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ENGINEERING KNOWLEDGING: CROSSING DOMAINS

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Abstract

The authors have published manuscripts concerning the impact of Generations Theory on engineering education at the ASEE National Meetings in 2002, 2004 and 2005 and ASEE Section Meetings from 2001 onward[1]. These publications position the current generation alignment of the engineering faculty with senior faculty as Boomers, younger faculty as Xers, and students as Millennials. The references describe Generations Theory as it applies to this faculty alignment.

Knowledge inherently divides itself into two related branches of learning. Traditional ordinary knowledge is obtained from systematic, purposeful, organized information; contrariwise, higher knowledge is produced by the use of insight and other creative mind processes. The knowledge age begins with ordinary knowledge coming from existing information and moves to higher knowledge as mental power increases. This dichotomy requires a broader interpretation of knowledge from a noun to a verb basis. The result is *knowledging,* which then allows the solving of new and different technical problems. However, *knowledging* is reversible – knowledge decays first to *informatics* then to routine public information.

Engineering faculty must begin *knowledging* by stressing insight, leading to a modified curriculum that culminates with more diversified capstone design courses that include new and improved design procedures. This learning process will ideally involve adjunct professors from industry and other domains outside engineering, such as law. Organized faculty development and further study of the design of learning in the context of Millennial Generation preferences will allow the teaching of knowledge with understanding as Millennials intellectually probe their X Generation professors in challenging ways.

In this manuscript, the authors move into a further explanation of the engineering *knowledging* process and show how seeking information from multiple domains potentially produces higher knowledge. This is doubly important when engineers apply their inherent mathematical analysis skills in conjunction with information and knowledge accumulated from a non-engineering domain.

Introduction

In traditional information age engineering education, the typical departmental model is to collect large amounts of information about an expert field of engineering since each engineering department considers themselves a collection of discipline-specific specialty areas. This traditional method of engineering education is what is now found worldwide; especially in countries like India[2] and China[3] where they annually produce many more engineers and technologists than the

United States. As the knowledge age proceeds, a more dynamic, holistic, flexible approach is needed whereby the information available to potentially form knowledge is not limited to a narrow expert source, but from a wide variety of domains.

Ordinary and Higher Knowledge

In today's literature, knowledge is commonly used as a noun. However, the Oxford English Dictionary, 2nd Edition, states that "knowledge" as a verb usage it goes back to the fourteenth century. In modern times, knowledge as a verb has been replaced with the verb "know." Therefore, instead of "to knowledge", knowledge is "to know." Further, knowledge can be the object of to know, i.e. to know knowledge. The Oxford English Dictionary also informs us that the verb acknowledge has in modern times largely replaced one aspect of knowledge as a verb. To acknowledge means to recognize, so acknowledgement is recognition, and acknowledging is recognizing, which has a relationship to insight. An important further use of knowledge as a verb involves the use of the gerund form, *knowledging*.

Knowledging as a noun has a narrow usage: meaning the teaching of knowledge. A broader definition, however, is the process of teaching, learning, and understanding knowledge. This broader definition was the focus of the author's manuscript in 2004.[1]

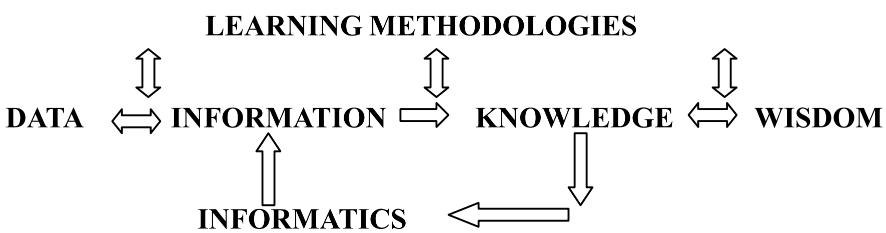

Figure 1: The 6 Part Cognition *Knowledging* Process

Knowledge is unstable; and, because of wide communication in the information age, decays to *informatics*[4] and then information. The time for this decay varies widely depending upon the information intensity of the domain where the knowledge first appears and also where the *informatics* first resides. In information age engineering, the process of knowledge moving from one field of engineering to another field of engineering via *informatics* is likely to be in the time frame of a decade.

The process of teaching *knowledging*[5] naturally divides itself into two parts in parallel with the two aspects of knowledge: ordinary and higher. Ordinary knowledge is based upon available information, whether obtained in the engineering domain or from other domains (i.e. law, business, etc.). Ordinary knowledge is defined as the systematic, purposeful, organization of information. This important definition has been useful for a half a century. The definition naturally requires the talent of engineers when they analyze available information (usually using mathematical tools) and decide what can be useful to create the required problem solving knowledge.

