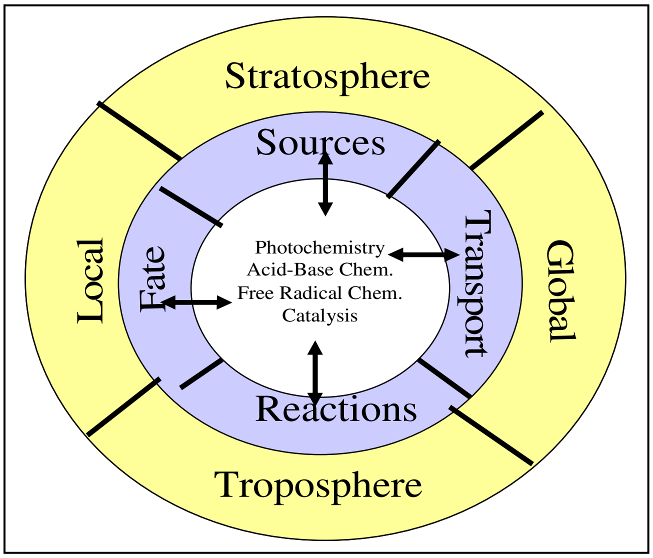

Figure 2. An example of a content/concept interactive strategy for PBL and Kolb learning cycles in an Atmospheric Chemical Engineering Course illustrating CCL.

the course.

The Kolb and Bloom models were subsequently unified into a helical model by O'Connor et al[5] which represents Kolb's experiential learning cycle in the x-y plane with the Bloom taxonomy aligned with the z-axis. This model allows the learning process to be described in terms of either a continuous progress or a quantum leap. This too is seen to be employed in a Multidisciplinary Engineering Foundation Spiral by Collura et al[8].

Figure 3. Illustration of CCL with a spiral or helical course/curriculum process.

Industrial Electrochemical Engineering as a course was offered at Lamar University in the autumn of 2006, with the goal of incorporating many of the aforementioned practices. The graduate level class consisted of nineteen students (2 United States, 1 Kenya, 1 Mexico, 1 Bangladesh, 1 Turkey, and 13 India), one post doctoral instructor and the professor. Figure 4 depicts the skeleton for the material that was expected to be examined. Since the possibilities of coverage and levels of mastery were manifold, it was expressed that the class as a whole would be responsible for the content. The condition that must be satisfied in the course was that concepts were to be learned and employed that revolved around the three Process pillars of Chemical Engineering: Control; Design and Optimization. In doing so, the student body was divided into four groups: Power, Production, Environment and Corrosion. These groups attempted to reasonably incorporate each individual's inherent research interests, i.e. their areas of study and projects being used as theses topics. To further instill that basic concepts were addressed, each group had a member that was responsible for each of the concepts associated with: Electrochemstry; Electrochemical Engineering; Commercial Merit and Electronics. These last items comprise the culling of ideas in the arena of Industrial Electrochemical Engineering.

While at first blush it may seem as though the subdivisions would lead to individualized piecemeal acquisition of knowledge, this conclusion is far from the truth. Weekly, each group would work on some aspects of their topic of interest, with at least one member giving a presentation on their findings before the class, generally in a PowerPoint format. In this manner, the class would teach itself with the instructor and professor providing appropriate guidance. Since there was no required textbook, the lion's share of the material would be culled from the internet and its rapidly growing source of on-line versions of refereed publications, with the library being a secondary resource. As the semester drew to a close, each group had developed an impressive document demonstrating expertise worthy of publication as a reference in their particular area of examination. Individually, each student was given an oral examination on the concepts of the contributions of their own, their group and those of the remainder of the class.

