Core Curriculum and Methods in Teaching Global Product Development

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Abstract — *One of the newer roles that engineering educators must assume is that of preparing engineering students to work in an economy that is increasingly global in nature. Today's graduating engineers can expect to work for multinational organizations in their native country as well as abroad. They will work and live in milieux that have different technical norms, standards, procedures, culture, and languages than those of their native country. Furthermore, in the global economy, engineers will also work increasingly in virtual multinational teams held together by modern information technology. This creates tough challenges of handling cross-cultural exchanges with limited experiential learning opportunities. Hence, the even greater need for prior education and training. A natural educational home for teaching the necessary skills, methods, and awareness, is a design course focused on global product development. Such a course presents a richly inter-disciplinary exposure to the global engineering process and should become an integral part of the engineering curriculum. In this paper we discuss the beginnings of a consensus around what a core curriculum in global product development should contain and methods for teaching that curriculum.*

Index Terms ¾ design curriculum, design education, global design, product development

INTRODUCTION

The engineering design process, whether implicitly or explicitly employed, is central to the practice of engineering. Because of this and pressures from the global economy and ABET—and increasingly from progress in engineering design education in Europe—engineering programs in the United States have made a growing commitment to teaching design. The growing commitment means the question "What is design?" is being addressed more and more successfully. One can now see a partial consensus around a new set of ideas that are closely related to the process of product design and development employed by industry. This movement had much of its beginnings in Europe but is now very alive in the U.S. The new consensus allows us to employ a pedagogical construct that is standard in other areas of the engineering curriculum: cumulative knowledge. Our students follow curricular paths that are full of necessary prerequisites, but generally not with respect to the design curriculum. We need to identify a cumulative learning process in design. In this paper we discuss the growing consensus around what a core curriculum in global product development should contain and methods for teaching that curriculum.

The ABET definition of engineering design is "the process of devising a system, component, or process to meet desired needs." [1] The design-related requirements that ABET places on U.S. engineering programs for accreditation state that a curriculum must include most of the following features:

- development of student creativity;
- use of open-ended problems;
- development and use of modern design theory and methodology;
- formulation of design problem statements and specifications;
- consideration of alternative solutions;
- feasibility considerations;
- production processes;
- concurrent engineering design; and
- detailed system descriptions.

When providing design projects, ABET also indicates that the design experience should:

- include a variety of realistic constraints, such as economic factors, safety, reliability, aesthetics, ethics, and social impact;
- be a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills;
- be taught in section sizes that are small enough to allow interaction between teacher and student;
- be an experience that must grow with the student's development; and
- focus the student's attention on professional practice and be drawn from past course work.

There exist various models of the design process, but all have certain features in common. All design efforts involve systematic problem solving, they are cyclical and iterative, and they have a start and a finish. ABET states that "among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis,

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construction, testing, and evaluation." *Cross* [2] summarizes many different design process models available in the literature. To provide a reference point, we posit that the engineering design process may be thought of as having roughly four phases, although it is important to note that the design process is iterative, and often the engineer must return to a previous phase:

- defining the problem;
- developing concepts or solutions;
- evaluating, and choosing among, solutions; and
- implementing and communicating the design.

ACCUMULATING AND ARTICULATING DESIGN KNOWLEDGE IN THE CURRICULUM

Design has been strengthened in the engineering curriculum over the last decade. Its main functions in the curriculum are the motivation and retention of students in lower division courses, as well as the use of capstone design courses to show students applications of engineering knowledge and to prepare them for the applied and collaborative workplace most will enter on graduation.

We are interested in taking design to the next level where it has the cumulative-knowledge status of other disciplines and capstone courses can be taught based on expectations—and possibly prerequisites—of knowledge of design already attained by the students taking the course. [3] Thus, design courses should be based on cumulative knowledge and articulated with expectations and prerequisites. It is also the case that two design courses bracketing their studies are not enough to adequately treat the subject and, ideally, students should be taking a design course each year. This is particularly true when experience rather than *knowledge and* experience is the approach taken to learning design

We have come to this position based not only on the development of design knowledge over the last 5–15 years but also on the degree of consensus that has emerged over the same time frame. This is the first such consensus and, not surprisingly, it has taken place around a trans-disciplinary approach to design. Heretofore, design was largely idiosyncratic with each exponent providing his or her views. The main exception, *Pahl and Beitz* [4]—which is used largely in Europe—is rather abstract and perhaps difficult to use in the classroom (although the second edition is much better than the first in this regard). *Cross* [2] has produced texts that are much easier to use in the classroom. The new view, focused on the best industrial practices, is well represented by *Ulrich and Eppinger* [5] and *Otto and Wood* [6]. Some other texts, which follow the new paradigm in varying degrees, include *Dieter* [7] and *Pugh* [8]. *Pahl and Beitz* and, later, *Cross* were early pioneers in the 1980s of a trans-disciplinary approach to design. *Ulrich and Eppinger* were very effective in reaching audiences in the United States with the first edition of their book in 1995.

