A "Basis Set" for Multidisciplinary Design Courses

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Abstract

We describe a variety of multidisciplinary design course formats developed and installed during the lifetime of the NSF–sponsored SUCCEED engineering education consortium. These formats provide design approaches to meeting the ABET/EC 2000 criterion mandating that all graduating students will have "a multidisciplinary experience" during their undergraduate careers in engineering.

In an earlier conference on these design courses, we noted that no consensus format existed within a group of nine courses on seven of the SUCCEED campuses(1). The intent of the present paper is to celebrate this diversity of design course formats by creating from them a "basis" set", as in algebra, from which complete, yet unique, multidisciplinary design courses may be easily constructed, as appropriate for each local setting.

A second dimension considered is the existing or modified administrative requirements of institution and engineering school. To enhance prospects for multidisciplinary course creation, each college should provide the following circumstances: parallel scheduling of design courses to encourage collaboration between departments, utilization of all available manpower for introducing multidisciplinary instruction, including faculty, local professional societies, and even graduate students, administrative salary support where annual funding is raised for design projects.

Introduction

We describe a variety of multidisciplinary design course formats developed and installed during the lifetime of the NSF–sponsored SUCCEED engineering education consortium. These formats provide design approaches to meeting the ABET/EC 2000 criterion mandating that all graduating students will have "a multidisciplinary experience" during their undergraduate careers in engineering.

In an earlier conference on these design courses, we noted that no consensus format existed within a group of nine courses on seven of the SUCCEED campuses(1).

Indeed, the ABET/EC 2000 criteria themselves may work against consensus, in the sense that individual engineering schools were invited to write their own mission statements, then departments within the schools did the same, etc, so that the new criteria encouraged diversity rather than conformity.

The present article takes the demonstrated diversity of multi-disciplinary design formats as an advantage. In particular, these various successful formats show that each of the dimensions typically present in a design course may be executed in any of several ways, thus providing an opportunity for interested faculty to inject multi-disciplinary design in new formats, individually tailored to the mission of each department and school. The intent of the present paper is to celebrate the diversity of design course formats by creating from them a "basis" set", as in algebra, from which complete, yet unique, multidisciplinary design courses may be constructed, as appropriate for each local setting.

This approach has been well received. The author has presented in the last three years more than 40 invited faculty workshops and seminars at various US engineering campuses and professional societies. These workshops have reviewed the SUCCEED "best practices and lessons learned", and involved local faculty in role playing exercises in order to create new versions suitable for local piloting and installation. The positive receipt of such workshops encourages the present summative article on this approach to creation and piloting of multidisciplinary design courses and projects.

A second dimension of course creation is also considered, namely, creation consistent with the existing or modified administrative requirements of institution and engineering school. In particular, it was found desirable that each college provide an atmosphere conducive to supporting such design experiences via arranging for the following circumstances:

(1) The scheduling of courses must provide "curricular transparency" wherein the ability of faculty to propose collaboration across departmental lines not be hindered by institutional restraints such as incompatible scheduling of design course hours and credits for departmental design courses.

(2) Utilization of available manpower for instruction, including faculty, local professional societies, and even graduate students, be allowed and encouraged so as to avoid the potential to "double" faculty design teaching time simply by requiring simultaneous participation of at least two disciplines.

(3) Arrangement for salary support for those design formats which require annual recruiting of funding from industry or other outside sources.

Formats for multidisciplinary design

In the following paragraphs, we summarize the central features of nine different formats for execution of multi-disciplinary design. These formats are not presented as cast in stone. Rather, we first summarize the formats demonstrated. Then we extract the key elements, and create a basis set of choices for each key element which may be useful for those faculty contemplating creation of new responses yet to the ongoing requirement of "multidisciplinary experiences" for all engineering undergraduates.

These formats appear by name in Table 1, and are briefly summarized in the following paragraphs. From their characteristics, we will deduce the key elements and create a "basis set" for choosing among the possibilities for each key element (Table 2, later). A final table will present recommendations for administrative support needed for the various formats. Thus, Table 2 is for faculty, and Table 3 for deans and department heads.

Table 1

Formats for Multidisciplinary Design

Format	Institution
Integrated Product and Process Design	University of Florida
Engineering Entrepreneurs	NC State University
Multi-University Design Teams	Clemson (UNC-Charlotte, Univ. South Carolina, Georgia Tech)
Virtual Corporation	Virginia Tech
Quality Improvement Partnership	NC State University
Cross-Disciplinary Education	Clemson University
Multidisciplinary Design in a Global Environment	Virginia Tech
Cross-college Collaboration Laboratory in Engineering and Art and Design	Virginia Tech.

