Northern Arizona University’s "Design4Practice" Sequence: Interdisciplinary Training in Engineering Design for the Global Era

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Abstract
Introduction of computer technology, changing corporate structures, and global competition have significantly changed modern corporate design contents, placing increasing emphasis on individual problem-solving creativity, interdisciplinary collaboration, and teaming and project management skills. NAU’s Design4Practice program explicitly teaches these skills within a novel curriculum centered around a carefully crafted sequence of project-oriented courses. This paper discusses our efforts to extend the program to provide international training opportunities, including integration of the Design4Practice curriculum with that of partner institutions abroad, support for joint projects, and international teaming in interdisciplinary project-oriented courses.

1.0 Introduction
A characteristic feature of economic change in the last decade has been the growing trend towards globalization. Through mergers with foreign partners or expansion into foreign markets, many large companies have developed subsidiaries spread across national, cultural, and linguistic borders. As a result, design and development initiatives often involve teams or team members separated by time, distance, and culture. An increasingly common practice in software development, for example, is to spread development of a project between subsidiaries in, say, San Francisco and Frankfurt; the time difference between the two allows the project to move forward non-stop, 24 hours a day. Working in such international teams raises two distinct challenges:

Coordination over distance. Coordination of work within distributed teams is extremely challenging, particularly in highly interdependent projects (Dourish and Bellotti 1992; Rogers 1993). Success in distributed teams requires team members to become proficient with sophisticated software tools (known as groupware) and to learn how best to apply them to support the collaborative needs of the team. For example, a team might rely on video-conferencing software to discuss project details, a shared drawing tool to jointly critique a design document, and a private group web page to archive shared resources.

Cultural Differences. A growing body of work indicates that cultural and social differences within work groups (whether distributed or co-located) play an enormous role in determining team dynamics, i.e., whether or not a team “comes together” into a cohesive and productive team entity (Vick 1998). In many cases, minor cultural misunderstandings can create serious rifts in cross-cultural teams. For example, European work schedules are commonly more flexible than those in the USA, e.g., a longer midday break followed by work later into the evening. Americans unaware of this difference might perceive continual noontime absence as “laziness”; team morale will suffer accordingly. Similarly, differences in linguistic idioms, social codes,
and modes of expression can easily lead to misinterpretation of the tone or intent of a communication between team members from different backgrounds. Social and cultural issues such as these may ultimately be far more important than technological issues in determining the success of cross-cultural teams.

We are convinced that corporate globalization and, as a direct consequence, increased emphasis on international teaming represent major themes in workforce development in the next decade; international training and experience is already a significant feature in the hiring and promotion policies of global corporations. Consequently, participating in the new global economy will require engineers to possess - in addition to traditional discipline-specific technical skills - a new set of social and technological skills to enable them to work effectively in distributed, cross-cultural contexts.

In the following sections, we first give a brief review of our interdisciplinary, practice-oriented training curriculum, the Design4Practice program, which was developed to reconnect engineering training and education with the realities and evolving challenges of real world engineering practice. In section 3, we describe our efforts to extend this program to integrate opportunities for international training and distributed teaming into the Design4Practice curriculum. Section 4 closes the paper with discussion of lessons learned and plans for future development of our international initiative.

2.0 Background: The Design4Practice Program

To address the challenges surrounding the teaching of real-world design skills, Northern Arizona University’s College of Engineering and Technology (CET) has developed a four-year interdisciplinary sequence of classes called Design4Practice (Hatfield, Collier et al. 1995; Collier, Hatfield et al. 1996; Howell, Harrington et al. 1996; Larson 1999). This practice-oriented engineering curriculum, crafted with extensive input from industry, is designed to provide students with hands-on learning experiences and continuous practice of a broad set of professional skills in order to better prepare them for careers as engineering practitioners.

Unique features of the program include:
- Cross-disciplinary collaboration in sequenced courses.
- Cooperative teaching and learning teams.
- The active participation of industry executives and engineers through teaching, program evaluation and project sponsorships.
- A required core for all engineering students incorporating the complete design cycle within industry simulated product development environments.