On the other hand, higher knowledge requires the use of innovative mind processes and is often referred to as the creative use of insight. Some refer to this as using innovation to solve problems that previously were unknown. In engineering, higher knowledge has traditionally been involved in graduate programs. However, in the knowledge age this will change. Knowledge age engineers (students & faculty) must master the ability to routinely produce ordinary knowledge in the baccalaureate program through improved methods of teaching and learning.[1] Further, students & faculty must also learn the processes to produce higher knowledge that will become an important part of their future professional practice.

Insight is important for *knowledging,* especially for conceiving higher knowledge. The domain of psychology divides insight into five commonly utilized progressive processes.[6] These are:

- Completing a schema when an integrated component fits into a larger system.
- Restructuring the given material by first making a mental or spatial visualization of the problem before one attempts a reorganization of the visual picture.
- Reformulating or restructuring goals or givens of a problem, which often first requires employing a qualitative approach before attempting a more familiar quantitative solution.
- Overcoming a mental block by finding a new approach to a problem by not depending only upon inappropriate past experience. In modern times this involves "creativity" and has been referred to as attempting a solution by "thinking outside of the box."
- Finding a problem analog, often from previous experience. Finding a problem analog involves thinking about the underlying structural principles of a problem rather than only about its surface features. This is probably the most common form of insight with respect to problem solving.

To move from ordinary knowledge to higher knowledge, often the first attempt is to apply analog insight to ordinary knowledge to determine the underlying structural aspects. This analog process leads to extrapolation beyond ordinary knowledge boundaries so that higher knowledge can be created. However in the knowledge age, this analog approach has limited application. Past experience often is not appropriate to future, new, never before encountered, problems. Thus, *knowledging* may well depend upon engineers creating new insight processes besides the progressive processes described above.

In teaching knowledge, (i.e., getting the students to understand these insight processes) professors will find this type of classroom instruction to be a valuable start in stimulating students to "push the envelope" from just information into ordinary knowledge. Since ordinary knowledge is the systematic, purposeful, organization of information to solve a given problem, the key to its mastery is the constructive analysis and manipulation of information upon demand, and often the further inclusion of *informatics*.

In the early information age, *informatics* was often accomplished in graduate school by assimilating appropriate information from libraries. This information could then be combined in a suitable manner to produce a skillful approach toward a given problem solution. The information age graduate student was then required to design and implement sufficient instrumentation to generate data that would prove that the result did truly solve the problem. Normally, only one domain in a given discipline of engineering was involved.

Now, in the knowledge age, the insight process must be accomplished quickly and effectively at the undergraduate level. A primary tool will be software "search engines" designed to not only find practical information (often from the Internet), but to suggest ways to analyze such information for good understanding in order to judge whether to prudently retain or discard it for the current iteration. Today, searches are often performed by a detailed procedure involving keyword attributes. Therefore, knowledge age professors must continually work toward the mastery of this information searching iteration process by suggesting illustrative key words for any given problem.

An example is using multiple class texts by putting such books on library reserve. However, the information technology procedure is to utilize multiple appropriate Internet web pages. Often, this results in not only solving advanced engineering problems but also multiple processing because the ongoing critical analysis suggests that the current solution is too narrow or incomplete. Today, such final analyses will often be performed with the aid of virtual experimentation (i.e., computational information technology) rather than the previously used information age, single domain experimentation.

When working with knowledge, it is important to recognize that multiple domains are often involved. Optimal problem solving in the context of multiple domains creates a situation of utilizing cross-functional teams that understand domain dependent jargon. Consequently, as the knowledge age proceeds, engineers need to acquire a broader range of experiences in domains external to engineering.[7] This broadening concept is now appearing in some engineering programs where, for instance, new departmental names, such as "chemical and biological engineering" and "bioscience engineering" are appearing.

General Engineering

The critical analysis of values has not been a strong suit of engineering. In the past 50 years, most engineers (students, faculty & practicing professionals) moved toward a strong value of developing expertise in a single discipline. Thus, engineering education was engrossed with individually strong engineering departments where information as well as *informatics* did not easily move across internal boundaries. This is well expressed by the quote:

"The modern world provides us with abundant secular examples of admirable values to which we cling under conditions where those values no longer make sense."[8]

In the future, engineering values need to be based upon obtaining as much beneficial and prudent information from all possible sources by readily crossing domain boundaries.

Current freshman engineering education courses serve to act as an introduction to engineering. In the future, these courses need to accentuate the concept that engineers in their future professional practice must easily cross domains looking for information that can help them create the needed knowledge to define and solve modern problems. Professors teaching these freshman courses must also emphasize the need to cross international domains.[2] Classroom discussions should focus on the need for language skills beyond traditional English.

