AC 2007-2779: RE-ENGINEERING THE ENGINEERING CURRICULUM: MEETING INTERNATIONAL REQUIREMENTS

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Re-engineering the Engineering Curriculum: Meeting International Requirements

Abstract

In 1998, the College of Engineering of the Pontificia Universidad Católica de Chile began an internationalization process. The first step was to compare our programs against international standards; in doing so, the College went through a self-evaluation process, required by ABET. As a consequence, in 2003 all engineering programs reached the substantial equivalence with the old criteria. At present ABET has started to apply the EC2000 criteria to the international evaluations, and it does not give the substantial equivalence anymore. Instead, it has started accrediting programs abroad.

The College of Engineering is going through a curricular reengineering process, to face these new challenges and to go a step further in the internationalization process. The goals proposed to the new curriculum are (1) to change the present paradigm towards a curriculum based on outcomes, (2) to fulfill the ABET EC2000 criteria, (3) to improve the efficiency of the education and learning process, (4) to meet the industry requirements, and (5) to improve the international exchange of students and doubles degrees. This process involves all the engineering majors, and it is a reengineering process, because every aspect of the curriculum is being reviewed and evaluated: years of study, number of credits, design component, curriculum structure, size of the lectures, new learning methodologies, learning assessment and financial issues.

This paper describes the methodology that has being used in the re-engineering process, and the results obtained so far. The paper also discusses the difference between the engineering education and professional exercise in Chile with the rest of the world, and how this has been taken into account for the curricular change.

1. Introduction

The school of Engineering of the Pontificia Universidad Católica de Chile -UC- (Pontifical Catholic University of Chile) , and its homonymous from the Universidad de Chile -UCH- (University of Chile), are deemed the two best schools in their field in Chile; both with over a century of existence. Presently some 30 universities in the country offer undergraduate programs in Engineering.

The whole Chilean university system makes use of a multiple alternatives selection test known as PSU – Prueba de Selección Universitaria – (University Selection Test); the final selection of students is done based on a weighed combination of the results in this test and of the high school score records of each student. Using this combination as an index for the quality of the students selected, The UC Engineering School recruits the very best high school graduates in the country, independent from the major to which they apply. This represents a source of legitimate pride for this school, and has allowed it, for decades, to educate and train a group of very talented youngsters, who afterwards in their professional life, excel in the various fields of the productive environment of the country.

From a different standpoint, in an effort for the internationalization of the programs of study, the school obtained in 2003 the substantial equivalence certification from ABET, for the curricular programs in Civil Engineering, Electrical Engineering, Mechanical Engineering, Computer Science Engineering and Chemical Engineering. This is the first Engineering School in Chile and the second in Latin America in obtaining this recognition.

Despite this encouraging situation, the School decided two years ago, to start a deep curricular revision process. One of the triggering facts for this decision was the award of public funding (project MECEUP UCH0403, www.reing.cl), in order to develop a joint initiative with our colleagues from Universidad de Chile. Its objective in short, was to do a thorough analysis of the methodologies that are been used internationally for curricular adjustment. In a broader scope, the project would review the actual status and the kind of discussions and issues addressed in relation to curricular analysis in the rest of the World, particularly in the USA and Europe[1].

The development of this Project, which is still active, has generated a very rich mind opening process in both academic institutions. A key aspect of this process has been the visit of specialists from different prestigious universities in the USA. They have offered seminaries and workshops about issues like curricular design based on competences and skills, course program construction, methodologies for teaching – learning, new approaches for the teaching of physics, the relevance of Design in the training of an engineer, active learning, etc. Appendix 1 shows a complete list of the professionals that have visited the project so far.

Two other elements have also driven the decision towards curricular change; the first refers to self-criticism with respect to previous curricular changes in the past, the second relates to the economic situation of the country, which poses new challenges for the training of engineers[2].

In addressing the first foresaid element, analysis has lead to the recognition that curricular changes in the past have been:
- Strongly auto referent
- Lacking formal methodologies conforming to international standards
- Lacking interaction with business environment or alumni
- Seeking continuity, without a disposition to discuss and analyze deeper curricular changes.

