

# Integrating Curricula for Senior Design Classes Across Multiple Disciplines

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## ***ABSTRACT***

In an effort to improve the student experience and increase the efficiency with which faculty resources are used, the process of integrating engineering design curricula was initiated five years ago at the University of Arizona. Much progress has been made, but the fact that more work remains is indicative of the organizational dynamics at a large university. While many national and university-level factors encouraged the integration of redundant, disciplinary courses into multidisciplinary experiences, strong local opposition to change was encountered. Results and data from the integration process highlight the local nature of change through surges in enrollment in certain courses resulting from changes in departmental policies. Additionally, results indicate that progress towards an integrated design experience has reduced the net workload on faculty without compromising a high quality student experience.

## ***INTRODUCTION***

While engineering as a discipline embodies the principle of efficiency, engineering organizations (in particular large engineering schools) function differently, suffering the bureaucratic load of social and institutional systems. Engineering colleges may be construed as inefficient in realizing organizational change and optimizing offerings. In simple terms, the educational value proposition of an engineering college might read “provide the highest quality educational experience to the students for the least cost”, with the cost being correlated to faculty workload and institutional resources, for example. Inefficiency in realizing such a proposition may be tied to bureaucratic structures that sub-optimize and resist organizational change.

Our interest is in the process of bringing about organizational change at a college level, understanding the tension between the departmental or local forces, the college-wide, and the overarching system forces. In particular, this paper focuses on experiences with integrating disciplinary senior design courses into a college-wide multidisciplinary design program at the University of Arizona. Such institutional change has many forces either pulling it further along or slowing its progress. These forces occur at multiple levels: the external system, the institution, the college, and the department. For instance, the requirement from the Accreditation Board for Educational Testing (ABET) that students “must have an ability to function on multi-disciplinary teams” is an external force that encourages the integration of disciplinary design courses<sup>1</sup>. At the college level, a push to reduce redundant courses offered within multiple departments can serve to pull the integration of design courses further along. At the departmental level, individuals willing to and in positions to champion the integration of design courses are crucial in effecting change. Resistance to change can occur within these same

institutional structures, and has served to slow the integration of design courses at the University of Arizona.

The process of change has as much to do with history and local dynamics as overall goals. Many of the local forces are transparent or even invisible to all but a few insiders, which can serve to slow the progress towards integration. At the same time, identifying, understanding, and working within the local forces of an institution is not without merit. A well-designed system must reflect the culture of the “user” or home institution. If it does not, the system cannot be successful over the long term.

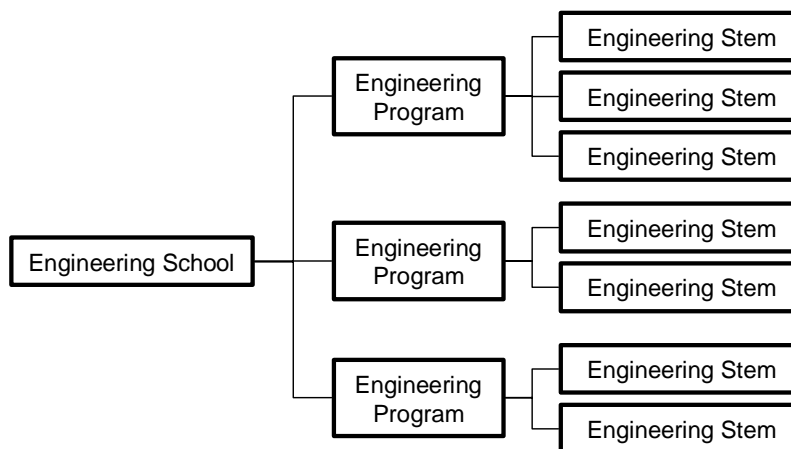
In this paper, we situate our design program relative to other US senior engineering design programs, and then describe our experiences of working within departmental, institutional, and broader dynamics to change the senior design programs at the University of Arizona from disciplinary to multidisciplinary and from separate to integrated. We then present some preliminary data measuring progress towards integration and the effect of integration on the quality of the student educational experience and instructional workload. Finally, we close with key lessons learned during the process.

