Proceedings of the ASME 2010 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference
IDETC/CIE 2010
August 15-18, 2010, Montreal, Quebec, Canada

DETC2010/DEC-28575

NAVIGATING THE BARRIERS TO INTERDISCIPLINARY DESIGN EDUCATION: LESSONS LEARNED FROM THE NSF DESIGN WORKSHOP SERIES

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ABSTRACT

Evidence suggests that transformational innovation occurs at the intersection of multiple disciplines rather than isolated within them. Design—being both pervasive and inherently interdisciplinary—has the power to transcend many disciplines and help break down the departmental "silos" that hinder such collaborative efforts. Many universities are now struggling to embrace the curricular innovations that are necessary to achieve and sustain interdisciplinary education. Given the already packed undergraduate engineering curricula, several universities have started to offer new design programs that span several disciplines at the masters and doctoral levels. In this paper, we examine the five interdisciplinary graduate design programs offered by three different universities—University of Michigan, Northwestern University, and Stanford University—that hosted the NSF Design Workshop Series in 2008-2009. Collectively, these programs represent "solutions" that span a variety of graduate degree offerings that are available and provide examples of ways to successfully navigate the barriers and hurdles to interdisciplinary design education. A recap of the NSF Design Workshop Series is also provided along with recommendations from the workshops to foster discussion and provide directions for future work.

1. INTRODUCTION

Innovation has been the key to America's success for more than a century. Evidence suggests that transformational innovations often occur at the intersection of multiple disciplines rather than isolated within them, and they require input from individuals with varying backgrounds, talents, and expertise [1]. Design—being both pervasive and inherently interdisciplinary—has the power to transcend multiple disciplines and help break down the departmental "silos" that hinder many such collaborative efforts. As in many industries, universities are now facing similar challenges, and many are struggling to embrace the curricular innovations that are necessary for interdisciplinary education, particularly in engineering classrooms that must accommodate numerous requirements to receive ABET Accreditation [2].

In engineering undergraduate curricula, due in large part to ABET requirements, one or more courses with a design "experience" (e.g., a capstone course) are required [2]. In graduate curricula this approach is less successful since structuring design courses to be "instruction in a discipline" rather than a "guided experience" is a major challenge. Issues arise in terms of both course content and instructor training due to the inherent trans-, multi-, or inter-disciplinary nature of most design activities. Nevertheless, many universities have started to offer design curricula that span several disciplines at the masters and doctoral levels. Courses tend to be oriented towards a narrow topic in design, following the instructors' research interests whereas a successful graduate program in design would naturally follow a broader appreciation of design as a discipline rather than as a mere collection of disciplines. The recently launched Singapore University of Technology and Design, a partnership between MIT and the Singapore Government, presents clear evidence of global recognition for the importance of design as a discipline that drives innovation and economic prosperity.

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The remainder of this report is organized as follows. Section 2 outlines the overall organization of the Design Workshop Series. Section 3 discusses the most pervasive theme at these workshops, namely, the barriers and challenges in creating (and sustaining) interdisciplinary graduate design programs. Section 4 summarizes "solutions" for overcoming these barriers and challenges, using the five programs offered by the three partner universities (University of Michigan, Northwestern University, and Stanford University) as exemplars that have successfully navigated these hurdles. Finally, Section 5 provides closing remarks and a summary of the outcomes and recommendations from the Design Workshop Series.

2. OVERVIEW OF THE DESIGN WORKSHOP SERIES

Following the success of the May 2008 Interdisciplinary Graduate Design Education Workshop held at NSF [3, 4], we initiated the *Design Workshop Series* seeking to capture, codify, share, and propagate instructional experiences and philosophies for teaching interdisciplinary design. The overarching goals of the Design Workshop Series were to: (1) strengthen existing and emerging interdisciplinary graduate design programs across the country, thus improving our innovation output at the workforce level and increasing our competitive economic advantage; (2) establish a repository of knowledge that can provide substantive guidance for other design programs to follow; (3) provide a moderated forum for the design community to discuss the challenges, successes, practices, and future directions of these programs, leading to broader exposure at professional society meetings and archival publications. The long-term outcome is to help train faculty who approach design—research and teaching—as a substantive and integrative discipline.