Integrated product and process design (IPPD)

In 1995, the University of Florida instituted an industry sponsored, one year design course which involved three resources per project: a design challenge from an industry sponsor, with industrial liaison engineer available for a finite weekly time (e.g., 2-4 hours), and project funding of $15,000. Each project included a contract for deliverables, namely, a first semester with "product specifications, concept generation and evaluation, a preliminary design report, a project plan, and an analytical and experiment plan and report, and a final report and project documentation". The subsequent semester allowed time for prototype realization, with an end-of-term demonstration to the industrial sponsor, to include "a systems level design report, prototype results and report, a production sample, and an acceptance test. This course, initiated in the mid-nineties, has grown to a steady state level of about 25-30 faculty and projects, and 125-150 seniors each year. A typical team consists of six seniors, and virtually all engineering disciplines at Florida have now been represented. (2,3).

This format is the only SUCCEED example requiring substantial external funding per project. Its successful installation at Florida, and the formation of a Mutidisciplinary Design Clinic at Florida State-Florida Agricultural and Mechanical University (FSU/FAMU) in similar format, required creation of an administrative post, occupied by a faculty member charged with organizing and effecting the annual drive for project solicitation and fundraising. Establishment of such adminstrative support for MD Design is found critical to the maintenance of this format. The occupant is a tenured member of the engineering faculty in both instances. A similar circumstance exists at the Univ. of Akron .

Engineering entrepreneurs

Begun in 1994, and continuing today, an engineering entrepreneurs course was created centered upon the formation of new companies and products. The course is organized in a seminar style with the weekly theme of small company management, venture capital provision, intellectual property protection, etc., serving as the focus through both weekly faculty-led discussions and an outside speaker seminar. Course enrollment has been almost entirely engineers. Student teams must organize their own semester calendar to produce written reports (progress) as well as oral reports; these are the basis for grades, as no exams are given. The inclusion of speakers from the start-up world provides not only factual information but also illustration of the local heroes of such enterprises(4).

Vertical integration allows inclusion of sophomores and juniors in this senior-led format. These earlier undergraduates agree to contracts (for modest team tasks) with the seniors, who in turn are responsible to faculty advisors. This "vertical integration" thus provides for pre-viewing of senior activity and responsibility, as well as giving earlier introduction to the breadth and open style typical in the start-up world(4).

Design, build, and fly

At Georgia Tech, a vertically integrated, multidisciplinary student team is led by a graduate student in the Masters program in Aeronautical Engineering. This team is a participant in the annual challenge of AIAA (American Institute of Aeronautics and Astronautics) for a design, build, and fly activity (5,6). The teams are large, typically 10-20 students, and have involved a multiplicity of disciplines including aeronautical, mechanical, industrial and electrical engineering. The basis for grades and evaluations are three: "individual participation, written and oral reports, and device aerial performance in a competition set out by AIAA annual specifications."

The graduate student activity leads to academic credit towards the MS degree. In this MS program, five courses are required (concurrent engineering, life cycle costs, multidisciplinary design optimization, and a pair of aerospace system design courses. Undergraduates at all levels are again involved via vertical integration. The performance craft are also stars during a spring high school recruiting for Georgia Tech, thereby providing a satisfying showcase for local consumption as well as the AIAA events.

In this instance, multiple teams address the same, annual AIAA challenge. The course heavily emphasizes concurrent engineering, wherein parallel design approaches (design for manufacturability, design for quality, design for maintenance, etc." are considered. This well established course has now been offered for more than a decade.

Multi-university collaboration

The Savannah River Project in South Carolina is a very large client, easily able to provide annually a host of design problems suitable for senior engineering design courses. These center upon nuclear power, nuclear safety and associated environmental remediation challenges. (7). Each year, a project list was created and presented to a four campus alliance, administered at Clemson University, and including partner institutions the University of South Carolina, UNC-Charlotte, South Carolina State University, and Georgia Tech. The faculty and student team membership was drawn from all campuses, thereby requiring a local communication network allowing frequent face-to-face conferencing via a high speed video line and data lines. In 1998, this program included eight faculty and 200 students; thus it was shown scalable to involve a considerable student population. As with the previous IPPD example, the Savannah River sponsor provides project descriptions at the outset, as well as project liaison engineers and on-site visits, culminating in a final presentation to the sponsor audience. Once again, a substantial management commitment is required, to allow for annual call for projects, and to schedule and maintain the intercampus communications hardware and activities(7).