## ***CURRENT PRACTICES***

### ***Senior Engineering Design at Other Institutions***

A fundamental characteristic of senior design classes at universities across the United States is that they are each different. These differences reflect many local influences such as the undergraduate curriculum, individuals teaching at these institutions, and the types of industry in the region. Relevant to this paper is classifying the different structures of design classes across the nation.

Lovas identified several levels at which senior design classes can be taught: the engineering school level, the engineering program level, and the engineering stem level. These are shown in Figure 1<sup>2</sup>.



**Figure 1 Levels at which Engineering Design can be Taught**

An engineering school level course includes students from multiple disciplines. An engineering program level course includes students from a single discipline. An engineering stem level course is aimed at one particular area within a discipline (e.g., a machine design course in

mechanical engineering). Dutson, et al., state that “the majority of capstone design courses appear to fall in the ‘engineering program’ category.

While most senior design courses are at the engineering program level, there are certainly many notable programs at the engineering school level. Most of these are aimed at creating multidisciplinary courses to prepare students for the reality of multidisciplinary design teams in industry and to address ABET requirements.

### **Senior Engineering Design at Arizona**

While the College of Engineering at the University of Arizona currently has a hybrid engineering program/engineering school design program, this grew out of a set of departmental senior design offerings. In the 2000-1 academic year, nine departments offered senior design classes in the College of Engineering. All but one of the departments offered two semesters of senior design. The structure and content of each course reflected the nature of each discipline and the department in which it was offered. For instance, the chemical engineering course involved the design of a plant (without implementing the design) while mechanical engineering projects involved the design of devices and required construction and testing. Most of the nine different courses, however, involved a team of students identifying needs, developing designs, building designs, and testing the designs over two semesters. Projects came from a variety of sources, with primary sources being industry, faculty, student clubs, and community organizations. Final design presentations were conducted by each class separately.

The University of Arizona is along a path towards integrating departmental or engineering program design courses to form an engineering school level program. The first stages have included the formation of a multidisciplinary design course that complements engineering program courses, and the development of an infrastructure that will allow a seamless transition towards full school integration over time. Challenges experienced to this point and the long term vision for design at the University of Arizona are described in the following section.

### ***A STRATEGY FOR INTEGRATION***

Three immutables of institutional change are 1) that it is hard work, 2) that any gains made today may be lost tomorrow, and 3) that nothing should be taken for granted. Those involved in institutional change recognize that change is a process that involves constantly working to find innovative ways to align stakeholders to an institutional vision and to keep the “dynamic bits” in place. Staying attached to the process and recognizing that just when you think you “have it” something else in the system changes is paramount to building sustainable institutional change.

At the University of Arizona, we have been involved in an incremental process of change since Fall 2000, working both bottom-up and top-down to bring about long-term multidisciplinary reform to the senior capstone design program. A broad vision of a college-wide multidisciplinary program was proposed to the Dean and Department Heads in fall 2000, and incremental steps have been taken in developing that program across key engineering departments over the last four years. The vision has matured over these years to best fit the stakeholders and organizational constraints. Because the process was largely bottom-up, this has allowed for considerable flexibility in prototyping the system, and iteratively optimizing the program over time. The first major milestone in integrating disciplinary design courses into a

multidisciplinary design experience was the development of ENGR 498, a multidisciplinary senior design course.

### **Development of ENGR 498**

#### *Program Structure and Operation*

The program structure and operation has evolved over time to reflect institutional readiness, faculty needs, student ability and drive, industry participation, and scale.

In the initial development, programs including the University of Florida, Harvey Mudd, Northern Arizona University, and Brigham Young were reviewed. Collaborating with a highly skilled systems engineer from a local company, a design process course was developed with the intent to give students a high quality, real-world taste for design process and design deliverables, team-taught with a ranked individual from industry who would lend strong credibility to the program. Initially, the vision was to create a 50-100 person class of top engineering students in a highly sought-after program. We launched the program with 3 projects and fewer than a dozen students, committed to building the program incrementally. In this first year, we built tools to support classroom activities and deliverables, which included a “Toolkit” that outlines elements that would be expected in each deliverable.

In the first year, it became apparent that there were a significant number of organizational structures that needed to be built to accommodate growth and sustainability of the multidisciplinary program. Course units varied from 3 to 7 units for senior design across the College; course times varied in each department with no easy way for student schedules to overlap; there was not a clear-cut process for recruiting and assigning students into design projects across the College; there was little institutional knowledge as capstone courses were largely taught by adjunct faculty across the College.

