TEACHING ENGINEERING KNOWLEDGE WITH UNDERSTANDING
IN THE 21ST CENTURY

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Abstract

The authors have published manuscripts concerning the impact of Generations Theory on engineering education at the ASEE National Meeting in 2002 and ASEE Section Meetings from 2001 onward. 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. In this manuscript, the authors move into the engineering curriculum arena and provide evidence how the current generational alignment possesses the dynamics to move toward undergraduate knowledge learning instead of traditional information teaching.

Introduction

This paper represents “Teaching Knowledge with Understanding: The Engineering Education Challenge for the Millennial Generation,” and the challenge is for the whole engineering profession, but it will fall more heavily upon the engineering college faculty. Further, it will be a continuing challenge for the American Society for Engineering Education (ASEE) during the 21st Century.

Futurists believe the cybernetic revolution of today is occurring in two phases: the information age that is winding down and the knowledge age that is underway. A century ago, the engineering profession evolved in the industrial revolution and during that time the engineer created and handled scarce but valuable information.¹ Today, such information is common. Consequently, engineers are trained today to primarily handle routine information, and the long-range consequences are that the cybernetic revolution with its ever more efficient computers will make engineers redundant or obsolete.

Engineers must shift into the knowledge age in order to survive as professionals.² Just as the information age eliminated middle managers, engineers may become expendable unless they embrace new learning concepts. Thus, this paper is about the early aspects of the knowledge age with accent upon engineers learning knowledge from professors that are teaching both information and knowledge.

Traditionally, 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 requires a broader interpretation of its namesake from a noun to a verb basis resulting in the gerund knowledging, which importantly now becomes a process articulating the accumulation of knowledge and allows solving new and different technical problems during the 21st century. However, knowledging is reversible – knowledge, once it enters the public realm, decays first to informatics, then to routine, public information, thus further escalating information overload.

To tackle this challenge, it is necessary to recognize several types of knowledge. The two most utilized are given identities of “ordinary knowledge” and “higher knowledge.” Engineers must master both to progress into the knowledge age.

Teaching knowledge, not just information, to the Millennial Generation — the generation in college today and for the next 20 years that represents a controlled, dominant, and energetic populous especially when compared to its predecessors — will not be easy since teaching knowledge represents advanced concepts for most engineering professors. To understand this challenge, one has to observe not only the expected capabilities of these Millennials but also comprehend the preferences of the previous generations, the Boomers and the Xers, since they will largely be the developers of curriculum and the early, formal teachers responsible for knowledging.

**Generations Theory**

Knowledging requires more than just a lecturer handling a large class and covering information. It requires a mentor match between a professor interested in presenting information and its relationship to knowledge and students willing and ready to absorb and utilize such knowledge. The current alignment of collegiate personnel presents the opportunity for knowledging to occur, as the Millennial students are inherently eager to “go the extra mile” and obtain the best education possible. The faculty knows knowledge and has the ability in the Boomer senior professors to lead the knowledging process with necessary and important backing from the Xer junior professors. Thus for understanding of knowledging in the College of Engineering, one must first appreciation the concept of Generations Theory.

The authors have previously published papers about Generations Theory and its connection with engineering. However, a brief summary follows to present enough information to make the remainder of this knowledge teaching paper coherent.

The theory of historical generations is a study of the time repetitions of basic social stresses over 80 to 90-year cycles (Figure 1). Each cycle normally has four types of generations; each cycle also has four turnings slightly out of phase with generational changes. Historians Strauss and Howe employ the generational types of Idealist, Reactive, Civic, and Adaptive. These generations follow each other and currently average 17-23 years in length. The 80 to 90-year repeating cycle (or to use the ancient Latin word, saeculum) extends back several centuries.
The characteristics of the four Generations Theory types are:

- **An Idealist** generation grows up as *increasingly indulged* post-Crisis children, comes of age as the narcissistic young crusaders of an Awakening, cultivates principle as moralistic mid-lifers, and emerges as wise elders guiding the next Crisis.
- **A Reactive** generation grows up as *under-protected* children during an Awakening, comes of age as the alienated young adults of a post-Awakening world, mellows into pragmatic midlife leaders during a Crisis, and ages into tough post-Crisis elders.
- **A Civic** generation grows up as *increasingly protected* post-Awakening children, comes of age as the heroic young team workers of a Crisis, demonstrates hubris as energetic mid-lifers, and emerges as powerful elders attacked by the next Awakening.
- **An Adaptive** generation grows up as *overprotected* children during a Crisis, comes of age as the sensitive young adults of a post-Crisis world, breaks free as indecisive midlife leaders during an Awakening, and ages into empathic post-Awakening elders.

