RESTRUCTURING ENGINEERING EDUCATION
AT LEVELS MORE PRECISE THAN
DEGREES AND COURSES

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Abstract

Knowledge can be divided into two main categories, personal and professional. While personal knowledge contains all solutions in a person's inventory, professional knowledge contains those solutions within a program of study. By issuance of a degree, educational institutions assume an individual has acquired a given set of solutions, understands how to inquire into the subject, and can apply appropriate technology associated with their discipline.

Currently, college degrees are quantified and qualified crudely by the concept of student credit hours to denote the amount of time the student has spent studying a discipline. We propose a new method to more precisely quantify and qualify knowledge for the purpose of restructuring engineering education. This new method of quantifying professional knowledge is called Epistecybernetics—The Science for the Stewardship of Knowledge. Epistecybernetics was derived from the Greek words episteme meaning knowledge and kybernetes meaning pilot or governor. This new science studies the evolution of disciplinary knowledge with the intent of improving knowledge stewardship.

Introduction

Personal knowledge can be considered as the summation of all of the solutions in a person's inventory of problem-solving devices. Professional knowledge is the summation of all the solutions contained in programs of study for a specific degree. Educational institutions provide certificates to persons who successfully complete a course of study. The certificate indicates that the individual person has demonstrated that he has acquired a certain number of solutions, that he understands how to inquire into certain subjects, and that he can apply the appropriate technology associated with certain disciplines.

For many centuries, college degrees have been indicators that their holders have mastered a body of knowledge and could practice a particular profession
representing the student's level of knowledge achievement. Unfortunately, in too many cases institutional certification has devolved into certification of student time spent in the system, rather than certification of the knowledge competency of the student.

Time is an important factor in education, but it should not be equated with proficiency. There is the expectation on the part of educators that students should master a particular body of knowledge according to an established schedule. Determining which knowledge elements should be mastered and how soon they should be achieved are subjects of increasing concern for academicians, because knowledge-stewardship responsibilities are expanding faster than existing theory and organizational structures allow.

There is a great need to develop new ways of thinking about knowledge quantification and to create new technologies that allow a restructuring of knowledge at levels more precise than degrees and courses. We will look closely at some new ways of restructuring disciplinary knowledge, student time, and certifications to meet current needs for improved efficiency and effectiveness in engineering education.

Degrees and Certificates—The First Level of Professional Knowledge Quantification

Knowledge achievement by people in our society is quantified very crudely at various levels within the educational enterprise by education institutions awarding degrees and certificates.

At the first level, knowledge quantification is expressed in general terms of degrees or certificates. Society quantifies, in a crude measure, the amount of knowledge a person has achieved in a particular field by having educational institutions grant certificates to students who have completed a program of study successfully. The certificate permits the holder of a certificate to enter advanced training programs and, ultimately, to practice a certain profession. The Ph.D. civil engineer is expected to hold three higher education degrees (B.S., M.S., and the Ph.D.), as well as elementary and secondary education diplomas. In earlier times, these degrees were adequate divisions of knowledge.

Today there is a general acknowledgement that holders of the B.S. degree have spent four or five years studying undergraduate knowledge in certain fields and have achieved a certain knowledge proficiency. Colleges (Engineering, Arts, Science, Law, Business, etc.) have the responsibility for prescribing a general program of study that leads the student to a certain level of knowledge mastery in general and within a discipline. Colleges have the responsibility for providing the education programs and then certifying to society that holders of their associate, baccalaureate, masters, and doctorate degrees are capable of delivering a certain level of professional services to their clients.
The total level of professional knowledge gained by an individual is quantified and qualified under the following general terms: number of bachelor degrees qualified by discipline, number of masters degrees qualified by discipline, and number of doctoral degrees qualified by discipline.

Courses of Study—Second Level of Professional Knowledge Quantification

The second level of knowledge quantification is expressed in terms of courses of study completed. Courses are designed by an instructor who requires that a student masters a certain amount of knowledge within a specific time period (quarter, semester, or academic year). The Civil Engineering student may need to complete fifty courses in order to be awarded the Bachelor of Science Degree. Student credit hours quantify the amount of time that a student has spent in class room instruction. For example, the engineering student who has passed CE 5310, Numerical Methods in Engineering, receives three SCHs for attending at least forty-eight hours of classes on civil engineering numerical techniques for the formulation and solution of discrete and continuous systems of equilibrium, eigenvalue, and propagation problems delivered by the faculty. Awarding a passing grade to the student by the instructor certifies that the student has mastered the knowledge outlined in the syllabus for that course.