The Design Workshop Series spanned one year (Fall 2008-Fall 2009) and focused explicitly on interdisciplinary graduate design education. Hosting and organizing responsibilities rotated between our four partner universities as follows:

- *The Design Science Program*, University of Michigan, 6-7 November 2008, *Focus:* Design as a Discipline, URL: http://designscience.umich.edu/designworkshop.html
- *Segal Design Institute*, Northwestern University, 16-17 April 2009, *Focus:* Spanning Design Boundaries, URL: http://www.segal.northwestern.edu/designworkshop/
- *2009 NSF CMII Grantees Conference*, Half-day Workshop, 22 June 2009, *Focus:* Design Research, URL: http://www.design.psu.edu/workshops/june09.php
- *Hasso Plattner Institute of Design*, Stanford University, 27-28 August 2009, *Focus:* Design Instruction, URL: http://www.stanford.edu/group/dschool/nsfdesignworkshop/

The faculty team at Penn State also provided coordination across the four workshops. Each university hosted a one-and-a-half day workshop. The first half day was typically spent discussing the host's design program(s) and touring its facilities. The second full day provided an opportunity for open discussion on specific graduate-design instructional topics chosen to match the strengths and experience of the host program. Meanwhile, a fourth half-day workshop that focused specifically on design research was organized in conjunction with the *2009 NSF CMMI Grantees Conference*.

All of these workshop activities were open to anyone to apply, and NSF funding was used to provide travel support for invited participants with the goal of broadening involvement in the larger design community (e.g., arts, architecture, business, engineering, industrial design, journalism, psychology). Since each workshop had applicants far in excess of available slots, participants were selected to balance the representation of the different disciplines. A total of 265 people attended one or more of the workshops, including the initial workshop held at NSF in May 2008 [3, 4]. This total includes 172 unique participants, of which 49 people (28.5%) attended two or more workshops[1]. Additional details on each workshop can be found at the aforementioned URLs, and the final report is available online at: http://www.design.psu.edu/workshops/.

3. THE BARRIERS TO INTERDISCIPLINARY DESIGN EDUCATION

Regardless of the workshop location or the participants involved, one pervasive theme was evident in every discussion: the barriers and challenges in creating (and sustaining) graduate interdisciplinary design programs. To help synthesize the discussions that occurred at the workshops, we have grouped these barriers and challenges into four areas: (1) resources, (2) faculty, (3) students, and (4) pedagogy/curriculum. Each of these is discussed in the remainder of this section. Key topics are highlighted in ***bold italics*** and consolidated at the start of Section 4 to facilitate a discussion of ways to overcome these barriers as demonstrated by the three host universities.

3.1 Resource Issues

Obtaining the resources to initiate—and ultimately sustain—a new interdisciplinary graduate design program was the first and foremost topic on everyone's mind. The timing of the workshops could not have made this issue more apparent, as they coincided with one of the worst economic downturns of the century forcing many universities to tighten their budgets. Finding ***program funding*** (e.g., the faculty involved, classroom space, labs) as well as ***student support*** had stifled many participants' attempts at their home institutions, and they were anxious to hear how existing programs had succeeded. Secondary to funding was the issue of space. Participants had a litany of question related to space, e.g.: Are faculty in the program co-located? Are the students? Where are classes taught? Where do students meet for labs and to conduct research? While these questions may seem intuitively obvious, how they are addressed will have serious implications on the culture of the resulting program, on the cross-fertilization among students, on the collaboration among the faculty, etc.

[1] Specifically, 22 people attended two workshops, 16 attended three workshops, 5 attended four workshops, and 6 people attended all five workshops

The issues surrounding resources were exacerbated by the fact that design (in the broadest sense) does not fit well into the rigid structure that currently defines most Universities—it spans many disciplines and cuts across departmental "silos". There were many different perspectives on design's place within the university, and each view manifested different challenges with getting ***administrative "buy in"*** for interdisciplinary graduate design programs. Participants were encouraged by the support shown from the senior administrators at the host institutions, especially the Dean of Engineering, Dr. Julio Ottino, at Northwestern University, an accomplished artist and engineer who was recently characterized in *Forbes* as the "prima facie example" of the "new leader America needs more of" [5]. All agreed that design must gain the blessings of administrators in leadership positions to navigate around the red tape and establish design education as a recognized and highly regarded program. To help gain the attention of senior administrators, the consensus was that exemplary programs need to be identified, compiled, and displayed to strengthen the case for design's place in academia. The Design Workshop Series is our first attempt to do this, leveraging the findings from our initial workshop [4], which are complemented by a recent review of interdisciplinary programs in product development [6].