In reviewing the economic situation of the country, it is important to state that Chile radically shifted its economic system 30 years ago, from a state oriented scheme and therefore a closed economy, to an open market economy, based on private venture and a drastic reduction of the role of the state in the economy. This change promoted a strong opening of the economy to the rest of the world, with a reduction of imports tariffs; increase of imports and of national exports. In the last years, the country has signed free trade agreements with an important number of countries and commercial zones. This strategy has generated an unprecedented growth rate of the economy (average yearly growth of 6% between 1986 and 2006). It is relevant to note that in this scheme, exports, which have experienced a significant and sustained increase in these 20 years, are principally raw materials, without further value added to them (copper, wood, fruit, fish, etc.).

Despite these accomplishments, there is consensus that the country has reached a second phase of development, which poses new challenges. One key aspect is to develop a massive capacity of innovation, for the creation of new products and processes, in order to keep competitive in the frame of global economy. A second challenge is to modify the country's elementary and high school system, which show low performance levels when compared to international standards[3].

According to the opinion of many, this last is the key factor that explains why a significant percentage of the population (approximately a 20%) is not capable of generating an income sufficient for a dignified life.

The second part of the article briefly describes the structure of the actual curriculum, which is very similar to the one in the Universidad de Chile. Being both schools the leaders in the country, the remaining universities have shown a tendency to follow these curricular designs. In this perspective, what these two schools develop in the area of curricular change will most likely generate curricular changes in all the national university system.

The third section shows in detail the curricular change methodology that is being developed. The fourth section describes the steps taken for the definition of transversal skills and program specific skills. In the fifth part, the authors comment about the actual status of the project, and finally in the last section they include their thoughts about this process, and about the results expected from it.

2. Actual curricular structure

The School is organized around 9 departments which are associated to specific fields of engineering (Mechanical and Metallurgical, Chemical and Bioprocess, Electrical, Hydraulic and Environmental, Structural and Geotechnical, Engineering and Construction Management, Computer Science, Transportation, and Industrial and Systems Engineering) and two centers (Mining Engineering, and Environmental Engineering).

All study programs have an extension of 6 years, which include two common years focused on the training in Mathematics, Physics, Chemistry and Computer Programming. After this, the students have the choice of a professional title in: Civil Engineering majoring in Structures, Construction, Hydraulics, Mining, Transportation, or Environmental engineering; Electrical Engineering; Mechanical Engineering; Computer Science Engineering; and Biotechnology Engineering. Finally they can opt for a professional title in Industrial Engineering; this last program includes a training combining management (which is delivered by the department of Industrial Engineering and Systems) and a certain technology (Electricity, Mechanics, Chemistry, Computer Science or Mining; recently there is the possibility to choose also the Hydraulics area). This last program has been particularly successful in the last decades (an average of approximately 65% of the students entering the school chooses this program) and highly valued by both the professional market and students.

Each curricular network requires the fulfillment of 570 credits or units, in which each credit corresponds to 1 hour of weekly dedication to the course during one semester (this considers lecture hours, teaching assistantships, labs and personal study). Ten credits or units in this scale correspond to approximately three units in the USA scale. Practically every course requires 10 credits, and the average workload of a student is 55 credits on any one semester.

At the end of the fourth year, students must take a written exam, which is equivalent to the Fundamentals of Engineering exam in the USA. Those who pass the exam earn the degree of "Licenciado en Ciencias de la Ingeniería". This degree does not license them for professional work, but allows them to enter directly to graduate programs (Master and Doctor). Additionally, starting their fifth year in their career, students can simultaneously continue their studies towards their professional title and enter a graduate studies program (Master or Doctor), in this process students can use their elective course requirements in order to take graduate courses with which they fulfill simultaneously their professional and their graduate program requirements. In this way, the additional requirement of the graduate program is only one additional year for a Thesis in the case of the Master's program, or two and a half years in the case of the Doctoral program.

As a final requirement for graduation, students have two choices: Take a written exam, equivalent to the Professional Engineer Exam in the USA, or develop a Professional Thesis, supervised by a full time member of the faculty. This thesis focuses in the solution of a problem of applied engineering. Alternatively it may focus in the development of a limited research work in which a full time professor is interested as tutor or guide; in this latter case it is not expected that the student shows independent research capacity, but to be able to make engineering developments that are part of a broader research project. Less than one third of the graduating students choose this alternative while the rest prefer the written exam.