The strategy behind the Design4Practice sequence is straightforward: to introduce the students to the design process early in their college careers, and maintain a constant rate of increasing complexity throughout the four years of study. By graduation, the students are well versed in the design process and hence have a greater ability to successfully contribute in their first professional employment. The Design4Practice program has been successful in reaching the objectives mentioned above, enhancing our students’ ability to contribute and succeed in industry immediately upon graduation.
Focus on interdisciplinary design

Focus on team skills and project management

- Small design projects
- Problem solving and modeling
- Ethics and professionalism
- Communication and teaming
- Planning for success

- Cross-disciplinary teaming
- Large and small teaming
- Sequential design
- Economics
- Documentation and communication
- Design, build and test
- Team taught

- Cross-disciplinary teaming
- Analysis tools and modeling
- Integrating research and design
- Prototyping and experimentation
- Scheduling and economics
- Project management
- Team taught

- Discipline-specific projects
- Real world corporate clients
- Outcomes based assessment
- Realistic application of all previous coursework
- Project management
- Capstone Conference

**Figure 1**: Overview of the four core Design4Practice courses, highlighting key features of each course. Each course also teaches discipline-specific technical skills associated with completing the project.

### 2.1 An integrated curriculum

The Design4Practice curriculum is built around four core design courses, one for each of the four years of the degree program: the freshman course, EGR 186 Engineering Design – Introduction; the sophomore course, EGR 286 Engineering Design - The Process; the junior course, xxx 386 Engineering Design - The Methods; and the senior course, xxx 486 Engineering Design - Senior Capstone. Each course builds upon the previous course in the sequence by threading of topical content from course to course. The courses are team-taught by faculty and practitioners who are experienced in engineering design.

Each course in the sequence has its own mission, objectives, strategies and educational outcomes that map directly into this higher level program.

As indicated in Figure 1, the four-course curriculum begins with a focus on interdisciplinary design and teaming in generally; this focus gradually shifts towards development of discipline-specific teaming skills and project management as students mature and gain design experience. The following paragraphs provide brief overviews of each course:

**EGR 186: Engineering Design – Introduction**

This freshman engineering design course is centered around multiple, small, team-based engineering design experiences that develop problem solving techniques, teaming and research

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1 The latter two courses, denoted xxx 386 and xxx 486, are discipline-specific. That is, the six disciplines within the CET (Civil, Environmental, Computer Science, Electrical and Mechanical Engineering) each teach their own sections (although 386 project teams remain cross-disciplinary). Thus, we use the notation xxx 386, for example, to represent CSE 386, ME 386, and so on.
skills, oral and written communications skills, and computer-based tools for academic and professional success. Over the course of a semester, student teams complete several small projects such as: a weight bearing bridge constructed with paper, glue, thread, and pins; an electrical learning machine that indicates correct and incorrect responses to a number of multiple choice questions; and a gravitational potential energy powered marshmallow launcher. These projects motivate the students to do library and Internet research, to strive for innovative designs, and to experiment with alternative design solutions.

**EGR 286: Engineering Design – The Process**

This three-credit sophomore design course introduces students to the corporate engineering environment via a semester-long, design-and-build robot project. The faculty play the role of CEOs of an imaginary corporation; students play the role of employee engineers. Each student belongs to a multidisciplinary team of five to seven students and that team is one of three or four teams in a division/mega-team.

After being introduced to the company’s culture, learning their roles in the organization, and being properly trained in teamwork, students are presented with an engineering problem by a customer. The remainder of the course is spent on requirements capture, specification writing, creativity and concept generation, design and analysis, documentation, building and testing a solution. The projects in EGR 286 are computer-controlled robotic devices with complex logic structures that interface with moving and grabbing mechanisms via various sensors. Examples of projects executed in past years include robots to scoop and move contaminated soil, search and map small tunnels while retrieving artifacts, and play an adapted version of basketball.

The central goal of EGR 286 projects is to encourage creativity and cross-disciplinary tinkering. At the same time, however, the students learn to program and build real-time graphical user interfaces in Visual C++; use electrical and mechanical hardware; deal with subsystem interface issues; machine, assemble, and test; and create industry-standard proposal, design, and as-built documents.