Integration of the capstone design courses across the College has been strongly tied to a combination of structures that accommodate integration without increasing the overhead for students, instructors, or faculty mentors. During the period from 2001 to 2004, the program integration activities focused on putting into place infrastructure that would break down barriers and move the program forward. Critical steps in the integration of the program included the following:

- an alignment of course times (which ultimately took 3 years and significant negotiation)
- an alignment of course syllabi
- development of a College-wide engineering design event
- construction of an integrated database system for mapping projects to sponsors, instructors, students, and faculty mentors.

With a multidisciplinary project focus, the disciplinary student mix of a design course can conflict with the disciplinary requirements of real-world design projects. With credit misalignment in one large department, and course time misalignment in a second large department, we were not being able to successfully populate projects with required skills, given the course size of approximately 50 students. That is, we lacked sufficient mechanical and electrical engineers for the sponsored projects. Actions taken included active recruiting,

alignment of the course time, co-publishing of design projects across the major departments and the multidisciplinary program, and an increase of credit hours (leaving a 1-unit disparity, which is still a barrier to some students).

Impetus for the alignment of course syllabi was an outcome of relationships developed during ongoing meetings between design faculty in key departments, and movement of faculty into influential positions. This will be discussed further in the section on faculty roles in the integration.

By creating a well-publicized College-wide event to showcase design in the College, departments became more aware of the varied quality of their design offerings, and more willing to participate in new program directions. For example, the Optical Science and Engineering Program, teaching design for its first year, was impressed with the quality of the event in 2004, and of the quality of the multidisciplinary projects such that they agreed to “outsource” their design program, and have all of their students participate in the multidisciplinary program in 2004-5; presentations from key College programs showed that the quality of the program is reflected in the quality of the output.

Lastly, in preparation for a growing integrated program, effort went into creating a database and user interface to simplify and streamline project authoring for sponsors, project selection for students, project information tracking for instructors, and project administration for the program. Without such a tool, the administrative overhead of scaling the design program would have been prohibitive. As such, the tool is designed to accommodate the potential for 400+ students, multiple departments, and 70-90 projects, supporting functions that include authoring projects, selecting projects, optimizing team formation with available students, managing team information, and administering the program.

All of the changes described in this section were driven from the bottom-up by local forces. Only two of the changes, aligning course times and credit-hours, required approval from institutional committees. Not surprisingly, these two changes required the most time to implement. The common themes to the process of making each of these changes are A) persistence among the local champions of the changes, B) continuously learning about the visible and implicit policies within the departments and college, and C) moving forward with changes not requiring committee approval as a means of showing the benefits of integration.

### *Institutional Elements*

Institutional forces have played a major role in the dynamic of integration, as institutional goals and priorities have shifted with external events. The roots of the design course lay with a “cubic centimeter of chance” that emerged in fall of 2000, when the Dean of the College of Engineering agreed to fund a position to develop a multidisciplinary capstone design course. The institutional climate during this first year created a setting where departments were willing to consider large-scale integration of the curriculum. Committees were involved in assessing redundancy of teaching across departments (e.g., numerous departmental thermodynamics courses, statistics courses, etc.), and thus there was an interest in reducing the number of design courses (and thus the costs) across the College. ABET’s accreditation was requiring departments to address a relative lack of multidisciplinary elements in their curriculum. The proposed multidisciplinary program launched at an auspicious institutional time.

In 2001, the University of Arizona was tasked with exceptionally deep budget cuts, which placed the program in jeopardy. A business model was proposed such that the program would be self funding through the budget cycle, which allowed the program to continue. In this environment, however, the university reorganization and renewed focus on research served to challenge cross-department educational innovation. It was not until this cycle tailed off that growth was again seen in the program. In 2003, institutional commitment was reflected in the decision to create a tenure-track position for a design faculty at the College level to push a design agenda at the University. This created a sustainable position to lead the program and a significant commitment on the part of the institution.