The main criticisms against the actual curriculum, arising from internal seminars among faculty members, meetings with students, informal conversation with employers and alumni, are the following:
- Scarcely motivating teachings of mathematics and Physics in the early years of study, disconnected from the student's interest for Engineering. (These courses are given by the schools of Mathematics and Physics of the University)
- Unusually long curriculum[4]; the widespread opinion among students is that during the last year of study there is no substantial learning
- Strong doubts with regards to the current graduation schemes; besides, in the case of professional thesis, this can delay graduation in even one full year (which implies a real length of seven years of study)
- Criticism of the Engineering faculty related to students preparation in mathematics and physics during the first years
- Doubts about the effectiveness of the evaluation mechanisms used in courses. These appear to be heterogeneous even among courses of the same type
- Lack of formal evaluation methodologies from the professional world, of the training delivered to the students
- Passive teaching schemes centered in lectures where the teacher, not the student, is the center of activity
- Lack of conceptual models for learning processes among students.

3. General methodology for curriculum change

By the end of 2003, the actual Dean of the School Professor Hernán de Sominhiac was nominated in a very tight elections process against another very prestigious professor of the same school. The first activity of the new Dean was to devise the School's Strategic plan for the following 5 years. This plan was prepared with an innovative and highly participative methodology (all the faculty, important alumni and students actively worked in it).

This plan identified 90 projects for the improvement of the school's activities in different areas (undergraduate and graduate teaching, research, continuous training, internal administrative management, infrastructure, etc.), receiving an ample backing by the university authorities (The detailed methodology used in it, and the main features of the strategic plan will appear in a forthcoming article that is in preparation.) The plan considered a total increase in undergraduate tuition of 20% materialized in two years. This measure, fully backed by students, increased the school's income, allowing assured financing for a significant portion of the 90 projects included in the strategic plan.

Clearly, these measures, and particularly the increase in tuitions, forced to serious commitments with the student board, stating that these revenues would go to projects closely tied to their learning process. One of the decisions incorporated in the strategic plan was a thorough review of the actual curriculum. The success attained with this plan, particularly the strong backing received from the Rector of the University meant a significant political backing for the dean inside the School, much higher than the one obtained in his election as dean. This is relevant in order to understand that the process for curricular change started with a significant support by the faculty.

The methodology for curricular change originated in the following key considerations: a) to carry out a profound curricular analysis, which would include all the relevant aspects, and benefit from the international state of the art in the design of modern engineering curricula. In this perspective, it was stated that this would be a paradigmatic change and, b) to include, as an integral part of the new curriculum, all the methodologies for learning – teaching as well as the evaluation mechanisms[5].

The steps followed in the process for curricular change can be summarized as follows:

- A committee for the general coordination of the project was established, conformed by the Assistant Dean of the school (first author of this paper) and two prestigious members of the faculty. Additionally, an executive office was formed, by hiring two young engineers, recently graduated from the school and with a strong motivation for the project.
- The committee developed a curriculum construction methodology. This was based from one part, on the methodology used by the School of Engineering of the University of Arizona which is based on the QFD technique (Quality, Function, Deployment) required by ABET. From the other part, it was based on the methodology of the CDIO coalition[6], based on the concepts Conception, Design, Implement, Operate; this last methodology is briefly described in section 4 of this article.

- A program for international visiting experts was established, that addressed various issues dealing with curriculum design and methodologies for teaching, resulting in numerous seminars and workshops for full time and part time members of the faculty (see Appendix 1).
- A Committee for Competences (learning outcomes) was created, dependent from the Coordinating Committee, and was integrated by one professor of every Department and Center in the School; this committee put the curricular construction methodology to work, at the level of each specific program.
- Regular information and discussion mechanisms were created with the full time faculty members in order to monitor the advancement of the project (mainly through lunch meetings every Friday, day in which professors have no lecture work, fact that allowed ample participation of faculty members).
- In a workshop lasting a complete afternoon where all full time faculty members were invited, the actual curriculum was analyzed in all its strengths and weaknesses. In this workshop four parallel groups were formed and discussion was established based on a list of issues prepared by de Coordinating Committee. Thirty-six members of the faculty participated in this workshop representing approximately a 45% of the faculty.
- Once the Committee for Competences had advanced significantly in its job, so that the curricular change process was adequately settling in every Department and Center, another 14 committees were created focusing on the analysis and propositions in specific areas of teaching in Engineering; these were:
  - Mathematics and Physics
  - Chemistry and Biology
  - Computers Programming
  - Methodologies for teaching - Learning
  - Innovation and entrepreneurship
  - Service learning and social responsibility
  - Design
  - Graduation mechanisms
  - Undergraduate – graduate articulation
  - ABET 2000 processes
  - Financial impact of the new curriculum
  - Communication strategies for the national media
  - Professional practice
  - Transversal competences