**XXX 386 Engineering Design – The Methods**

XXX 386 emphasizes the use of analytical modeling skills and related computer tools; rigorous design methodologies with system level thinking about social, environmental, and cultural impacts; and sophisticated project and team management that includes careful planning, scheduling, cost estimation, and economics. This course is again structured around a virtual company that consists of discipline-specific divisions working on appropriate parts of a central project. The various divisions must collaborate and coordinate extensively to complete the overall project. Course organizational structure allows the junior students to focus heavily on appropriate analysis and design methods for their discipline without obscuring the interdisciplinary nature of the course.

**XXX 486 Engineering Design - Senior Capstone**

XXX 486 is the final capstone course in which students are expected to complete a real-world design project with little instructor intervention. Students in this course communicate directly and extensively with clients from outside the university. They apply knowledge and skills to solve a real problem, beginning with problem definition and finishing with a functional prototype.
Four separate and discipline-specific sections of XXX 486 are offered each spring semester. Within each section, the students are formed into 2-5 person teams to complete industry-sponsored projects, supported by a course instructor who acts as the project manager, and a technical advisor from the general faculty that has expertise related to the project.

The curriculum culminates with the annual Capstone Design Conference, in which XXX 486 students present their projects to their industrial sponsors, technical advisors, project managers, NAU CET faculty, the general student body, members of the College of Engineering Industrial Advisory Council (CEIC), and the general public.

3.0 Internationalizing the Design4Practice Program

As part of a broad initiative to provide opportunities for international study and exposure within the CET curriculum, we are developing mechanisms to support international teaming within the Design4Practice program. Traditionally, Design4Practice teams have consisted solely of co-located teams (i.e., resident NAU students). With recent advances in internet technologies technical obstacles to the participation of team members located elsewhere within the USA and the world have largely disappeared. A variety of commercial and experimental applications enable, in principle, quite robust distributed collaborative work. Indeed, our experience indicates that the central challenges to supporting international teaming in educational contexts are social and logistic rather than technical in nature.

We begin this section with a brief overview of the evolving technical environment we have developed to support remote participation in Design4Practice courses. We then examine two approaches to providing students with international training that we are currently exploring within our international engineering initiative.

3.1 Supporting Distributed Design Teams with Groupware Tools

We have developed a suite of groupware applications to support remote participation in Design4Practice teams. These tools are integrated into a “virtual teamspace,” a secure website that serves as the hub of team development activities. With all team design activity firmly rooted in the virtual space, the geographic location of team members becomes less relevant. Specific groupware tools that we have deployed include:

- **Conferencing tools** – A central requirement for collaborative work is that participants must be able to communicate. To support such communication in distributed contexts, we have deployed a variety of commercial products (Netmeeting, ICQ, etc.) that allow participants to communicate in real time using some combination of typed text, video and audio.

- **Real-time shared workspaces** - In task-oriented contexts, conversation is always about something, e.g., a blueprint, a segment of computer code, or a CAD/CAM drawing. Our environment provides a shared workspace in which participants can view, annotate, and attach comments to a shared document, working either independently (“off-line”) or all together in real-time. Because commercial whiteboard products have proved inadequate (poor version control, no persistence past end of session, etc.), we have developed our own custom document viewing and annotation tool.
• **A working archive** – Most group work is a long-term process, with the end product taking shape and evolving over weeks or months. Capturing and archiving design rationale and other critical discussion is important for maintaining a sense of project trajectory and documenting design work. We have built a custom software component to support such archiving. The function is similar to a USENET newsgroup, but has been augmented with strong security and authentication mechanisms and a flexible permissions architecture to provide tightly controlled access to archived discussions.

• **Workplace awareness** – A key characteristic of successful work groups is a cohesive group dynamic, a sense of trust and shared purpose between members. A growing body of evidence indicates that group cohesion is extremely difficult to establish and maintain in distributed teaming contexts, primarily because participants have few resources for establishing mutual trust and commitment (Moreland and Levine 1989; Jones and Marsh 1997). How can one be certain that others are working hard? How can group members monitor each other’s progress in a virtual workplace? In traditional co-located contexts, this awareness is trivially maintained: one sees other team members in the lab and meets them in the hallways. To support such “workplace awareness” in a virtual context, we have designed a tool that indicates when others are on-line and logs what they work on and for how long.