3.2 Faculty Issues

Assuming resources have been provided or obtained to initiate a new graduate interdisciplinary design program, the next question is: who are the faculty involved? Design (in the broad sense) is not its own discipline and does not fit in a single department; therefore, where is the ***home department for faculty*** involved with such programs? Adjunct, affiliate, and joint appointments provide some means to accommodate faculty interests across a wide range of disciplines; however, this can be very dangerous to new, untenured faculty as many warned. Therefore, what are the realities for ***"tenure-ability" of faculty*** involved with such programs? For instance, where do they publish given the trans-, multi-, and inter-disciplinary nature of their work? How is publishing outside of one's discipline perceived by colleagues in that faculty's department? Some even raised the question of whether such faculty should be on the tenure-track versus being clinical or adjunct appointments of industry practitioners. The idea that faculty working in design were "misfits" received a good deal of attention (as a positive attribute) even though it was offered rather jokingly at first. The ensuing discussion indicated that many faculty felt that they had "no true home" in one field or another and had struggled to find a place within the confines of the system. The consensus was that it was important for faculty to work within their own institution to resolve challenges surrounding interdisciplinary research and corresponding graduate programs.

Although it did not receive as much attention, many agreed that faculty's roles in such design programs differ as well. These workshops reinforced the notion of the power of interdisciplinary teaching teams, which echoed many comments in the original NSF Workshop [4]. Participants were exposed to this notion at the Michigan and Northwestern workshops, and the Stanford workshop put added weight and additional precision as to what this means in actual practice. The Stanford workshops also brought to the fore the importance of including skilled industrial practitioners as both teachers and resources for student guidance and inspiration. Finally, participants agreed the nature of the training in this type of program requires a lot of coaching and mentoring, and individualized project work. Therefore, the faculty would serve as "champions" for students in supporting their individual endeavors. Also, many felt that this mentoring should occur at several levels, not just among the faculty. For instance, Ph.D. students could help mentor M.S. students who in turn could serve as mentors to undergraduates or students in K-12 settings.

3.3 Student Issues

Once the program is established, where do the students come from and what will they leave with when they graduate? Also, it was not clear if the goal of such programs was to produce the next big name in design or a larger number of competent students. Consequently, there were many discussions regarding the types of students to attract and skills to teach, where design might best fit into the current arrangement of higher learning, and the type of graduates to produce. Identifying the target audience and determining the suitable ***degree(s) granted*** are important when developing such a program. Many agreed that the type of degree offered (e.g., M.Des. vs. M.S. vs. MBA vs. Ph.D.) will heavily influence the employment opportunities available for graduates, particularly when it comes to design [4]. Another significant challenge is how to attract diverse students considering significant funding disparities between graduate arts and engineering education.

Pertinent to the type of degree being granted is the issue involving breadth versus depth. The concept of the T-shaped student arose on several occasions, particularly at Stanford's d.school. This concept represents students' abilities in the form of the letter T. The vertical shaft represents the students' depth areas. These could be in any area, including the design of objects; however, we usually think of these in terms of disciplines such as engineering, architecture, law, medicine, business or any subspecialty thereof. The vertical leg is what traditional university education purveys. The horizontal bar represents the ability to work in groups with people outside one's discipline and to think in a more holistic way than the traditional specialist. It is the horizontal bar that a good interdisciplinary design program can bring into a student's development while enabling them to gain a healthy respect for other disciplines involved with design. For instance, courses in Michigan's Design Science Program are structured so that students build the horizontal bar upon the vertical shaft they acquired in their undergraduate and master's studies. Many participants felt this gave them a broader perspective on their roles and the possibilities of supporting students to make strong social contributions by using the empowerment afforded by student participation in interdisciplinary design teams.