Specific professors were nominated as leaders of these committees (one per committee) and as part of their job, they should invite other professors to join these teams. The task assigned to them was to review how their specific area of interest was handled in the actual curriculum, to review the international state of the art on how it was handled in the most prestigious universities, and to make concrete propositions to be incorporated in the new curriculum.

One month after these committees started to work, a daylong workshop took place, in which each committee presented the advancements of its task in 15 minutes followed by a 10 minutes discussion and analysis period. This workshop was attended by 75% of the faculty, attendance considered highly successful, if due account is taken of faculty members attending international conferences and other unavoidable commitments. The dynamics of the workshop was extraordinary, as was the quality of the propositions presented.

Clearly, the areas of interest of these commissions overlap to certain extent with the task of the Committee for Competences (CxC), so in the final phase of the Project all these efforts will have to be stream lined and made compatible.

4. Specific methodology for the identification of competencies – skills at the level of each engineering specialty

As it appears in the previous section, the Committee for Competences (CxC) incorporates professors of every Department and Center of the School of Engineering of the Pontificia Universidad Católica de Chile, a committee of 12 members, for which it is difficult even the coordination of meetings.

Hereinafter appear the steps followed in order to identify the skills and competences – the core of the curricular change for each engineering specialty.

a) Definition of a program mission
A mission was specified for each educational program (major) which was linked to the educational objectives and the required profile of the graduating student. The mission should clearly state the reasons for offering the program, and its consistency with the mission of the School and with the mission of the University.

b) Definition of the Educational Objectives
The Department(s) responsible for the program (coordinated by their representative in the CxC) defined a maximum of six undergraduate educational objectives for each engineering specialty, which should contribute to the fulfillment of the departmental and institutional mission. These objectives shall be evaluated (through skills and competences) therefore indicating the quality and the accomplishments of the program.

c) Definition of transversal Competences and Skills
Once the educational objectives were defined the task of skills and competences definition began. In order to accomplish this, the CDIO Syllabus was used as a base, after submitting it to modifications that incorporated the particular seal of the University. In order to define the transversal skills and competences the Coordination Committee reviewed the corresponding contents of the CDIO Syllabus and came up with a new version of the syllabus (CDIO/UC Syllabus) according to the educational objectives and the institutional mission.

d) Definition of Specific skills and competences
The skills and competences are actually being defined – the curricular renewal project is actually at this stage - for each engineering specialty at three levels: basic sciences, fundamentals and advanced knowledge. This will allow the definition and the incorporation of evaluation activities for the skills and objectives at different career levels, and the segmentation in the task of definition of skills and competences in different groups.

d.1) Skills definition at the level of Fundamentals of each specialty: In order to define the skills and competences at a specialty level it is necessary to compare: i) Competences and skills in the actual program, ii) skills and competences in prestigious international programs and iii) skills and competences standards developed by organizations and professional associations. (Special remarks deserve those found in PE and FE exams, ABET and professional organizations like ASCE, IEEE, ASME, ASEM, AICHE, etc). As skills and competences in fundamentals of an engineering specialty, all of those considered as necessary and that constitute therefore the nucleus of it will be included.

The Department or entity in charge of the program shall generate, based on all the information received, a final list with the skills and competences that are deemed the fundamentals of the specialty, and shall compare it with the international references. Finally, for each skill or competence in fundamentals of the specialty, the required knowledge of the student in mathematics, physics, chemistry and biology shall be defined, in order to attain such skill or competence.

d.2) Definition of skills and competences at the level of advanced knowledge: The former exercise shall be repeated but related to more advanced courses. The Department or entity in charge of the program will discriminate and define different lines of knowledge or sub specializations within the specialty.