The key to Generations Theory is the italicized wording preceding “children” in the first phrase of these generation type explanations, for this early exposure sets the basis for the children’s lifetime performance. These are: Idealist — *increasingly indulged (unprotected)*; Reactive — *under-protected*; Civic — *increasingly protected*; Adaptive — *overprotected*. The dichotomy between social “degree of freedom” and “degree of protection” governs the children’s empathy toward educational accomplishment as well as their performance in future adult years. A current example is the transition from Civic to Adaptive generations that is occurring after September 11, 2001 — the apparent catalyst for the next Crisis cycle — with the increased emphasis upon safety as society moves the highest protection status for children.

[Note: These types are all defined with respect to a Crisis, which according to Generation Theory is currently beginning - September 11, 2001 was the likely catalyst for the next Crisis cycle.]

The common media names for the currently living generations starting with the youngest are:

- **Millennial** - Civic type with birth years of 1982 – 2003;
- **X** - Reactive type with birth years of 1961 – 1981;
- **Boomer** - Idealist type with birth years of 1943 – 1960;
- **Silent** - Adaptive type with birth years of 1925 – 1942;
- **GI** - Civic type with birth years of 1901 – 1924.

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The generational age location in history is shown in Figure 2.

![Figure 2: Generational Age Location in History](image)

The Millennial Generation (Civic) is our prime concern and its age is under 22. This Millennial Generation (Civic) is community oriented and secular in nature; conversely, the Boomer Generation (Idealist), the other dominant type, is individualistic and highly spiritual. The other two types being recessive in behavior tend to initially follow the behavior of their next oldest generation but by midlife develop their own identity — the Adaptive is secular like the Civic while the Reactive is spiritual like the Idealist.

For the author’s purpose, the sterling learning academic characteristics (socially behaved, concrete/linear learners, and willing to take orders from parents and teachers) of the Millennial Generation (Civic) are significant. These characteristics are important in comparison to the increasingly pragmatic with age actions (strong individualism, abstract/random thinking, entrepreneurial, and “liberal – don’t follow the rules” social behavior) of the teachers that are of the X Generation (Reactive). Further, both sets of characteristics are important to compare the virtues (individualistic, spiritual/moralistic, and uncompromising) of the Boomer Generation (Idealist) that are the senior professors. A summary of campus life the next ten years is shown in Figure 3.

![Figure 3: Campus Life the Next Twenty Years](image)
Knowledge

The intellectual subject is epistemology, particularly knowledge teaching and learning, and this importantly precedes the conquest of knowledging that follows as the necessary intellectual process. What is knowledge? The dictionary has many definitions, one of which says it is information – confusing! Further, recent studies introduce terminology and use interactive definitions of information, knowledge and learning – really confusing! The authors of this paper contend that knowledge and information are separate identities even though they can represent the same scholarship at different times. Information teaching is what is commonly performed in undergraduate engineering education. This discussion is about replacing some of that information with knowledge.

Peter Drucker, a ninety-three year old management guru, wisely defined knowledge as:

Knowledge is systematic, purposeful, organized information.

This was written over forty years ago and is still a good definition for most purposes, but not a complete definition for the current situation. This definition is based only upon reordering information and represents “ordinary knowledge.” However, as will be shown, the ability to create “higher (new) knowledge” will require information (“ordinary knowledge”) plus insight and the ability to make judgments. Consequently, in a pragmatic sense, this upcoming concept may sparsely employ “educated” engineers in the knowledge age, whereas many “menial” engineers have been involved in the information age.