Virtual corporations

At Virginia Tech, an annual multidisciplinary design opportunity was created and has been offered since 1997. The continuing structure which enables this activity is existence of two standing virtual companies. The Personal Rapid Transit Systems (PERTS) and the Distributed Information Systems Corporations (DISC) each execute an annual design project with multiple departmental involvement. The PERTS students are drawn from electrical, mechanical, civil and industrial engineers; and the DISC corporation includes the disciplines of chemical engineering, computer science, electrical and industrial engineering, along with related fields such as biochemical sciences. Business and other majors may also participate, as appropriate. More than 25 disciplines have now been involved. The structure is that of a corporation, with the important engineering posts manned by seniors, but juniors and sophomores also participate, to provide again a vertically integrated experience for the students Again, multi-year involvement is possible. Between the two corporations, involvement of all Virginia Tech engineering disciplines is possible.

Summer internships

Begun in 1991, the NCSU College of Textiles, led by Prof. John Rust, sponsors a programs involving a team of 10-15 students who pass an entire design summer on-site at a major manufacturing facility (9). Example past participants have included Milliken Industries and Burlington Industries (textiles) as well as Northern Telecom (telecommunications). As with IPPD, the industry sponsor creates the problem description, provides on-site information, as well as liaison. Further, the sponsor also supports summer salaries for students and faculty. The "team-in-residence" stays at or near the manufacturing site. Over the summer visit, the team is expected to provide a substantial design response for alteration/optimization of an existing product line. In advance of this on-site experience, all students enroll in a spring course in Quality Improvement Processes, thereby receiving training in those aspects of professional development which are key to team play and management.

This activity has included multiple campuses, with NC State, Virginia Tech, UNC-Charlotte, and Clemson University all providing students at one time or another. A direct cost example with one Milliken summer team was about $50,000, where the experiment resulted in recommendations which saved over $1.2 million annually. This example illustrates how one successful team might provide financial "cover" for several others.

Local design

Professor Joel Greenstein of Clemson University's Civil Engineering department created an early design experience for sophomores, which was available to all engineering disciplines. The source of design challenges was the Campus Planning and Architecture department, responsible for repair and maintenance of campus facilities (10). This on-site university office provided a continuing stream of projects, and importantly, also continual availability of consultants for the ongoing annual projects. The project multi-disciplinarity was thus created with minimal added cost to engineering school. Project outcomes have occasionally been accepted and altered by the Planning and Architecture office, then implemented appropriately, at times before the contributing "sophomores" had graduated. As all campuses have such facilities architecture and planning offices, this under-used resource for design would appear to provide a natural multidisciplinary partner for engineering design teams. Similarly, the central power plant for campuses has an on-site office which may provide annual projects for senior design teams. In both instances, the ability of a student to "give back" to his/her campus some educational fruits of labor would appear to be a satisfying approach to creating appreciated and loyal alumni.

International teams

An aeronautical professor, James Marchman, at Virginia Tech, has organized and led bi-national design teams (11) Here, in a one semester effort, student teams allied with students from another, foreign institution, to create a design activity involving weeklong visits at each campus, as well as continuing email communication. To date, collaborative design efforts have included engineering institutions in Toulouse (France), Loughborough (England), and Japan, the latter funded by Boeing.

Combining design courses via cross-college collaboration

Richard Goff, Professor of the First Year Engineering Program at Virginia Tech, formed an alliance with the VT College of Art and Design (12). Here, Goff's first year engineering lab (activities included LEGO kits, and design/assembly challenges) partnered with the first course in Industrial Design, to annually involve nearly 600 students in a massive studio space. Each design team received its own semester long desk space in the large 100 desk studio of the Art and Design College. Bi-disciplinary teams respond to product design and realization challenges via consideration of "design for performance" (engineering) and "design for aesthetics and culture"(art and design).

An intriguing feature of this effort is the early provision of a bi-disciplinary experience via the simple combination of two existing courses. Here, an example of a no-added costs approach. Clearly, the integration of the course materials and contents required true partnering, wherein each faculty participant retained key elements of disciplinary character, while surrendering some time to allow for course integration to occur.

Multiple design formats: A "basis set" construction

The variety of formats indicates the creative potential of faculty, as well as the administrative anarchy which could follow an arbitrary course structure. We take the variety presented, and turn potential anarchy into clear-cut organization. In particular, we first decompose the Table 1 course formats into basic elements. Subsequently, the serial consideration of these elements will guide faculty at other campuses during construction of multidisciplinary design courses of their own, complete with respect to basic elements, yet distinctive with respect to faculty preferences and strengths, as well as institutional character and engineering school mission statements.