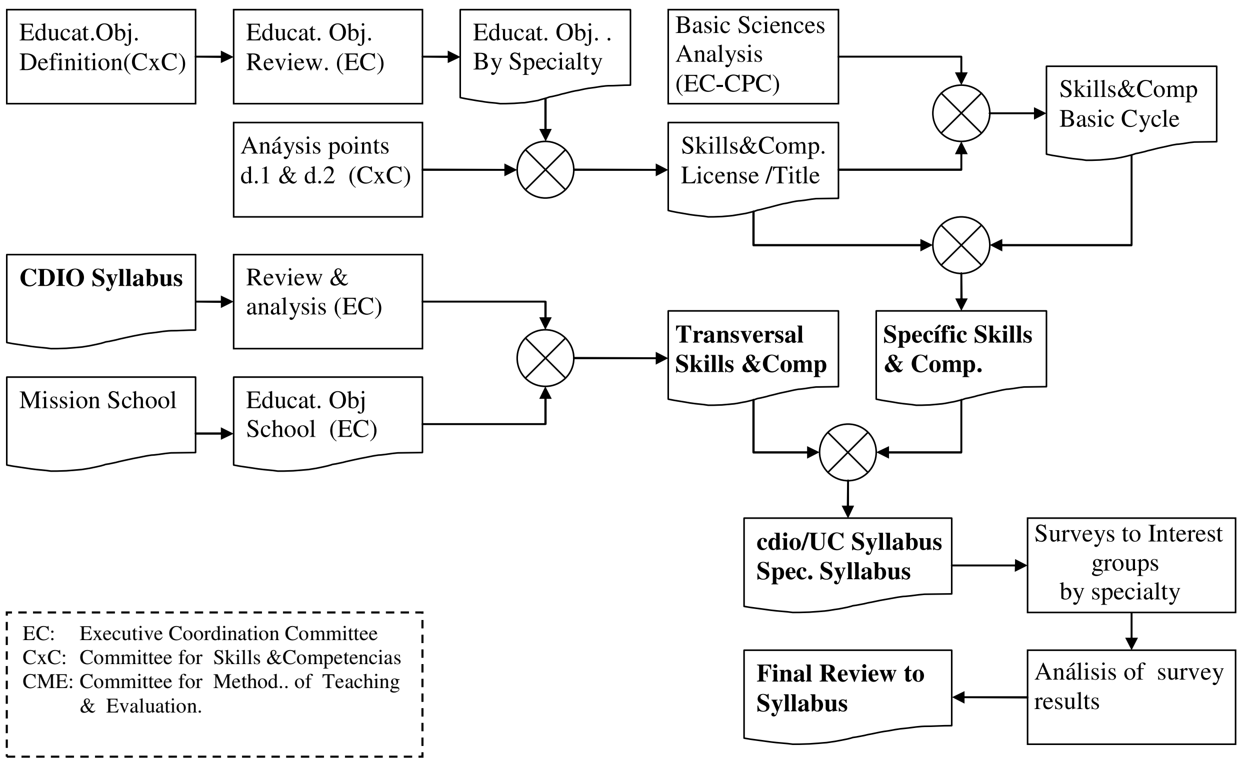
d.3) Specialty Syllabus definition: Based on the foresaid exercises a complete specialty syllabus shall be defined.

d.4) Survey to interest groups: Surveys shall be applied to faculty, students, engineers, employers, governmental agencies and professionals in order to validate the level of importance and achievement needed for each group of skills and competences. For each skill or competence, it is proposed to use the following scale of proficiency level, based on bloom's taxonomy[7]:

- Level 0: It is not necessary any proficiency in this skill or competence
- Level 1: To know (to have experience or to have been exposed to the skill or competence
- Level 2: To participate and contribute (know and discriminate situations or activities that require the skill or competence)
- Level 3: To understand and explain (ability to transmit the competence to others and train them in it)
- Level 4: To apply (capacity to put to practice or implement the knowledge or the ability in the right situation)
- Level 5: To innovate (capacity of handling and applying the skill or competence in a way that allows innovation, leadership and creation of new knowledge in the area)

d.5) Final adjustments to the Specialty Syllabus: Based on the results of the surveys by specialty, the Syllabus shall be adjusted (when necessary) and the final definition of skills and competences will be done.

The following diagram summarizes the process of determination of skills and competences (a.- to d.-).



e) Curricular matrix definition.
The curricular matrix is a tool that allows us to see in which courses certain specific competence or skill is delivered or developed. At least two matrices will be used, one for the basic cycle and other for advanced courses and graduation. The levels in which a course can contribute to each competence are three: Introduction (I), teaching (T), usage (U). In this manner, it will be possible to detect possible loopholes in the new curriculum.