Consider the four-step progression:

DATA \(\rightarrow\) INFORMATION \(\rightarrow\) KNOWLEDGE \(\rightarrow\) WISDOM

This progression comes from Stan Davis’ business writing and indicates that information is transferred into knowledge, and therefore is, in a sense, a higher level of intelligence — Drucker suggested this some 32 years before Davis. This further indicates the transition from the information age to the knowledge age, and indicates that the concept of an upcoming “wisdom age” must not be totally ignored as the 21st Century proceeds. Davis pulled this concept from a poem of T.S. Elliot written about a century ago. However, this hypothesis goes much further back into the civilization of the Greeks and is broadly explained in Plato’s The Republic.

Plato presented the stages of cognition as:

1. Uncritical and unthinking acceptance of the world of appearance;
2. Critical examination of society’s conventional beliefs;
3. Knowledge pursued by advancing beyond opinion and into the abstract study of mathematics and astronomy;
4. Perception of people’s abstract humanity and the recognition of ourselves in them.

These four stages have a certain mirroring of Davis’ concept, especially when one considers the passage in time of nearly two and a half millennium. Davis wrote the four-part sequence as a se-
rial process moving from data to information to knowledge to wisdom. However, for a modern meaning of knowledge, the process must also be reversible. Thus:

\[
\text{DATA} \iff \text{INFORMATION} \iff \text{KNOWLEDGE} \iff \text{WISDOM}
\]

For current purposes, the critical two-way transformation is between information and knowledge and allows knowledge to revert to information. Therefore, “old knowledge” is reclassified as a form of information – the term informatics is employed and is defined in the dictionary as information science; thus, its use is thus appropriate for today’s cybernetics era featuring computers.

Data is sometimes called “raw data” as it represents something concrete; i.e. one can determine it from the use of the senses, or as Plato referred to it as the world of appearances. Data is often numerical, particularly today in our digital age, but other forms are possible. Often the modern question is whether data is factual, and if so, can it be proved; thus, the accuracy of data is important. Data is often assumed to occur in real time, like what our senses are telling us now. That data is then stored in our memory.

Information is data that has been classified in some manner, such as by Plato’s critical examination. For instance, books coming to the library are not put on the shelves in the order received from the publisher; no, they are classified by title, author, subject, and other attributes before shelving occurs. However, with modern computer storage replacing the multiple library file drawers of the past, it is easy to search many attributes including key words of the title, abstract, first page, or even the total piece of writing.

This ease in looking up information has given rise to the concept of information overload, and to potentially obtain knowledge, a la Drucker, from this activity often requires an elaborate procedure, such as an Internet search engine. In similar fashion, a key finding from How People Learn is:

To develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge (information), (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge (information) in ways that facilitate retrieval and application.\(^7\)

What then is knowledge as utilized in Davis’ four-part scenario? In the case of problem solving, as commonly utilized in engineering, knowledge is often more than just selected information, knowledge also includes rejected information. Both of these aspects require judgment and understanding often masquerading as insight. Therefore, knowledge also represents a process. And, with such a definition, an adaptation occurs from the noun usage of knowledge into the verb form. This common noun usage as an infrequent verb is typical in the English language. For instance, the noun “engineer” has been with us for centuries, but the verb usage as “to engineer” occurred in the twentieth century. And further, going to the gerund form “engineering” – now a noun or verb depending upon its use – is also common; thus, at universities one finds a College of Engineering.

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Knowledging & Knowledge Teaching

To knowledge or not to knowledge, that is the question! This paper started with the noun usage of knowledge but now represents a verb analog – a further form of insight – modeled from 17th century Shakespearean writing. Continuing this verb form, the concept of knowledging means teaching students not only the basic information, but also the analysis of that information into knowledge; yet, knowledging is not restricted to this narrow role as it includes continued successful employment of both ordinary knowledge and higher knowledge.

Insight is important for knowledging, especially for creating higher knowledge. Insight is divided by the psychology domain into five commonly used progressive processes. They are: completing a schema; reorganizing visual information; reformulating a problem; overcoming a mental block; and, finding a problem analog.