Another significant outcome of deep budget cuts at the University over the last several years has been a severe lack of teaching faculty, as faculty “lines” have been held at the Provost’s level, and not filled quickly at the department level. It is this environment of teaching faculty shortages that is currently allowing for further growth and development of the multidisciplinary capstone option, by finding ways to more efficiently teach students.

In an ongoing way, it has been necessary to align the multidisciplinary design program with these changing institutional objectives.

### *Design faculty*

The departmental design faculty have been at the heart of the design integration activity, as they have ultimately become the largest asset and the largest barriers for change. A significant challenge in curricular integration has been the lack of tenured faculty participating in the process. At the University of Arizona, many of the design faculty are adjunct teaching faculty, with limited ability to influence departmental decision-making regarding curricular change, and limited drive to create changes that might impact their job security.

Starting in 2002, when ongoing discussions with the College administration did not yield more substantial leadership from the top to promote an integrated program, the director of the program began to work bottom-up with stakeholders to move forward a vision of a College-wide integrated design course. We brought together the team of design faculty from across the College to discuss ways that integration might be accomplished. An outcome of this process was for faculty to understand how similar their syllabi were, to offer teaching materials to each other in areas of strength, and to ask for materials in areas of comparable weakness. This group, however, dominated by a number of adjunct faculty whose job security was directly tied to their design course, did not come to a consensus about an integrated design program. But the seeds were sown with key players who were to influence later steps towards integration.

In 2003, a single faculty member was both teaching the mechanical engineering course and the multidisciplinary course, taking steps to optimize the strengths from each program and create a shared Mechanical/multidisciplinary syllabus. This faculty then became an advocate for a shared syllabus. During this year, meetings occurred between faculty involved in Electrical and Computer Engineering and the multidisciplinary team to discuss a shared syllabus with shared deliverables in an effort to improve the quality of the Electrical and Computer Engineering Design program. The next year, in 2004, two events occurred which created an institutional environment to support integration: 1) the adjunct Mechanical design faculty who had taught in the multidisciplinary program was offered a tenure-track position with the College to teach design, leaving the Mechanical program with no active faculty to teach their course, and 2) with

much negotiation, the adjunct instructor in the Electrical and Computer Engineering program was replaced with a faculty who clearly saw the value of integration.

As a result, the Mechanical Engineering program agreed to co-convene their course with the multidisciplinary course, thus leveraging a faculty they knew and trusted, and moving them one step closer to full integration, as the lectures were co-taught. And with the transition to a new tenured faculty in Electrical and Computer Engineering, an advocate for increasing College-wide integration of projects with more substantial departmental influence on curriculum decisions was gained.

As such, design faculty across the College have been critical players in the move towards integration. Relationships with design faculty have been at the core of movement toward integration, either through influencing departments' choices in appointing design instructors, or in making grass-roots progress towards an integrated design program.

### *Students*

Students have driven change within the integration effort, as we have sought to balance our expectations for the design experience with students' interests and drive. We have found that students who join the program do so for a range of reasons, but often to try something a little different. We have actively worked to recruit students to the program, grappling with the "word on the street" that the program has a heavy workload. Our intent is to balance the fun and exploration with design with a serious and credible design experience that prepares students for application of the design process in their worklife following graduation. Our challenge has been to attract a sufficient number of engaged students to fulfill the project disciplinary needs in the program.

Since 2002, efforts have included active recruiting in junior-level classrooms in the year prior to the program; making the choice of the multidisciplinary program more visible in departmental curriculum requirements, and jointly publishing ALL available design projects for the largest departments (Electrical and Computer, and Mechanical) at the beginning of the year (such that students would be able to move across courses based on their choosing projects of high interest). Student overhead for choosing the multidisciplinary projects/course over their own departmental projects/course was thus reduced.

More seriously, in a survey conducted in 2003, students who chose not to take the multidisciplinary course noted a general lack of desire to work outside of their discipline, away from their friends, and to be uniquely responsible for a disciplinary contribution. It is clear that student disciplinary identity is a key barrier in integration, particularly if the perception is that the departmental program is easier, their friends are there, or that they do not have sufficient disciplinary confidence to work as a lone disciplinary member on a multidisciplinary team.