The student transcript certifies that the student has attended certain courses for a specified number of SCHs and earned certain grades (A,B,C,D,F). The Civil Engineering student may need to successfully complete 150 SCHs in order to be awarded a bachelors degree. Currently, degrees can be quantified in the following manner:

- Bachelors Degree= 150+ Undergraduate SCHs
- Masters Degree= BA + 24+ Graduate SCHs + Thesis
- Ph. D. Degree= BA + 60+ Graduate SCHs + Dissertation

Syllabi Topics—Third Level of Professional Knowledge Quantification

Courses are divided into topics that outline the major groupings of similar types of problem-solving devices. A syllabus lists the topics that should be taught in a particular course. Generally, there are ten to forty topics that are considered in a course. Courses contain twenty-five topics on the average. The number of topics taught is a function of student learning time and the complexity of the concept. Instructors typically assume the average student can master a topic in one or two class periods. The knowledge that a person is expected to learn in a bachelor of science degree program in engineering can be expressed in terms of syllabi topics (ST) and can be quantified in a third-level knowledge equation such as the following:
B.S.C.E. = Courses X Average Syllabi Topics Per Course or 
B.S.C.E = 50 Courses X 25 ST= 1,250 ST

**Essential Elements of Knowledge-The Fourth**

**Level of Professional Knowledge Quantification**

When the EKEs—the generic solutions to the general problems of a discipline—can be identified, placed within a model of the structure of knowledge for a discipline, and validated for relevancy, academicians will have created a technology that permits teachers and students to utilize their time much more efficiently, to greatly improve the mastery of essential knowledge, to enhance their application of problem solving techniques, and to facilitate their use of appropriate technology. For instance, the concept of *standard deviation* is a generic solution that allows the engineer to determine the standard amount of deviation in a set of observations and then to discuss the dispersion of the sample of observations within the context of certain mathematical and engineering assumptions.

When the student has mastered the prerequisite knowledge, statistics professors may estimate that it takes a teacher approximately 1.2 hours to present the concomitant theory and to demonstrate its application to particular problems and that it may take the student another 4.8 hours of practice to master the concept of *standard deviations*.

There are usually 3 to 10 EKEs within a syllabi topic. For example, we will assume that there is an average of 5 EKEs per ST. This means an instructor can possibly cover 125 EKEs in a course. The equation for the fourth-level knowledge quantification is:

\[
\text{Course EKEs} = \text{ST's} \times \text{Average EKEs per ST} \\
\text{Course EKEs} = 25 \text{ ST} \times 5 \text{ EKEs} = 125 \text{ EKEs}
\]

The overall knowledge that a person is expected to learn in a bachelor of science degree program in engineering could be expressed in terms of EKEs and can be quantified in a fourth-level knowledge equation such as the following:

\[
\text{B.S.C.E. EKEs} = \text{Courses} \times \text{Avg. STs per Course} \times \text{EKEs per ST} \\
\text{B.S.C.E. EKEs} = 50 \text{ Cs} \times 25 \text{ STs} \times 5 \text{ EKEs} = 6,250 \text{ EKEs}
\]

The knowledge contained in a Master of Science Degree in Civil Engineering could be expressed in the following fourth-level knowledge equation:

\[
\text{M.S.C.E. EKEs} = 10 \text{ Cs} \times 25 \text{ STs} \times 5 \text{ EKEs} = 1,250 \text{ EKEs}
\]
The EKEs in a Doctor of Philosophy Degree beyond the B.S. in Civil Engineering might be expressed as

Ph.D. C.E. = 24 Cs X 25 STs X 5 EKEs or
Ph.D. EKEs = 24 Cs X 25 STs X 5 EKEs = 3,000 EKEs

Therefore, the engineering knowledge inventory of the person who just earned a Ph. D. in Civil Engineering in 1991 is estimated to be greater than 6,000 EKEs. The total EKEs assumes that half of the engineer’s undergraduate study was related to the engineering disciplines and all of the graduate work was devoted to civil engineering or a complementary discipline.

The Significance of Quantifying Professional Knowledge
The foregoing explication of knowledge quantification for a discipline in the existing American higher education system sometimes seems to the authors to belabor the obvious. Unfortunately, the detailed theory is absolutely necessary for modern higher education, as many people who impact the system do not understand the tremendous complexity of the system and the central role knowledge plays in its operation. For example, the established methods of measuring and then paying for education according to time units (SCHs) are under great criticism by students and politicians. Some states are now seriously considering changing their formulae for funding higher education from a SCH base to a knowledge proficiency base. Texas is such a state. If legislators change their base for funding, academe must have a system for quantifying knowledge proficiency, for the state will then fund higher education institutions according to the value-added concept associated with knowledge achievement. The previously discussed quantification theory offers the most objective way of looking at knowledge achievement of students as they progress through the higher education system.