Faculty and staff should work to convince college students to communicate with their home high schools about the importance of students taking modern language classes (Spanish, Chinese, Japanese, etc.) while still in high school. Further, the mathematics topics in high school should include additional emphasis on basic statistics. It has not been too many years ago that high schools adopted the expanded math domain concept that beginning calculus could be taught. The authors believe the math domain should now be extended to include statistics; statistical methods are important to the *knowledging* analyses that will be performed with the aid of virtual experimentation.

Additionally at the college freshman level, the concept of general engineering is a natural introduction to future responsibilities as a professional, especially when composite engineering fields such as environmental engineering, architectural engineering, and agricultural engineering are studied for their cross-domain requirements. Except for general engineering courses aimed at students who have not decided on a major, most departmental orientation courses are discipline specific. However, the future crossing domain requirements suggest that all departmental orientation courses include "general engineering" concepts (or at least relate discipline specific information to broader classroom applications).

Considering some history, the mid-20th Century concept of obtaining a general engineering degree was approached by some engineering programs.[9] Typically, these programs created a four-year degree that did not specialize into any particular one engineering discipline (or focused on a specialized area (i.e., nuclear) while relating course work to a primary engineering discipline (i.e., chemical)). These programs consisted of basic information from the first three years from several disciplines of engineering. If students wanted a more definitive degree, they took additional classes that consisted of the normal final year coursework from a given engineering discipline. This broad "general engineering" degree approach ceased to exist (in part) because industry did not want to pay for a five-year education and had difficulty placing graduates into discipline specific departments.

In the 1950's - 60's, industry leaders did not appreciate the fact that the industrial revolution was diminishing rapidly while the cybernetic revolution requiring knowledge over information was rapidly increasing. Today, the knowledge age is being widely recognized. Consequently, the concept of a general engineering degree is again being discussed. However, with few exceptions, current industry leaders are not likely ready to incorporate such a concept into their organizations. College recruiters continue to regularly seek the traditional discipline specific graduates.

Cross -domain Education

Learning is often divided into two cognitive bases. First, is the concrete basis where the accent is on "hands on" operations. Data is obtained via the senses at laboratory or site locations. This was the traditional approach to engineering problem solving in the industrial revolution and the early information age of the cybernetic revolution. The proof was a "hands on" usable product. The second cognitive base is the abstract where the solution includes much in the form of ideas and perceptions. In the current cybernetic revolution, this abstract form for engineering solutions is mostly computer generated and (based on the author's experiences researching information for this manuscript) is often referred to as virtual elucidation.

A number of educators have argued that faculty are more abstract and students more concrete in the teaching/learning process.[1] However, the concrete/abstract dichotomy is also generations dependent.[1] The authors of this manuscript have previously expressed concern that the rift between students and faculty is widening because of the current generational trends. The Boomers and Xers, the senior and junior engineering professors respectively, easily work in the abstract area; conversely, the student Millennials tend more toward the concrete.

Therefore, as the authors explained previously,[10] it is the responsibility of the Boomers as the senior, more experienced professors to teach beginning courses for Millennial students to upgrade them to the abstract area of learning as well as resourcefully have them convert abstract results into concrete outcomes. These actions will also help greater society, which is more concrete oriented, to understand the importance of engineering activities.

The first task when one crosses a domain boundary is to understand the concept of terminology. Each domain develops its own jargon. For instance, each department of engineering uses words that are not common across all fields of engineering. As an example, in chemical engineering the concept of "stoichiometry" is borrowed from the field of chemistry and certainly makes no sense to other engineers. Further, in electrical engineering, a common concept is "Ohm's Law" that does not easily cross departmental domain boundaries. Therefore, when one starts a new domain of learning, the first course has to concentrate on teaching much of the jargon resulting in additional courses that are then intelligible.

As a further example, the senior author holds a Juris Doctor degree from Law School. Once one enters the domain of law, the first year of law school is essentially the accumulation of information that represents the terminology of law. Typical items included are: Using the law library; differentiating civil and criminal law; understanding the various court systems; mastering the case system, and appreciating legal ethics. Two additional years then develop on this basis.

Members of the American Society of Civil Engineers (ASCE) have been advocating that engineers, if they are to obtain sufficient information from other domains so that they can create knowledge from their broad accumulation of information across multiple domains, must add hours to their undergraduate program of study. Ideally (to ASCE), engineering now becomes a five-year program. Should this happen, the authors argue that at least part of the extra year be spent learning about information available from other important domains and not be limited to discipline specific coursework. (Another option is to fully implement the effective use of learning technologies and fully integrate *knowledging* into the curricula.