The new consensus in design is paying more attention to problem development and customers needs, project management and the development process leading to and including aspects of manufacturing, concept generation, objectives trees, and selection processes; technology assessment (tradeoffs), prototype development and testing; designing for manufacturing and industrial design; and production economics. There is also an implicit assumption about skill development in such areas as CAD and graphics, tolerances, and generating and analyzing data. There has been a tendency to reduce design to (consumer) product design that will need corrective action at some point to include services, systems, life cycle assessment and social impact, and public sector engineering, among other topics of design.

The context of engineering design and development is becoming global in nature. The process of economic and cultural globalization has continued to the point where it now must be a focal point for training engineers for the future. Students need to be aware of the changing nature and scope of the global economy; emerging patterns of corporate structure in the global economy including the use of the 24-hour world clock in performing design and manufacturing tasks in all time zones; the regulatory environment and the intersection between national and international practices and standards in engineering; global technological diversity; new environmental methodologies such as life-cycle assessment; cultural and language differences; the role of cultural and national diversity in product design and development; and cross-cultural issues in the management of technology in the global economy. Not only are these complex subjects they are also dynamic subjects and we need to prepare students with tools for rapid adaptation and learning in cross-cultural milieux.

Other issues that need to be addressed, but which fall outside the new approach to design, are those covered by some of the ABET requirements concerning the ethical, social, environmental, and business environments of the global economy. For example, ABET requires that to be accredited, schools of engineering must provide engineering students with "the broad education necessary to understand the impact of engineering solutions in a global and societal context." (ABET 2000, 3(h)). [1] Students should study the corporate and stakeholder environments of product design and development; social and environmental impact; and diversity in approaches to users, customers and markets.

CURRICULUM FOR GLOBAL PRODUCT DEVELOPMENT

Engineering Design Curriculum

Presently, many engineering programs in the U.S. have two courses containing the primary engineering design content, these being a first or sophomore year introductory engineering design course and a senior capstone design class. In most programs, however, the capstone design class is not based on assumptions about the level of knowledge of the design process that incoming students have. Design currently does not have the cumulative-knowledge status of other disciplines; hence, capstone courses cannot be taught based on design knowledge prerequisites. Thus, design courses throughout the curriculum should be based on cumulative knowledge and articulated with expectations and prerequisites.

How broad-based the new approach is may be open to some debate and something we will address in a future article. We know that Penn State faculty in Mechanical Engineering, Industrial Engineering, Electrical Engineering, Engineering Entrepreneurship, and the first-year design course have all independently chosen to use *Ulrich and Eppinger* or significant portions of it. Faculty in Industrial Engineering at Arizona State University also use this text, and the same approach, using *Pahl and Beitz*, is used in Mechanical Engineering at the University of Leeds in the UK. We believe the basic tenets of the approach have very broad applications in engineering and we hope to discuss this in the future. In this article we certainly assume that this new approach has broken the mold of discipline-based design—which will still continue, of course, and should be enriched by the new paradigm.

Having a first-year or introductory design experience and then a capstone senior course in design raises several obvious issues. We may establish competencies that are learned in the first year design course as desirable and known for entry into the senior course. However, as two or more years go by, retention of knowledge learned will not be high. As a result, capstone design courses are often taught as standalone pre-professional courses that owe little if anything to the entry-level course. This is a result of lack of retention and no accumulation. Even if cumulative, two courses cannot cover all, or even enough, aspects of design anymore. Perhaps we do not need to require more courses of all students but all those entering a career of design should have far more than these two courses. To be fair, there are some other specialized courses in design as well as other courses that are very relevant to design. But in terms of a trans-disciplinary approach dealing with the advances of the last decade or so, there is very little in the middle years. Indeed, if even some students who were interested in design took one or two courses in the middle years, one can speculate that the availability of these courses would make a marked impact on the capstone courses and provide a natural cohort of team leaders. The performance in capstone design courses of students who have only had a "motivational" design course in their first or second year are frequently criticized for lacking basic design skills.