### **Restructuring of Entire System**

Based on some good institutional openings towards integration, in 2005, plans are to substantially restructure and streamline the integrated design program, leveraging the learning from the prior four years of the program and the current shortage of instructors being experienced across the College. Currently, there is institutional interest in having a reduction in the faculty teaching load for design. Many departments have used adjuncts in the past, and continue to see this as a low-cost, good quality solution to design courses. We have proposed an

integrated multidisciplinary design course that utilizes a strong centralized design faculty “owning” and teaching the design process course, with 1:1 team meetings with individual disciplinary instructors in small “recitation” sections. Strengths of this model include: a reduction in faculty teaching load with an improvement in the quality of the student experience, centralized control and improvement of the course material by a design faculty, centralized control of administration of the program, reducing administrative loads on individual department faculty, and centralized contact with sponsors providing a streamlined relationship with the College.

Without question, integration of the capstone design course has been a process requiring attention to institutional patterns and needs, faculty and student requirements, and the construction of infrastructure to sustain the program. Key elements that were put in place include an institutional commitment through tenure-track faculty, alignment of design units and course times across the College, and the development of a community of faculty who are not threatened by proposed integration. A gradual building of awareness of the benefits of a multidisciplinary program has been facilitated through public events like a College-wide design day, the participation of design faculty in improvement discussions, and a growing awareness that most real-world design problems simply are not departmentally located and require a multidisciplinary approach.

## ***RESULTS***

Key results that indicate the degree to which integration of disciplinary design courses “provide the highest quality educational experience to the students for the least cost” are presented in this section. The measures are presented in groups according to the questions that they address. Three basic questions are addressed with the results:

- Is the senior design experience at the University of Arizona moving from a disciplinary (i.e., engineering program) level model to a more **integrated** (i.e., engineering school) model?
- Is the **quality of the educational experience** for students improved by integration?
- Is the **faculty workload** (i.e., cost) reduced through integration?

The first stage of the strategy presented in the previous section, the development of ENGR 498, was implemented in 2001 and therefore data concerning its effects are available. Alignment of senior design course times and deliverables was implemented in fall 2004, so no data are currently available.

### **Raw data on Integration**

As detailed in an earlier section, much effort has been put towards integration of disciplinary design classes over the past several years. The degree of integration accomplished during this time is reported on in this section.

Over the past four years, ENGR 498 has grown from nine students in its first year to seventy-five during the 2004-5 year. Five disciplines have a significant number of students consistently enrolling in the class. The complete set of data is shown in Tables 1 and 2.



**Table 1 Enrollment Data for Integrated Class and Disciplinary Class**

	AME 412 (Mechanical)			ENGR 498 (Multidisciplinary)		
	Total	# women	% women	Total	# women	% women
<b>2001-2</b>	58	5	9%	9	0	0%
<b>2002-3</b>	49	2	4%	47	14	30%
<b>2003-4</b>	68	6	9%	44	15	34%
<b>2004-5</b>	38	1	3%	75	19	25%

**Table 2 Disciplinary Mix in Integrated Class (ENGR 498)**

	2001-2	2002-3	2003-4	2004-5	Comments
<b>Aerospace &amp; Mechanical</b>	2	5	7	13	Steady increase, substantial participation; alignment of course times in 04-05
<b>Ag/Bio</b>	0	3	0	3	
<b>Chemical</b>	0	3	1	1	
<b>Computer</b>	0	7	12	8	Substantial, steady participation
<b>Electrical</b>	2	7	13	11	Substantial, steady participation
<b>Material Science</b>	1	5	4	0	Decrease in 04-05
<b>Optical Science</b>	0	0	0	31	All OSE students must take ENGR 498 starting in 04-05
<b>Systems &amp; Industrial</b>	3	13	4	7	Substantial, steady participation
<b>Other</b>	1	4	3	1	

The large increase in enrollment in 2004-5 is due to the Optical Science department (OSE) eliminating its disciplinary senior design course and requiring all of its seniors to take ENGR 498. Including all majors except OSE, the enrollment of ENGR 498 has stabilized at roughly forty-five students per year. Including the OSE students, ENGR 498 is the second largest senior design class at the University of Arizona (electrical and computer engineering is larger).