Groups also need a sense of “place” in which group activities are situated, a sort of virtual office or lab. Accordingly, each distributed team is given a team website (Figure 2) within which all of the above tools are integrated into a cohesive work environment.

![Figure 2: A sample group site (window in background) showing the collaborative annotator (open file being annotated) and an open discussion archive.](image-url)
Access to all group resources on the site is strictly controlled. Group members are able to control what documents and resources (if any) are visible to the public; changes to archived resources, discussion forums and so on can be made only by bona fide members.

Although we are still in the process of refining these groupware tools, preliminary results are encouraging. In particular, our tight focus on providing only tools directly useful for collaborative design (i.e., low clutter, low complexity), implementing a strong authentication and security policy in all tools, and providing for workplace awareness has provided a strong basis for robust and efficient group work.

3.2 Internationalizing Design Curricula: Logistics
We have pursued a combination of two strategies in our efforts to internationalize the Design4Practice curriculum: traditional exchange study and mixed-mode international teaming.

3.2.1 Internationalizing traditional co-located teams.
After developing robust partnerships with several practice-oriented engineering programs in Europe, we collaborated with these partners to establish equivalencies among design courses at our respective institutions. This has made possible easy exchange study between institutions: their students participate in our Design4Practice courses; NAU students study abroad, substituting equivalent design courses taken at partner institutions for Design4Practice courses. For example, students at our partner institution in Dresden, Germany are required to complete a “practicum semester” at (approximately) the start of their junior year; frequently they intern with a German company. We have established an equivalency between this practicum experience and our EGR286 or XXX386 Design4Practice courses, thereby encouraging German students to visit NAU and participate in Design4Practice courses. Similarly, various research and project opportunities in Dresden have been made available to our students and are accepted as equivalent to EGR286 or XXX386.

Although this strategy is straightforward and provides excellent cross-cultural teaming experience, it suffers from several shortcomings. First, it does not provide any training in the tools and techniques of distributed teaming which, as mentioned earlier, will become increasingly common in industrial practice over the next few years. Second, the asynchrony in semester timing between many European institutions and American ones makes this simple exchange model impractical; students may have to miss two semesters at their home institution in order to take one Design4Practice course at NAU. In Germany, for example, fall semester starts in mid-October and runs through February; Spring semester starts in February and runs into July. In the USA, by contrast, fall semesters typically begin in late August and end in December; spring semester begins in January and runs through mid-May. Thus, a German student taking XXX 386 in the spring semester at NAU, would have to miss both fall and spring semesters at his or her home institution. Finally, we have found that many students are simply too involved in their lives locally (school, work, family) to leave the country for an extended period.

3.2.2 Mixed-Mode International Teaming
Recognizing the drawbacks of traditional exchange study, we considered other avenues towards internationalizing Design4Practice courses. Motivated by a university-wide distance-education initiate, our initial goal was to apply our strong technological expertise to support purely remote international teaming: membership in Design4Practice teams in courses offered at NAU would be open to students from partner institutions. Experimental work could be done by remote
students using labs at their local institution; results could be reported to team members at NAU and integrated into the evolving design.

Although this remote teaming model works reasonably well in certain contexts (e.g. software development projects), it is not suitable for most other engineering projects – particularly in a learning context. In particular, the commitment in Design4Practice courses to the eventual production of a designed artifact means that, during the closing phases of the course, the emphasis of team work shifts from analysis and design to hands-on prototype development. During this phase, teams spend long hours in the design lab, integrating individual design efforts and refining prototypes into the completed product. It is difficult to imagine how network technology could ever substitute for physical presence in this crucial experimental phase.

In response to this obstacle, we have developed a scheme that addresses the scheduling and social challenges mentioned above, while also meeting our central goals of providing cross-cultural exposure and remote teaming experience: Design courses are offered at either NAU or a partner institution abroad (which we henceforth refer to as the “local” institution); teams are composed of students from both institutions. Non-local students initially participate in their teams remotely, using the groupware technologies discussed earlier. During the closing weeks of the design project, the non-local students then travel to the local institution to join their team physically for the critical final development stage.