In the process of curricular renovation, each matrix shall be filled with the actual courses and conditions. This will allow a clear vision of the level of fulfillment that the curriculum has, will help to modify it in order to obtain a better achievement of the wished level of competences and skills, and finally this will help to the better design of courses and activities in the new curriculum. Once the new curricular proposal is defined, the curricular matrices shall be completed again.

f) Definition of a matrix for the evaluation of competences and skills
The skills and competence evaluation matrix is a tool that allows us to know in which activities the skills and competences are being evaluated. The matrix will have all the activities developed in one axis i.e. course evaluations, laboratories, reports. The skills and competences will go in the other axis. In the intersection, information about the courses or circumstances where such evaluation activities take place shall be incorporated.

g) Definition of the evaluation activities for the educational program (continuous improvement)
In order to verify the achievements of the curriculum, it is necessary to evaluate the attainment of the educational objectives of the program. An important part of this is to check the level of learning, skills and competences achieved by the students. For this, the interest groups will be surveyed regularly in order to get from them an evaluation of the graduates in relation to their knowledge, skills and attitude. Whenever possible, they will also be surveyed regarding the perceived level of fulfillment of the objectives and other relevant issues.

5. Where we stand

Actually, the project is in the middle of its execution. From one part, transversal skills and competences, and specialty skills and competences are being defined. From the other, 15 committees are defining their final proposals for the new curriculum.

The target of this project is to have a new curriculum in every specialty of the School for the 2008 incoming generation. This means there are six months left for the final delivery of the new curriculum (until July 2007) since after that, it is necessary to fulfill all formalities required by the University in order to enact a new curriculum.

By the end of January 2007, a two-day workshop will develop at a school level, where all relevant members (faculty, students, university authorities, alumni and industry leaders) will share the results of the committees work, put forward final proposals and define for the first time a new curriculum based on specific skills and competences.

6. Conclusions and final comments

The process that the UC School of Engineering has undergone these last years, has lead to a complete revision of every aspect of its actual curriculum. It has been defined that a new curriculum is a necessity, and to fulfill this need, the three key elements of it will undergo total re-engineering: they are, curriculum, methodologies of learning – teaching and evaluation systems. In order to carry out this re-engineering process, several methodologies for curricular change have been reviewed and a new own methodology was developed, based on the state of the art.

Up to this date, it has been concluded that it is necessary to focus this change into a five-year curriculum for various reasons: 1) it is consistent with actual international standards. 2) It will bring an important social benefit to the country and to the families of the students. 3) Even more important, this is possible to achieve thanks to the new tools available (new teaching methodologies, skills based courses) which will bring more efficiency and efficacy in teaching the engineers of the opening century. The challenge assumed is double. The graduates of the School are highly regarded professionally, and recruited among the best students in Chile; the task before us is to deliver them a better education in a shorter time.

Another conclusion attained is that it is necessary to lower the elective nature of the curriculum. The actual curriculum allows for an important amount of credit of elective nature, where the student can satisfy his own interests. Nevertheless, this feature has a very high cost for the School, for the student and for society in general. It has been decided to explore with decision that the elective credits take a bigger specialization level in the curriculum (depth vs. breadth). This will be done always keeping the necessary spaces for generality, specially, at the level of fundamentals and transversal competences and skills.

7. Acknowledgements

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Appendix 1: Specialists visiting Chile

This is a list of the specialists in methodologies of teaching – learning, curricular design and evaluation that have visited Chile as well as the lectures that they delivered.

- Doris Brodeur
    - CDIO: Overview, Standards, and Processes
    - CDIO Curriculum Design
    - Course Development in Engineering Education
    - Learning Objectives
    - Active Learning
    - Assessing Student Learning
- Woody Flowers
    - On the design of creative design exercises
    - On the need for change in engineering education
- Jeff Froyd
    - Assessment and evaluation, including preparing for ABET accreditation
    - Curricular change, resistance, and leadership
    - Curriculum integration
    - Active/cooperative learning, student teams
- Carver Mead
    - Teaching in a Changing World
    - Electromagnetism and Quantum Physics as a Single Discipline