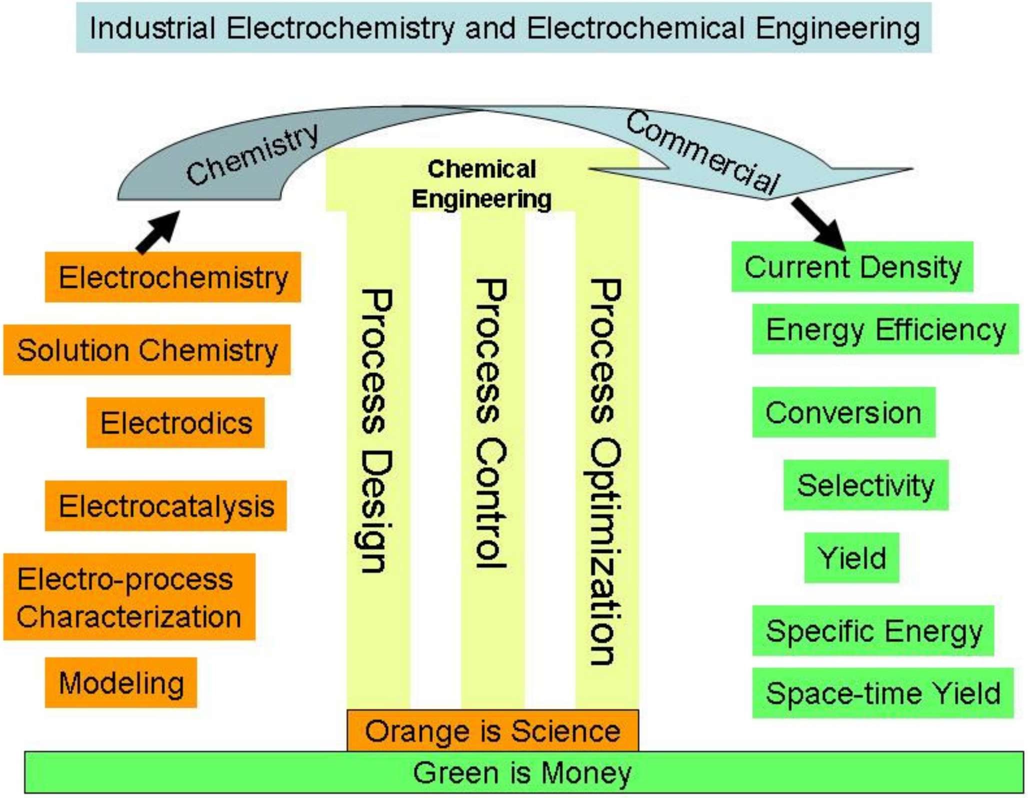

Figure 4. Skeletal outline for concepts to be examined in a course on Elecrochemical Engineering

Basic science of chemistry and the attendant commercial application of engineering were the two guardians providing the concepts for the course. As these concepts were acquired, they were critically assessed against members of their side, as well as those from the opposite list. Proficiency in understanding these concepts allowed each person to view their inter-relationships with one another and create the tenets to provide support to the central pillars of chemical engineering. It is in the circular advancement in a helical weaving of these concept-based tenets that allowed the student to design a unique tapestry to wrap up their understanding of electrochemical engineering.

As an example, the group that investigated power examined the word, and what concepts constitute it. Devices for production, storage and usage naturally followed suit. The history of batteries in how they were developed and operate culminated in an intensive examination of a lithium-ion battery. One member was responsible for collecting and composing concepts of electronics related to the battery and ensuring that first his teammates were enlightened, followed by a presentation for the remainder of the class. In addition, it was this person's task to clarify items regarding electronics that were presented by other groups and guest lecturers to their team. Throughout a project the topics are revisited again and again. When explaining electrochemistry, several related topics must be explored. Solution chemistry and electrodics are among many topics that are critical for electrochemical clarification. Therefore, while one individual is specializing in one area of a topic, they are learning the core concepts of the other group members. Similarly in this way, every individual in the class was both an active learner and teacher. Synergy of effort and talent allowed a great deal more understanding to be observed by the leaders of the course in examinations, a view also conveyed in the exit surveys of the participating students.

A plethora of avenues may be used to describe both what constitutes how one learns, as well as the content of that learning. These have been bandied about continuously in the great conversation of western thought that is certainly paralleled in other traditions. No definitive conclusions have been drawn by some of the seminal minds of all times. What is knowledge will be left for another paper. What is addressed here is an initial amendment of the ideas that survive from the ancient Greeks, to one of concepts as the tea leaves that flavor the brew in the cup first tasted on the tip of ones tongue.

The route for learning may be mapped as a sinuous and convoluted path upon an irregular surface that consists of three spatial coordinates that vary along with a temporal component, unique for each individual. This surface may expand outward or contract as concepts may be added or lost. Elasticity may vary for each concept and dictate how far the idea may be extended as a useful tool. For example, Plane Euclidean geometry and related trigonometry may work well for describing position on surfaces that have very little curvature yet breakdown rapidly when applied to position on a sphere like the Earth. Therefore a new set of concepts relating spherical geometry is required. Concepts that are lost to recollection may be represented as exceeding the ultimate strength and breaking. Others may be buried far enough and surpassed by ones that are as yet unlearned. In moving from one locale to another, knowing how to ride a bicycle may have similarities to locomotion by rail, yet it is unlikely many of us would knowingly hop aboard a subway driven by an untrained engineer.

Like a pile of tailings, the inverted mountain of conceptual fragments may expand outward horizontally as well as grow vertically. It is most similar to a helical spiral where one may have to: blaze a path alone; trek an ill marked road; survive a beaten path; travel a busy street, et cetera. While choices exist at almost every step, conditioning and habit form the framework for the predominant paradigm that unknowingly guides us. It is through sagacious application of concepts provided by experience that enhances one's success at traversing difficult sections and detours encountered. The decision is often skewed by those guides that have proved successful in the past in recognizing the pattern of action to move. In the course setting, we are guiding agents that may still actively precipitate good possible choices from seemingly thin air to the amazement of our traveler. Difficulty often arises when we attempt to inculcate them with the understanding behind the choice to enable them to respond without our prodding or presence in the future. When we define concepts, we need to call upon items that are common to the lexicon and concept universe of everyone that will use them. If not present, a means to slow the ascent to explain and collect the concepts is needed. If this proves insufficient, regrouping and perhaps backtracking is required to attempt an alternative approach based upon the concepts available and offer the additional opportunity to rejoin the trek. Since the sheer number of successful individuals that one observes decreases commensurately where the learning slopes are steepest, vigor is often tested when a larger number of concepts must be aggregated to make progress. These are distilled from the wealth of skills that exist within a person's repertoire and the requisite understanding of how to best employ it. If success is met, then a new method may be added to this expanding base. If it is failure, then knowledge of what does not work can be recognized. Hence, it is through continued attempts to reach the ever-illusive apex that the gems of lasting knowledge are separated from the tailings, and new inventory is added to our storehouse of knowledge.