Global Product Design

One area in which an intermediate course would be of great value would be in product design and development. Preferably, such a course would be set in the global economy and also serve as preparation for what is an increasingly important source of the best jobs. Using information technology, it is very easy to form (but perhaps not necessarily operate) cross-national student teams and to use faculty in other countries to give lectures and lead discussions. We have done this in one course for the last five years, usually in a bi-lingual mode, and we are planning expansion to multi-point teams. [10] In this course, half of the industry design projects come from industries in France, and on one occasion we were able to have an audio–visual (AV) conference between the French and American students and a representative of the French industry. The Spring 2002 semester, students at Penn State and Leeds were involved in point-to-point cross-national a design project experience. [11] In providing these experiences we can enhance the knowledge of the participating students of the global economy and of engineering practice in other national economies. We can also improve the ability of the students to work with people in other countries and with people from other cultures.

Under global product design and development, a wide array of topics may be covered including the corporate and stakeholder environments of product design and development; diversity in approaches to users, customers and markets; concept generation, trees, and selection processes; technology assessment (tradeoffs), including social and environmental life cycle assessment; prototype development and testing; designing for manufacturing and industrial design; production economics; and project management. National and international standards, design ethics, teamwork, conflict resolution, cross-cultural awareness, and human resource development should also be studied.

To address the subject of globalization we are developing web resources and expanding the use of cross-national design projects. We will use AV conferencing for lectures and discussions for studying the following topics: the changing nature and scope of the global economy; emerging patterns of corporate structure in the global economy including the use of the 24-hour world clock in performing design and manufacturing tasks in all time zones; the regulatory environment and the intersection between national and international practices and standards in engineering; global technological diversity; new environmental methodologies such as life cycle assessment; cultural and language differences; the role of cultural and national diversity in product design and development; and cross cultural issues in the management of technology in the global economy.

STRUCTURING CROSS-NATIONAL STUDENT DESIGN TEAMS

Jenkinson, et al. [12] suggest four methods of structuring international collaborations: discussions of case studies, "show and tell" exchanges, parallel teams, and integrated teams. We think they oversimplify the possibilities and would rather identify six key dimensions for constructing cross-national teams. For each there are two or three possible modes.

Node frequency: (1) bi-nodal, (2) tri-nodal, or (3) more

Relationship type: (1) collaborative (continuous, inter-dependent, integrated), (2) competitive: inter-corporate (multi-national teams) or international (national teams), (3) cooperative (occasional sharing): show and tell, or parallel

Status relations: (1) equal partners, (2) "sub-contracting" mode

Languages: (1) mono-lingual, (2) multi-lingual

Curricular structure: (1) in class (multiple teams), (2) out of class (single teams)

Duration: (1) expository, (2) short term, (3) long term, (4) indefinite.

These variables imply a large number of combinatorial possibilities. We will need to do some research to answer the question: What are the objectives in education and industry for such teams and which modes are most attractive for attaining them?

Discussion

There are several different uses of information technology for internationalizing the engineering curriculum. These include lectures and discussions by and with engineers, faculty, and students around the world and also by forming multinational teams, as we discuss in this article. Variations in modes for running multinational student design teams include whether or not there are multiple teams formed within a regular class [10,11] or whether a single team is formed outside of the usual class setting [13]. The latter is likely to be long duration and the in-class setting is likely to be short duration. Another variation is how many countries are involved, that is, whether the collaboration and communication is point-to-point or multi-point. [14]

The "sub-contracting" model is where one national group does a specific part of the project while another has the overall responsibility. This works well when the subcontracting group can only work for less than the full time of the project. For example, the project may be for two semesters at one university, while the students at the other university can only work for one of those semesters. However, this mode may be attractive for other reasons such as students who have less time even on a weekly basis, or who perhaps are more junior.

Another variable is whether the teams are bi-national or multi-national. Communications can multi-point in the latter case, which will add to the complexity of logistics. However, they may also work sequentially and have a hand-off mode in a 24-hour clock mode where the design is, in principle, continuous. In an academic setting, this might be simulated or done once or twice on a trial basis, but it is not likely to be practiced throughout a semester because of the demands from other courses.

It also may be that parallel teams could be explicitly in competition with each other. Even though competition in the global economy is increasingly inter-corporate, international competition is still a factor. Certainly, even within integrated international teams the sentiment that "our ideas are better than their ideas" still appears in student discourse quite frequently.