CUES Protocols and the four levels of knowledge quantification provide tools that previously were not available for curriculum restructuring, education policy studies, and cost/benefit analyses. Next, we will look at epistecybernetics—the new science that studies the evolution of disciplinary knowledge with the intent of improving its stewardship.

Epistecybernetics: A New Way of Thinking About Engineering
Using Several Modes of Inquiry to Study Engineering Education
This section describes several years of collaborative work of two professors who believe that education must be radically restructured if it is to meet the needs of our technological society. Both authors have been dissatisfied with the existing way of thinking about knowledge within disciplines and the
way students have been taught. They believe that academe is the place to start studying knowledge with the intent of improving education. They started a new way of thinking about education and knowledge and developed a number of tools that assist in the study of education and that have upgraded the education of their students significantly. Companion and subsequent papers describe the results of their interdisciplinary investigations using epistecybernetic principles.

In 1990, the term epistecybernetics was developed to describe the science that has the purposes of explaining the evolution of knowledge within disciplines and of improving the efficiency of knowledge creation, organization, storage, dissemination, and utilization. Epistecybernetics is the science of knowledge that advances investigation into the nature, creation, organization, dissemination, and utilization of knowledge with the practical purpose of improving its efficient dissemination and use. It is derived from the Greek words episteme meaning knowledge and cybheretes meaning pilot or governor.

The Need for New Disciplined Thinking About Knowledge and Education

Epistecybernetics was deliberately created, because there was no discipline that directs attention to a comprehensive study of knowledge. Colleges of Education are the logical places for the study of knowledge. Unfortunately, as they are currently constituted and philosophically oriented, they are not capable of undertaking such responsibilities. Disciplinarians in the arts and sciences and the professional schools are so committed to research, teaching, and service in their specific disciplines they have no time for looking at universal knowledge problems. Philosophers, whose predecessors started inquiries into knowledge, remain locked into classical ways of thinking that render their ideas irrelevant for explaining the nature of contemporary knowledge. Information scientists are usually concerned with applying computer technology to management problems for information. In short, until Epistecybernetics was developed no discipline had as its purpose the study of knowledge with the intent of improving knowledge stewardship by applying industrial engineering, expert systems, and cost-accounting modes of inquiry to the knowledge enterprise. Epistecyberneticians approach the study of knowledge differently, and they think about education problems in a new way. Currently, any strategies for advancing education emanating from Colleges of Education are rejected by disciplinarians and the general public. Consequently, we wanted to develop a theory of knowledge that would not be entangled with the dogma of progressive education or the subjective-rationalism of classical epistemology. Although educationists and philosophers have a large stake in the study of knowledge and should be investigating knowledge according to epistecybernetic principles, neither do so.

We believe the proper beginning for a renaissance in American education is the creation of a whole new discipline concerned with improving the
We believe the proper beginning for a renaissance in American education is the creation of a whole new discipline concerned with improving the educational systems efficiency, one that can accurately model knowledge in the real world.

For sometime, American education has been divided into two philosophical camps. The educationists form one camp; the *disciplinarians* form another. Colleges of Education have been composed largely of child-oriented educationists, and the traditional disciplines have hired subject-oriented disciplinarians. American higher education needs an alternative to the dogma of progressive education that has been dominated by educational psychologists who have focused inquiry on the characteristics of children and general-learning theory. It also needs an alternative to a disciplinarian philosophy that is concerned only with pressing more and more subject matter into existing degrees, courses, and texts without considering the student needs, i.e., learning time, concept complexity, and relevancy. Epistecybernetics provides these alternatives by focusing attention on the most effective ways of providing for the stewardship of knowledge and developing the most efficient ways of disseminating knowledge.

**Applying the Principles of Epistecybernetics**

The first principle in restructuring a discipline is to identify and functionally structure knowledge within disciplines. The second principle in restructuring education is to form partnerships between faculty and students to study a body of knowledge. The third principle is to determine the most efficient and effective methods of disseminating the knowledge. These guiding principles have a large number of very practical applications.