Other examples of cross-domain proposals include discussions surrounding proposed chemical and biological engineering (or bioscience engineering) degrees. This cross-domain program will likely have an extra year taken up with courses from the domain of biology. If that does not occur, then traditional information only chemical engineering courses will be eliminated to allow time for the biology courses. Consequently, the chemical engineering faculty are not likely to favor such a change. An additional possible consequence is a graduate lacking sufficient chemical engineering coursework to enter a purely chemical engineering profession should they choose to make a career change from bio-engineering.

The current university paradigm is for baccalaureate engineers to study some further domain in graduate school. This entails making up undergraduate classes in order to accumulate the needed basic information for that field of study. Engineering *knowledging* is designed to shorten that undergraduate system to four years. Shortening the undergraduate system leaves room for future learning in that baccalaureate engineers can then obtain graduate degrees when they broaden their accumulated information as a practicing professional.

Another current requirement of the engineering curriculum is taking designated humanities & social science courses. This is again one of those values that need critical review for the knowledge age. Such courses should be directed at future needs of professional engineers and could include the study of appropriate modern languages, history, and increased oral and written communication skills.

Cross-domain Faculty Development

To serve as knowledge age catalysts, engineering faculty must develop a new value related to their role as a teacher and researcher. According to Andy Hargreaves,[11] faculty must:

- Promote deep cognitive learning;
- Learn to teach in ways they were not taught;
- Commit to continuous professional learning;
- Work and learn in collegial teams;
- Treat parents as partners in learning;
- Develop and draw on collective intelligence;
- Build a capacity for change and risk, and;
- Foster trust in processes.

An additional aspect of crossing domains is for the engineering faculty to drop their value of assembly in the Student Union as a group at a large table for a “coffee break.” Such engineering faculty should spread out and have their coffee with faculty members from other domains. After several years of such *cross-domain coffeeing*, the engineering faculty will begin to appreciate the jargon and information from many other university fields of academic study as well as further present engineering rationality to other domains.

Another value change for the traditional university faculty to consider is to identify and accept adjunct professor positions. The traditional research faculty member will often claim industrial experience by working 2-4 years in an industrial research position before returning to campus. While valuable, these “industrial experiences” are mostly extensions of the university research environment and are not really rooted in practical “hands on” domain experiences. Experienced adjunct professors ideally represent a crossing of domains and can significantly act as a mentor for students crossing domains.

A further value change to be considered is to hire faculty members that represent multiple domains. For instance, at MIT Neville Hogan is professor of mechanical engineering and professor of brain and cognitive sciences.[12] Another example comes via the senior author when attending a sabbatical year in 1967 at the University of Southern California. Richard Bellman was professor of electrical engineering, professor of mathematics, and professor of medicine. This occurred because of his expertise in computer applications across a wide swath of domains at that time in history. The junior author worked in industry for 20 years in cross-disciplinary roles (i.e., systems engineering, human resources, and management consulting) before joining the faculty to teach general engineering courses.

The Student - Millennial Generation Challenge

As explained above, current students represent the Millennial Generation and are naturally quite concrete in their approach to problem solving. Some often prefer algebra to calculus since the former is more concrete while the latter is more abstract. For instance, an algebraic problem starts out with a physical, concrete setup — *the problem definition* — whereby one or more unknown physical quantities are required. Then algebraic equations are written that express known facts about the physical relationships so that a potential solution is possible. Note that the algebraic equations are now transferred to the abstract arena and are divorced from their physical, concrete nature and then elucidated — *solve the problem*. The abstract solution so obtained is then converted back into the concrete arena and checked for pragmatic results — *analyze the solution*. Finally, the result is transmitted to the appropriate teacher, boss, etc. for approval — *communicate the solution*. Notice that only one of the steps is abstract in nature. Further note that the italic phrases represent a four-part solution scheme. However, in practice, this solution scheme is utilized in an iterative manner where all four positions are available for any continuing activity.

Now using engineering *knowledging*, essentially the majority of the procedure occurs in the abstract arena, particularly when complex computer solutions are involved. Consequently, it becomes important for the Millennial Generation to quickly master this required abstract discipline. As presented previously[13], the senior professors of the Boomer Generation have this transition responsibility in teaching early engineering courses and further mentoring engineering students to cross-domains with their learning so as to broaden the potential for knowledge creation. Finally the junior professors of the X-Generation then have the responsibility of teaching the full *knowledging* process during the upper engineering courses particularly involving capstone design.[1]

Future Challenges

The early Millennials are now graduating from college with bachelor degrees in engineering. Some are entering graduate school, and many are going to work in industry. In both instances, their life long continuing education consists of more and more exposure to the creation of new knowledge as information across domains increases and better understanding into engineering *knowledging* continues. In graduate studies, some of these Millennials will train to become future engineering professors that will better teach *knowledging*. In industry, properly educated

Millennials will be ready to accept the new, currently unknown, knowledge challenges to continue the profession of engineering with prominence.

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