In the learning process at the baccalaureate level, professors make the selection and rejection of the information to be included in any particular course. This is performed under several constraints, such as the accredited curriculum, the textbooks available, the time allowed, etc. Yet, what professors typically teach students is information, not knowledge, since it is only gleaned from the available information and thus, in one sense, is restricted to old problems. With the cybernetic revolution, however, most of the problems to be solved by working engineers will be novel problems, often created by new technology. Certainly, professors created knowledge previously in their mind, yet they did not transmit to the students the insights and judgment processes producing the knowledge about why the selected information was actually included in the course, and the reasons that other information was excluded. Useful insights on how experts (professors) differ from novices (students) enhances this understanding.

Knowledging is to teach the student the process of creating by judgment the knowledge to solve the given problem. Yet, once this knowledge, which is new to the student, is firmly in place, it now likely reverts to information since it is available for others to use, especially if it appears in communicative form at any time. This likely is transient knowledge, since it easily reverts to a form of information – informatics – now further defined as previous knowledge when that knowledge becomes widely available to the general public, which is often via modern computers and electronic communication systems.

The four-part cognition now emerges under these circumstances to a fifth part as the knowledging process:

\[
\text{DATA} \quad \leftrightarrow \quad \text{INFORMATION} \quad \rightarrow \quad \text{KNOWLEDGE} \quad \leftrightarrow \quad \text{WISDOM}
\]

\[
\text{INFORMATICS}
\]

Here, the delay between informatics passing to information is a function of the domain of the knowledge. Engineering as a domain is broken down into a number of fields, such as mechani-
cal, electrical, civil, chemical, etc. Each field develops its own knowledge, but some potentially reverts to informatics as it is transferred over a reasonable time to other fields of engineering.

To fully understand the cognition process, clarification of the term “learning” with respect to the terms “knowledge” and “information” is needed. Further, effective application of learning methodologies will enhance and accelerate the knowledging process. Thus, the five part cognition knowledging process transitions to a six-part definition:

**LEARNING METHODOLOGIES**

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\begin{array}{c}
\text{DATA} \\
\text{INFORMATION} \\
\text{KNOWLEDGE} \\
\text{WISDOM} \\
\text{INFORMATICS}
\end{array}
\]

The relationship of learning methodologies to the knowledging process is therefore dependent upon student preconceptions, amount of acquired information, and metacognitive abilities. The relationship is also dependent upon other factors such as teacher expertise, teaching ability, defined curriculum, and learning environment. Further, effective assessment techniques and faculty professional development strengthen the bonds between learning and knowledging. Particularly in current times, an additional important aspect becomes generational preferences.

**Knowledging the Curriculum & Capstone Courses**

Undergraduate engineering education is currently composed of information. Certainly, the first three years are primarily involved with information teaching and learning. Yet, these classes in engineering are potentially available to transfer some knowledge — perform knowledging — if the professors recognize that knowledge transfer is important. To date this has not been a common occurrence. In addition, expertise in an area does not guarantee that one can effectively teach others about that area. Further, knowledging is also dependent upon the ability of students to teach themselves. Therefore, engineering faculty must design the four-year curriculum to include knowledging.

The senior year occurs with its capstone courses featuring an accent upon product design and its peripheral subjects such as safety, legal liability, ethics, cost analysis, etc. In the domain of engineering, the word “design” has a reduced meaning from that commonly found in our society since design does not usually start with a blank slate but with a prototype that is to be optimized according some given new specifications. Thus, design means, “design analysis.”

The basic question remains; will the professors teaching design courses teach the required information with considerable added knowledge? Further, does the professor perform knowledging? The capstone course involving design analysis generally has a team of students working on a pro-
ject, and the class has a number of projects going simultaneously, each with a different set of specifications. The knowledge involved in these classes occurs in at least several aspects.

First is the reasoning of the professor in selecting the particular set of projects rather than some other set. Yet, this selection process is rarely transmitted to the students directly, although it is often available indirectly by insightful student questioning.