This decomposition includes the dimensions of problem source, financial support required, collaborating instructional staff, types of disciplinary integration, length of project or course, and team size. Our summary basis set analysis is presented in Table 2.

An additional degree of freedom is available from this table. In particular, a 1998 survey of these courses indicated that even the most successful enrolled only about 15% of all engineering students. Thus, no single format appeared capable of providing a school-wide response to the need for a multidisciplinary experience through design. Accordingly, within each engineering school, the availability of multiple formats for course design and project execution would seem to provide a more durable, and flexible academic approach to creating a locally sustainable experience in multidisciplinary design.

Table 2
Basis Set for Multidisciplinary Courses

1. Project source
   Industry client
   Government client
   Professional society
   Non-profit agency
   Civic planning group
   Campus planning and architecture
   Campus power plant

2. Financial support
   Industry sponsor
   Academic lab (instrumentation, analysis)
   Alumni donations (engineering entrepreneurs)
   Academic office of dean or department head

3. Collaborators
   Industrial liaison
   Planning office liaison
   Professional society chapter
   Other faculty
   Graduate student team leader

4. Disciplinary integration
   Horizontal (required of multi-disciplinary design)
   Seniors only
   Seniors plus earlier undergraduates
   Grad students as well as undergraduates

5. Course length
   Semester
   Year (two semester)
   Summer
   Summer + semester

6. Team size
   Few (small projects; engineering entrepreneurs ; seniors only teams)
   Many (design, build fly; large summer internships; virtual corporations; extensive vertical integrations).

A note of financial importance is the variety of collaborators available with in the local community of "town, gown, and society". Graduate students, local government, professional engineering and technical societies, and non-profit civic groups all have the potential, and self-interest, to be involved in such multi-disciplinary design teams. In these examples, provision of additional disciplines comes at no additional financial costs to the engineering school, although additional organizational times is certainly required in all cases, to maintain communication, recruit annual participants and projects. This manpower resource area appears to be one of the most under-utilized in academia.

Given these examples, spreading the word is not difficult, as has been demonstrated with in the SUCCEED organization, and beyond. Following the 1998 conference reporting out on these 9 experiences, a “Call for Proposal” was issued within the SUCCEED consortium and resulted in two successive years of funding $8-10K mini-grants to initiate 18 new MD Design courses.

Reflections on encouraging faculty collaborations

The initiation of a new course is always a challenge. Choosing among the multiple possible design formats presented here would spear perhaps even more challenging. The author has found the following exercise to be a useful academic icebreaker with both local faculty and administrators during his visits at various schools to present Multidisciplinary Design workshops:

1-Match faculty up in teams, with no discipline represented more than once on each team.

2-Ask each team to choose a particular format.

3-Ask the team members to outline a design project consistent with the multidisciplinary design format chosen

4-Repeat the exercise for two other formats of their choice.

These first passes at outlining collaborations show the faculty that a project can be invented for almost any format. The creation of two page outlines on paper, which are then passed on to the department heads and associate deans will illustrate to administration how faculty can productively collaborate. Administrators invariably can find enthusiasm for activities for which the faculty themselves appear as leaders, albeit not without simultaneous consideration of costs for such a design course. The conversations regarding formats to choose should take place with faculty and administration both present.

Institutional issues

Four items require administrative attention in order to allow broad inclusion of new multidisciplinary course and project possibilities: industry-academia co-ordination, curricular transparency, innovation rewards, and college leadership. These are described briefly in Table 3 below.

Table 3

Administrative Arrangements Conducive to Cross-Disciplinary Collaboration

Industry-academia co-ordination: Successful programs require provision of half-time)FSU/FAMU) or full time (U. Florida) administration to provide consistent representation of academia to industry, annual recruitment of projects and funding, and formation and scheduling of design teams.

Curricular transparency: Deans and departments must schedule design courses in a coordinated fashion, to allow facile year-by-year collaborations to form and dissolve, without need for substantial administrative efforts in each case.

Innovation rewards: faculty participants should be rewarded for taking risks in establishing approaches to multidisciplinary design courses and projects.

College leadership: No single department head can command participation of faculty from other disciplines, yet the ABET/EC 2000 requirement of a multidisciplinary experience exists. Only the dean's office can provide the needed all-college leadership to make the responses to the first three items accessible to all faculty and students.

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