We do not yet know enough about the objectives of such teams in education and industry and which modes are the most attractive for attaining them. Some clusters of choices will emerge over time, and different choices will be made when piloting the use of such teams than later when the same partners have had some experience with each other. Some may choose to begin with a few cooperative experiences based on discussions and sharing of ideas. The reason for this is that logistics have always been the biggest difficulty in doing such projects. The logistics begin with establishing the cross-national relationships among faculty, sharing the various calendar constraints, establishing academic objectives that work for everyone, choosing days and times for the real-time interactions, and finding access to the necessary information technology at those times.

While the experience of participating in such teams is very important, there are key learning opportunities that must be used well.

- The interactions must involve efficient use of the time and of the software tools available. Good communication is a goal that must continuously drive the normative assessments.
- There are good curricula methods available to facilitate cross-cultural learning and this subject should be explicitly and well addressed.
- Good project management becomes even more desirable when virtual teams are used. There must be clear project role and task assignments, shared project timelines, and plentiful well organized archives of clearly dated materials that are on-line resources for all the participants.

Valuing *Virtual* Global Teams

We need to use information technology as a cost-effective way to globalize the curriculum and to provide students with international experiences without the cost in time and money of overseas study and work experiences. Information technology may be used in a variety of ways to bring the world into the classroom. The most potent ways of doing this is to use real-time experiences in cross-national formats such as discussions and teams. In this way, potentially all students could have such virtual experiences in the global economy. Actual travel-based experiences will probably never be possible for even a half of the engineering undergraduate student body at most schools (10% is a more realistic figure). However, virtual experiences are expected to raise the interest levels and participation rates for overseas study and work opportunities.

Virtual teams have been made possible by information technology. They have been made attractive by the comparative advantage offered of deploying the best human resources without the need to assemble them all in one place. The use of virtual teams increasingly characterizes the modern engineering workplace, and such teams can, and do, cross national boundaries as corporations seek to optimize their global resources and to run their design and development operations on a 24-hour clock.

Diversity created by international teams may, if mishandled, lead to conflicts and miscommunications. However, diversity in a team may also be used to advantage to get more views, ideas, and information to enrich the design process. For global product design and development, the use of global teams also allows for customer needs assessment to be done in more than one country and for local resources and constraints to be taken into account. We posit that global teams provide an enrichment process in terms of the design outcomes and the marketability and utility of the product. Through virtual global teams, students can thus be introduced to international experiences, global resources, the virtual teams of the contemporary workplace, and the software tools that make them function.

PRESTIGE CONSORTIUM

The PRESTIGE (Preparing Engineering Students to work In the Global Economy) Consortium has three U.S. universities: Penn State University (lead U.S. institution), Arizona State University, and the University of Washington. In Europe it includes the University of Leeds (lead EC institution), École Centrale de Lyon and the IUT of the University of Artois in France, and Tecnun, the technical campus of the University of Navarra in San Sebastian, Spain. At Penn State the participants are in the School for Engineering Design and Professional Programs and IE and ME.

PRESTIGE is focused on global product design and development. It will develop web-based modules, run cross-national teams, and fund student travel for study and work. The materials will be developed in three languages, English, French, and Spanish. The cost of running cross-national teams goes from nothing to a few thousand dollars per class as compared to a few thousand per student studying or traveling abroad. Since PRESTIGE funds both we will be able to compare their relative costs and benefits.

It is proposed that the expansion of the use of virtual cross-national teams begin with these seven partners who are dedicated to doing such teams. This takes us past the first and major logistic barrier of creating the relationships to carry out such projects. Moreover, PRESTIGE plans include multi-point as well as point-to-point teams and both in-class and out-of-class teams. We will have a rich opportunity to assess different strategies to preparing students for the global economy.

SUMMARY

As engineering educators, we must prepare engineering students to work in an economy that is increasingly global in nature. As global-economy engineers they will also need to be prepared to work in virtual multinational teams held together by modern information technology. This creates tough challenges of handling cross-cultural exchanges with limited experiential learning opportunities. Hence, there is a large need for prior education and training.

A natural educational home for teaching the necessary skills required, methods used, and awareness needed, is a design course focused on global product development. This type of course presents a richly interdisciplinary exposure to the global engineering process and as such must become an integral part of the engineering curriculum.

The recently formed PRESTIGE Consortium of universities in the U.S. and Europe is focused on global product design and development. It will develop curricular materials and web-based modules, run cross-national teams, and fund student travel for study and work. The materials will be developed in three languages, English, French, and Spanish.

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