**Identifying and Structuring Knowledge**

Disciplinarians should identify the EKEs in their discipline and classify them functionally within a SOK for their discipline. Identifying the EKEs and placing them in a SOK provides the disciplinarian with a knowledge classification tool that should help them better organize their subject matter. First, the disciplinarian should create a model of their SOKs, so all can see the present major functions of the discipline and how they relate to one another. Also, disciplinarians should organize the major topics and knowledge elements with established functions. Associated with each EKE is a student Average Learning Time (ALT). As new knowledge comes into the discipline, the academician should be able to classify the new knowledge within an accepted taxonomy that upgrades the organization of the discipline. This can greatly enhance the articulation of education programs. Disciplines can be structured as shown in Figure 1 and Figure 2.
Figure 1. The generic model for the structures of the functional operations of knowledge for all disciplines.

Figure 2. A model illustrating the functional operations for mathematics.
Faculty/Student Partnerships

Education is a partnership based on instructors teaching students who are dedicated to learning. Students are unorganized in regard to their education, for they have not passed through that discipline before. Because they are inexperienced in the full realm of study, they cannot be expected to be able to organize it. They look to their teachers to organize their programs of study. Teachers, in the most efficient manner, are expected to organize the knowledge and information they expect students to know. This requires teachers to organize knowledge more precisely than degrees and courses allow. They must organize their courses around the topics and essential knowledge elements in a way that allows students to plan their study time more precisely. Essential Knowledge Elements should organize knowledge in a manner that assists the student in achieving a clear understanding of the purposes of each knowledge element, in acquiring the ability to reproduce the generic models and theory, in applying the theory to practice and thinking in a manner that allows the practitioner to improve upon the practice, and in thinking in new ways that bring innovations to bear on the general problem. Overlap, redundancies, and voids should be eliminated.

In the next section, we will look at how a teacher used the CUES Protocol to structure the essential elements of knowledge for their assessment of learning time and the validity of the knowledge disseminated. Student time is valuable. Instructors should organize the knowledge into the most efficient study unit possible to save student time.

The Cues Protocol: A Technology for the Engineering Classroom

If teachers are to effectively organize knowledge functionally within the discipline, they must have an informed idea about the total number of knowledge elements within a discipline and the approximate amount of learning time required to achieve a certain level of proficiency. Knowledge element numbers and average learning times can be found by using the fourth-level knowledge equation.

How is this done in the classroom? We must start from where we are. In the beginning, each program faculty should restructure their program to assure they have all of the courses necessary for certifying that their students are proficient in the knowledge of a particular profession and have earned a particular degree. Presently, program restructuring occurs every six years or as required by an accrediting agency such as ABET. We suspect it should be occurring more frequently. Each faculty member responsible for a particular course should draft a course syllabus containing a list of all the syllabus topics. The program faculty should review each syllabus to assure its contribution to the development of a professional in their field. Each faculty member teaching a course should provide the class with a course outline listing the major topics
and course objectives. To reach the fourth-level of knowledge quantification, the instructor must compile a CUES Protocol that contains all of the EKEs to be covered in that course. The teacher should initially estimate the amounts of time they anticipate will be required to learn each EKE. This completes a 1st Generation CUES Protocol.

A 2nd Generation CUES Protocol is developed by the students maintaining a CUES Protocol for their course and incorporating that protocol into their study strategy. Each student records the time they spent listening to formal lectures on a particular knowledge element. The student also records the time and exposures required in reading the text, doing laboratory assignments, discussion time, group work, and other assignments. Note in Figure 3 the example of the CUES Protocol for Statistics I; each of the times spent in the major learning modes can be summed in the Total Time Column. Students are asked to provide their assessment of the Relevancy of the Knowledge Element and their Self-Evaluation of their knowledge of the element. At the end of each semester, the students’ CUES Protocols are collected and the ALT for each EKE is computed. Subsequent generations of the CUES Protocol for a certain course then carry range and average times needed by previous students to achieve mastery of a particular knowledge element.

We have found that students like using this information in designing their study strategies. Another CUES fellow, Dr. Paul Randolph, has even computerized the Statistics I course using the CUES Protocol for the purpose of collecting data directly from students. His students immediately know how they are doing in relation to past classes and how they relate to the average work being done by the members in their class. The faculty in return has immediate feedback as to the amount of time the average student is spending on each knowledge element.

The CUES Protocol provides the faculty with empirical evidence of student time on each EKE. The aggregate of CUES Protocols for all courses in a program provides a complete knowledge inventory for each program. This allows the faculty to attain a precision beyond estimates of time and knowledge elements in restructuring their degree programs and courses.
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Figure 3. Partial format of the the CUES protocol form as it applies to the essential elements of statistics time and exposure.