Resistance to discovery varies per individual, concept and idea, with a multitude of permutations possible. Attempting to match the impedance for each element by reducing the opposition to acquiring the concept often requires art as well as science. While one may know of a wonderful means to convey information to some, it will undoubtedly fail for others. This is owing to the variety of individual learning styles and preparedness. While orchestrating this interaction, each of us is a conductor that attempts to use the greatest range of our instruments and create organized notes from a cacophony of ideas that we think are the keys to excellence in performance on our stage. The crux is that there is generally a tremendous body of potential knowledge that exists, of which a fraction will ever be completely known and an even smaller part used to master a discipline. While many would agree that larger portions are needed to know a subject well, the exact fraction is unknown.

Scaling a formidable mass of knowledge like Engineering requires experiences from a host of sources and multifaceted disciplines. Acquiring this information and the judicious application of it necessitates a good deal of rigor that may only be garnered through much exertion and perspiration. Recalling our own experiential learning, often the road was well traveled and nearly flat, like the recognition that a bicycle can get one from one point to another and to do so proves easy enough if we have the means to procure one. It is not until much further along the road that most recognize that turning the handlebar one direction or another causes you and the bicycle to move in that direction. The motion of both requires some degree of balance and speed to succeed at cycling without the knowledge of why. It is only with the miles behind the nascent rider that these concepts are better understood in various applications. One may also glean the knowledge of why balance and angular momentum are important in riding a bicycle without actually pedaling one. Therefore, knowledge may be enhanced by prior direct experience that may serve to offer an example that eases its acquisition. More perplexing is the set of advanced skills one may see others possess like riding and turning their bicycle without using their hands on the handlebar. While it represents a path many of us did not take on the road to our success we may understand how they might accomplish their feats even if they do not. Eventually they may, if they persevere, attain a grasp of Newtonian Mechanics and the vector operations needed to reach a more complete explanation. They may acquire the knowledge via concepts that are obviously different from a non-stunt rider through a continual process of assimilation. To acquire the same understanding as if you had ridden the bicycle demands a bit more of a discontinuity to make the grade through instruction in lieu of riding. Therefore, we propose that the learning process incorporates elements of both continual and discrete natures.

While most of the acquisition of knowledge appears as though it is a continual smooth process, there is discontinuity that may rear its head on occasion. In between there are many instances that may be such small discrete steps as to appear continual. The conclusion to draw is that there exist modes of learning that are analog and digital just like the information that propagates as light. While light can coexist simultaneously as both a particle and a wave, it is viewed primarily as one or the other in most applications.

The dominant mode for learning may be to continually acquire concepts with varying degrees of difficulty in achieving the grade of the helical path, both spatially and temporally. Perhaps an apt analogy may be provided by a mechanical system where mitigating friction and maximizing the efficiency in the transfer of information occurs when a resonant condition exists. This is when the impulse frequency most nearly matches a fundamental mode or one of its harmonics, that the transfer is most efficacious. Most of the accumulation appears, as gradual, while some is a consequence of a step up. It is the “Eureka!!” experience of Archimedes upon discovering the means to determine the relative purity of gold content in his crowning moment that affords a jump up akin to a quantum leap. It is here that the authors tend to depart from previous paths expounded that allude to a more homogeneous transition in learning. Many individuals may be presented the same data yet experience much different results. Some may grasp the significance of an event that allows them to take a larger step up in increasing their own potential energy for solving this and future problems. Some may recognize it as one more obstacle to circumvent and advance by learning to solve the dilemma in another fashion or they may pass by without a solution. These choices may represent new and possibly different concepts of varying degrees of value. Additional concepts are used and created that add to the internal body of this helical path that loosely bounds an internal fountain of knowledge, a unique repository for each individual.

Conclusion

Utilizing the constructivist’s approach and combining Bloom’s taxonomy, Kolb’s learning cycles, and PBL has opened the way to create a concept-centered learning process that is ideal for spiral- and helical-learning processes in engineering. Developing the skills to appropriately employ concepts, will empower the individual to be more creative in thinking processes and provide the necessary tools to innovatively address engineering challenges.

While a vital aspect of any group endeavor is communication, with the various nationalities represented communication initially proved difficult. This impediment was reduced as the semester unfolded. Exit exams and student surveys suggested the class was a success. The authors feel that with the proper motivation by other professor’s, classroom leaders and student bodies, the enriching experience may be replicated at other institutions and in less advanced courses.

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