The enrollment of aerospace and mechanical engineering (AME) students nearly doubled in 2004-5. This increase is attributed to the alignment of ENGR 498 and mechanical design course in 2004-5. Mechanical engineering students can take ENGR 498 in place of their disciplinary design course to meet graduation requirements. These courses had previously been taught at different times, making switching between classes difficult for students. In 2004-5, the two courses are taught at the same time, by the same instructor, in the same room (except for four days where the two courses split to cover disciplinary material). Progress in identifying and overcoming departmental barriers to integration is clearly evident in the data.

More important than the numbers in Table 2 is the number of projects in ENGR 498 that are multidisciplinary. Due to a variety of reasons (projects, program changes, which students enroll in the class), there are some projects in ENGR 498 that are composed of students all from one discipline. In the 2002-3 academic year, all ten projects were composed of students from at least

two disciplines. In 2003-4, two of the nine projects were composed of a mix of electrical and computer engineers while the rest were composed of a broader mix of majors. In 2004-5, five of the seventeen projects were populated by solely optical engineering students and one project only had mechanical engineers on it. This large percentage of single-discipline teams in ENGR 498 was due to large number of optical engineering students in the class resulting from the elimination of the optical engineering senior design course. Team composition data and project descriptions for all of the projects in ENGR 498 are available online at <http://classes.engr.arizona.edu/engr498/>.

Another indicator of the degree of integration of design courses at the University of Arizona is the number of disciplines participating in Engineering Design Day, an annual event at which senior design teams present their final designs to judges from industry. Before the 2001-2 academic year, each discipline held their final presentations separately. In the 2001-2 year, three senior design courses participated in the joint event. In 2002-3, seven courses participated. In 2003-4, ten senior design courses in the College of Engineering participated. In four years, the College of Engineering went from completely segregated final design presentations to a fully integrated event.

The final two results concerning progress towards integration, while not numerical, are key indicators of the movement towards integration. First, at the institutional level, a tenure-track position was created for a faculty member to teach design in the college. In particular, this position provides support for a person to teach the multidisciplinary design course, lead the freshman engineering design course, and lead the college towards a more effective design experience for students. Second, through an arduous three year process of talking with each department, all senior design courses are now taught at the same time (TTH from 3:30-6:15) and the three largest all follow the same structure. The lack of alignment proved to be a significant barrier for students switching into ENGR 498. There was significant resistance to the alignment of times at the departmental level as it required several course times to be moved: it took three years for this goal to be accomplished. As noted earlier in this section, the alignment led to the number of AME students in ENGR 498 nearly doubling.

An unintended benefit of integration, the large percentage of women in ENGR 498, warrants comment. Since the 2002-3 year, the percent women in ENGR 498 has been consistently higher than the percentage of women in the College of Engineering (14.8% in 2003<sup>3</sup>) and than the mechanical engineering senior design class. Additionally, while the mechanical class has less than 10% women students, 33% of the 21 mechanical engineering students that chose to take ENGR 498 in the 2003-4 and 2004-5 academic years were women.

The data clearly answers the question, "Is the senior design experience at the University of Arizona moving from a disciplinary level model to a more integrated model?" in the affirmative. Enrollment in the integrated class is continually increasing with solid involvement from students in several departments. Furthermore, departmental participation in Engineering Design Day has increased each year. Additionally, the two largest disciplinary design courses have aligned times and structure with ENGR 498 and a new faculty member has been hired in design. The hard work described in the preceding section has indeed led towards a more integrated design experience.

**Quality of Student Experience Data**

As integration of the disciplinary design experiences progresses, it is critical to understand if this integration creates an improved educational experience for the students. Three measures of the quality of the student experience are presented in this section. First, scores of students on a design skills assessment protocol are compared between ENGR 498 and the mechanical engineering design course. The second measure is the number of awards open to all departments that are won at Engineering Design Day by each department. The third measure is from course evaluations.

A design skills assessment is being developed at the University of Arizona<sup>4</sup>. Students critique a proposed design process and their responses are scored using an analytic scoring rubric. To date, two design processes for critique and associated rubrics have been developed: one for the design of a shopping cart and the other for the design of a device to count eggs on a conveyor belt. While validation of these two tests is ongoing, early data suggest that the egg counter version has stronger validity than the shopping cart version\*.