Next is the content of the specifications given to each student team. The knowledge occurs in the particular selection by the professor and the reasons for that selection. Sometimes the professor has contacts in industry, resulting in a selection based upon industrial insight. This is a form of knowledge, since in the industrial concern the general background for this decision is likely involved with intellectual property, like trade secrets. Yet, because of this restriction, students are not likely to understand the reasoning behind such specifications, and knowing suffers.

If the specifications are solely that of the professor, then the knowledge behind such a selection ideally is learned by the students, especially if the professor has had pre-professorial or summer industrial experience in that specific field. Yet the professor has to make a definite effort to transmit this knowledge — it is not something always discussed in class.

The reason behind unfavorable — as judged by the professor — solutions to the design project is another knowing opportunity. The peripheral subjects, such as safety, legal liability, ethical decision-making, and cost, always involve tradeoffs that represent knowledge from that field, that domain, and often other domains. The difficulty is that this knowledge is often only obtained through industrial experience, or sometimes from information available in a different domain. For instance, legal liability involving both product liability and professional liability requires information from the domain of law. And if this is to become engineering knowledge, it requires a blending of this legal information with information from the particular field of engineering in order to produce insight into potential legal liability associated with the particular class projects. Yet, the professor teaching the design class does likely not know this information, let alone its knowledge content.

The above aspects of the knowledge involved in these design classes make it apparent that a broader background is required than professors teaching such classes normally possess. In addition to organized faculty development, a potential answer to this situation is to have one or more adjunct professors also associated with the class. For instance, these could be from industry, law, management or other important peripheral fields and domains. Each one could be scheduled to appear at least twice during the class duration — once early to present the importance of this field or domain to the design projects, and once late to discuss questions that have arisen. Expert evaluation/discussion of team solutions at the end of the class is essential.

The previous discussion suggests that for knowing to be taught, a team approach across fields, and perhaps domains, is necessary. Thus, looking to the future in engineering, the capstone design course must become a college-wide (perhaps university-wide) senior course involving professors from all the fields composing the domain of engineering and additionally have teams composed of students from each field. Further, this broadly based effort will require
strong leadership, facilitation, and organization from department heads and the Office(s) of the Dean. In this realm Williams offers additional insight on needed engineering education reform; revised understanding of engineering education, the convergence of technological and liberal arts education, and perspectives on curriculum change.\textsuperscript{17}

Business-as-usual collaboration in the university will not occur quickly for it narrows the differences between the fields of engineering and other domains. However, the dramatic and rapid international outsourcing of white-collar jobs\textsuperscript{18} suggests that traditionally slow-to-change professorate and university systems must quicken the rate of change or risk obsolescence. Change is possible with strong leadership, by starting with trial college-wide capstone courses, and then further exploring design project knowledge characteristics, both positive and negative. Improved knowledging within capstone design courses will provide course design informatics and supply information that leads to improved curriculum design.

The Millennial Student in the Knowledging Process

For knowledging to occur, a revisiting of the distinctiveness of the Millennials is required. Generations Theory does not normally use the abstract/random, concrete/linear description of each generation. However, the Idealist and Reactive are largely abstract/random; conversely, the Civic and Adaptive are largely concrete/linear. This means that the ability of the Millennial Generation (Civic) is that of concrete/linear students good in mathematics, science, and having the ability to develop good insight. Insight is important for knowledge learning since it occurs as a particular knowledge state.\textsuperscript{14} For engineers, insight often involves either reformulating a problem or finding a problem analog; thus, insight and judgment are significant aspects of successful knowledging.

The authors’ next article will tackle the significant problem of having the Millennial Generation as students, the X Generation as younger faculty, and the Boomer Generation as senior faculty/administrators. An enlightening discussion directed at modern schools in presented in Hargreaves book, \textit{Teaching in the Knowledge Society: Education in the Age of Insecurity}.\textsuperscript{16} Chapters 3 & 4 of Hargreaves work discusses the Boomer – Xer dichotomy although the author does not employ Generations Theory nomenclature. An example is the discussion of the divergent value systems of the Boomers that represent the school system senior planning and financial staff compared to that of the Xers who represent the majority of classroom teachers and principals.

This clash of generations represents an important practical challenge in order for knowledge transfer to occur.

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