![Diagram](image)

**Figure 3:** Mixed-mode participation of a German student in CET XXX 386 course.

For example, Figure 3 illustrates how a German student might participate in the XXX 386 course offered every spring semester at NAU. During the German fall semester, the student would participate in regular courses at his or her home institution, perhaps taking a somewhat lighter load in anticipation of remote participation in XXX 386 later in the semester. When the XXX 386 course begins with the NAU spring semester in January, the German student joins one of the design teams and begins participating in the early design process via the internet. This might include participating in on-line design meetings, evaluating and annotating design documents, and contributing analysis work. The student might also be assigned development of mechanical components in his or her local lab facility, guided by joint on-line discussion of CAD/CAM documents. When the German semester ends in March, the student joins the rest of the design team at NAU to participate directly in the critical closing phases of the project. The German
A student could also add one or two additional web-enabled NAU courses to fill out his or her Spring semester schedule at NAU.

In sum, we have been able to enhance our highly effective Design4Practice program to provide international teaming opportunities by supporting a combination of tradition exchange study and mixed-mode international teaming supported by sophisticated network technologies. In an interesting side development, the network technologies that we have developed to support distributed teams (i.e., the team website, including the various collaboration tools) have proven to be popular with co-located teams as well, simply as a means of coordinating teamwork among members who have divergent schedules and working habits. We speculate that, in future, all Design4Practice teams will routinely use these tools; allowing remote participation by students from international partner institutions will become seamless and completely ordinary.

4.0 Conclusion

Sweeping changes in corporate structure and the global economy have greatly altered the structure of modern corporate design and development teams and the expectations placed on their members. Project teams have become smaller and less structured; all team members are expected to be able to creatively solve problems and work both independently and as efficient collaborators within their working groups. In an increasingly global environment, teams are often separated geographically and may be cross-cultural in nature.

These changes in work context have increased the importance of project management, communication, and teaming skills in engineering graduates; learning to effectively apply these skills in cross-cultural and widely-distributed teaming contexts presents particularly significant new challenges. The Design4Practice program developed within the CET at Northern Arizona University is designed to address these critical needs by situating traditional technical coursework within a curriculum centered around a progressive, interdisciplinary sequence of project-oriented courses that mimic the structure and overall constraints of design in a real-world corporate environment. Our extensive and on-going evaluations of the program have shown that, in addition to exercising discipline-specific technical skills, these courses develop problem-solving and teaming skills that allow graduates to be immediately productive in the real-world design contexts.

Although it is too early to evaluate outcomes, our recent efforts to address the pressing need for training in international teaming and project management show great promise and have been enthusiastically received by students. In particular, the combination of traditional exchange study tailored specifically around practice-oriented design training, and support for mixed-mode international teaming ensures that students have a wide range of international training opportunities to choose from throughout the Design4Practice curriculum.

The problems that we have encountered in developing our international initiative have been primarily logistic in nature, e.g., establishing course content equivalencies, accommodating differences in semester scheduling, providing adequate technological and communications infrastructure, and so on. Such problems are transitory in nature; we expect the program to become more robust as it evolves.

Motivating students to pursue training in international engineering is an important factor in the success of any international training initiative. In spite of all efforts to make international exposure an easy and natural part of the curriculum, the fact remains that pursuing international
training requires more commitment and effort than a traditional “domestic” curriculum. Our efforts to address the motivation issue center around providing students with tangible rewards for participation. Specifically, we have recently implemented an International Engineering Certificate program with international exposure as a core requirement. The certificate is issued as an addendum to the regular undergraduate degree and appears as a diploma-like document which students can display to potential employers.

Another significant challenge to developing international training partnerships is finding funding to support the added expense of international collaboration. Experience has shown that robust international partnerships require strong personal and professional relationships between faculties, relationships that can only be established and nurtured through regular visits. Similarly, a strong international initiative should ideally provide subsidies or scholarships to support student travel under both the traditional and the mixed mode models discussed earlier. Thus far we have been able to leverage various development resources to support core travel and infrastructure needs; students have been asked to cover their own travel expenses. It is clear, however, that supporting a robust international initiative will require finding additional long-term funding.

References


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