In spring 2004, students in both ENGR 498 and the mechanical engineering senior design course, AME 412, took both tests roughly one month before the end of the two semester courses. Results are shown in Table 3. A higher raw score indicates better knowledge of how to apply a design process.

**Table 3 Scores of Seniors on Design Skills Assessment**

Shopping Cart				Egg Counter			
Raw Scores		t-test value	p-value	Raw Scores		t-test value	p-value
ENGR 498	AME 412 <sup>1</sup>	("+" means ENGR 498 has higher scores)		ENGR 498	AME 412 <sup>1</sup>	("+" means ENGR 498 has higher scores)	
10.86	11.31	-.346	.732	14.36	11.03	2.454	.018

<sup>1</sup>AME 412 is the mechanical engineering senior design class.

Based on the data, the shopping cart test shows no statistical difference between the two courses. The egg counter data, however, shows a very different picture. ENGR 498 students did score significantly higher on the egg counter test than the AME 412 students. A more detailed analysis shows that the areas in which ENGR 498 students excel the most concern identifying needs and using them throughout a design process to guide decisions, understanding the importance of documenting throughout a design process, and seeing the big picture of how a design process fits together.

The number of awards won by ENGR 498 teams at Engineering Design Day is another indicator of the quality of the student experience. Winners of the awards are selected by a panel of judges from industry. Awards at Design Day that were open to all disciplines were dominated by mechanical engineering teams in 2002 and 2003. In fact, teams from other disciplines did not receive serious consideration for the awards from the judges. This changed in 2004, when the

\* In hindsight, this is not too surprising since the shopping cart is more focused at mechanical engineering and the egg counter relates to a broader range of disciplines.

Best Overall Award (the highest award) was won by an ENGR 498 team. The award data is shown in Table 4.

**Table 4 Engineering Design Day Award Data**

Year	# of Awards Available	# Awards Won by ENGR 498 Teams	Comments
2002	5	0	All won by mechanical teams.
2003	1	0	All won by mechanical teams.
2004	2	1	Best Overall won by ENGR 498 team.

The final indicator of the quality of the student experience is from course evaluations. One question asked on course evaluations is particularly relevant to the quality of the student experience. As shown in Table 5, ENGR 498 students feel that they are more able to design a system to meet a set of needs than the mechanical engineering students do (2003-4 academic year). The data in the table are for both the first and second semesters of the two semester courses. It will be particularly interesting to compare this data to the following year's data, when available, since the two classes have been aligned and are taught together by the same instructor (thereby eliminating some confounding factors of the data in Table 5).

**Table 5 Course Evaluation Comparison**

"This course enhanced my ability to design a system to meet a set of needs." 1=strongly disagree; 5=strongly agree		
	Fall 2003	Spring 2004
ENGR 498 n <sub>fall</sub> =18, n <sub>spring</sub> =42 48 enrolled in fall, 44 in spring	4.33 ± 0.23	4.19 ± 0.29
AME 412 n <sub>fall</sub> =44, n <sub>spring</sub> =47 68 enrolled each semester	3.75 ± 0.30	3.83 ± 0.29

While the amount of data on the quality of the student experience is too small to be conclusive, it is helpful in answering a key question concerning integration of disciplinary courses into multidisciplinary courses: is the quality of the educational experience for the students improved by integration? The current data suggests that the student experience is indeed improved.

**Teaching Workload Data**

Another reason for integration of disciplinary design courses is the expected reduction in net workload for senior design courses across the college. Teaching workload data for four senior design courses (ECE, ME, OSE, and multidisciplinary) have been tracked for the past five years. This data is shown in Table 6.

**Table 6 Teaching Workload Data**

	ECE		ME		Multidisciplinary		OSE		# of Courses	Total	
	Teach	Support <sup>1</sup>	Teach	Support	Teach	Support	Teach	Support		Teach	Support
2000-1	2	0	2	0	N/A <sup>2</sup>	N/A	N/A <sup>2</sup>	N/A	2	4	0
2001-2	2	0	2	0	2	0	N/A	N/A	3	6	0
2002-3	2	0	2	0	2	0	N/A	N/A	3	6	0
2003-4	2	0	1 <sup>3</sup>	0	2	1	1	0	4	6	1
2004-5	2	0	0 <sup>4</sup>	1	2	1	0 <sup>5</sup>	1	4	4	3
Δ from 2000 to 2005	no Δ	no Δ	-2	+1	no Δ	+1	-1	+1	+2	no Δ	+3

<sup>1</sup>Teaching refers to faculty regularly involved with classroom teaching while Support refers to faculty regularly involved in activities such as recruiting projects, managing course logistics, and running final presentations. TA's and graders are not reflected in the numbers in Table 6.

<sup>2</sup>The multidisciplinary course was not started until the 2001-2 academic year. The OSE class was started in 2003-4.

<sup>3</sup>The ME instructor also was one of two faculty teaching the multidisciplinary class, but taught the two classes separately.

<sup>4</sup>ME students and multidisciplinary students attend the same lecture/classroom experience.

<sup>5</sup>OSE moved to having all its students take the multidisciplinary class in 2004-5.

The overall trend over the last four years is to increase the number of courses while reducing the teaching load on faculty from a maximum of six faculty for three courses to four faculty for four courses in the 2004-5 academic year. This has been accomplished by A) teaching the ME and multidisciplinary classes concurrently in one room, and B) eliminating the OSE class (all OSE seniors now take the multidisciplinary class). The alignment of class times across the college was critical in making this happen. The ME and multidisciplinary class did not meet at the same time before the 2004-5 academic year and therefore could not meet in one classroom. The OSE program could not require their students to take ENGR 498 if it did not fit into their schedule of classes – which it does since all senior design classes now use the same time slot.

Extra non-teaching personnel are used to support the courses: these personnel experience a large workload up front to manage project solicitation and intellectual property, but a much lower load after first three weeks of semester. This has allowed the instructors to be reduced in number and also to focus more on student learning and less on course management.

One of the college-level forces for integration was reducing net instructor workload across the college. In terms of faculty teaching the course, integration clearly led to higher efficiency by moving from two faculty per class to one per class. When support faculty are included, however, efficiency is still improved but the picture is less clear. At the University of Arizona, support faculty for senior design classes make significant contributions through recruiting projects, managing the interface with the clients, and, in some cases, maintaining course grades. The workload for such activities spikes early in the term but is overall less than the workload for those directly teaching the course. Hence, the net efficiency with which faculty resources are used has increased as a result of integrating senior design curricula.

## ***LESSONS LEARNED***

The dominant lessons learned concern identifying and addressing the multi-leveled forces behind institutional change. In our case, the predominant national-level driver was and is ABET. The plan to integrate design courses to create a multidisciplinary design experience aligns well with one of ABET's criteria for engineering programs. A key for the slow but continual progress made towards integration was aligning with an institutional action to reduce redundant courses while not reducing the quality of the student experience. The combination of ABET and a key institutional action set the stage on which a collective of individual players in the College of Engineering could effect change.

At the departmental level, a growing nucleus of people to champion integration of design courses was and is needed to work through the resistance of departments and individuals. A continual process of learning the "insider" or informal policies of departments has been necessary. That said, moving forward with changes that do not require departmental approval has been beneficial to the progress we have made towards full integration. Aligning syllabi and creating the college-wide Engineering Design Day are two examples of moving forward as a means to show departments the benefits of integrating design courses.

Based on the data presented in this paper, some of the key results are that:

- Enrollment in the multidisciplinary class is growing as local barriers to integration are removed.
  - An unintended benefit of the multidisciplinary class is that it preferentially attracted women students.
- Multiple measures of the quality of the student experience show that the multidisciplinary design experience is at least as effective as the strongest disciplinary design program at the University of Arizona.
- One approach to reducing the net workload on faculty is to separate the coordination/support functions from the teaching functions.

## ***CLOSURE***

Institutional change is difficult, it takes time, and it must reflect the unique characteristics of the people and programs at an institution. In the case of creating an integrated senior design experience, national forces such as ABET requirements are not enough on their own to cause change. It was necessary to couple such high-level forces with other actions; in our case, a second key influence is the pressing institutional need to increase the efficiency with which faculty resources are used to teach students. Even with such motivation for integration, individuals are needed to navigate local dynamics and overcome local resistance at the departmental level. Data on the efforts at the University of Arizona indicate slow but steady progress towards goals of creating a better learning experience for senior design students while reducing the net workload on faculty.

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