Finally, for Ph.D. programs in particular, the ***advisor structure*** was cited as an important issue, making sure to represent the individual disciplines involved in the students' research (e.g., engineering and psychology and business). Candidacy (qualifying) exams for such projects also present unique challenges of their own given the interdisciplinary nature of the work. This was particularly relevant to the discussions at Michigan and its Ph.D. in Design Science, which requires two co-advisors from two different disciplines (schools) for each Ph.D. student. The consensus was that there is no single way to guide the discipline, neither in research direction nor in doctoral-level training, except for very broad strokes that entail any scientific discipline. Design Science draws from multiple disciplines, but ultimately, it should also develop its own paradigms, its own body of knowledge, and its own training mechanisms to produce successful researchers and future (design) faculty. As different Ph.D. programs in design emerge, there will be different research and training models. This was seen as a positive direction by most participants regardless of whether they agreed with the notion of "design as a science" (vs. an art vs. some combination thereof).

3.4 Pedagogy/Curriculum Issues

In all of the workshops, it was apparent that interdisciplinary design is a very broad subject area, and it includes many different perspectives. As a result, the ***curriculum architecture*** and ***core course areas*** vary significantly by program, depending on the disciplines involved within the university. Many argued the tradeoffs between training in formal quantitative models, qualitative approaches, and other less-formal aspects of design such as sketching and prototyping. Striking an appropriate balance between science and art in design was also discussed extensively, as were the connotations of Design Science and Design Thinking [7]. As indicated in Table 1, the Stanford workshop was an opportunity to look at instruction as an activity in its own right outside of the usual association with research, and many attendees were very positive about the opportunity to participate in actual Design Thinking exercises. These provided valuable experiences, in terms of learning new instructional techniques and also as a point of departure to reflect on one's own methodologies, points of view, and course objectives. The experiences invoked heated-but-friendly discussion among the many participants with their different viewpoints about design.

On the positive side, there was overwhelming agreement among the participants that an interdisciplinary graduate design program should emphasize project-based learning, teamwork, collaboration, creativity, interdisciplinarity, and systems (or design) thinking. The experience of learning-by-doing is also proving to be much more powerful than traditional learning by passive listening and artificial problem sets. In learning-by-doing a student not only learns problem solving skills, teamwork, prototyping and presentations skills, but, most importantly, the students learn how to use the world as a place to learn from, and realize that which goes on in the classroom is just the 'tip of the iceberg' as far as learning is concerned. Design students should be taught less and mentored more, either by their teachers, senior students, or both. This fostering of individual growth was regarded to be extremely important and would dictate higher faculty/student ratios in such classes. Consequently, there was consensus that the design of such programs should take a user-centered approach and allow for customization depending on the individual. The programs should be structured to enable students to explore interests through individualized studio work or independent studies in order to develop/hone skills in their areas of interest.

4. APPROACHES FOR NAVIGATING THE BARRIERS

While the preceding discussions may appear pessimistic, they are the reality, and for many, an excuse not to proceed, despite this being an area of great opportunity for transformative impact. Fortunately, we have examples of programs that have managed to navigate their institutional barriers and overcome the challenges of obtaining resources and administrative buy-in, finding and hiring suitable faculty, meeting the needs of students, and developing a suitable interdisciplinary curriculum based on their design activities. The three host universities are leading the way, in fact, and provide robust examples for others to follow as we illustrate.

To facilitate the discussion and enable cross-program comparisons, we offer the "morphological matrix" [8] shown in Table 1 to help design interdisciplinary graduate design programs. As shown in the table, each row begins with one "issue" highlighted in Section 3, and the remaining columns summarize the "solutions" that successful programs have used (e.g., RA/TA support for Funding students). We assert that each new interdisciplinary graduate design program will employ one (or more) of the solutions listed in the table in order to overcome the barriers and challenges that are commonly associated with their launch (and sustainment). While this list is not meant to be exhaustive, it captures the wide range of solutions that were offered by the host universities and the 172 unique participants involved in the Design Workshop Series.

The following sections provide a brief overview of the five programs offered by the three host universities. Websites have been included for more detailed information on each program. Following each overview, we instantiate Table 1 to illustrate how each program "solved" its own barriers/challenges. These tables were developed by faculty involved with the creation and current administration of each program at the host universities.

4.1 Design Science Program, University of Michigan

Approved in 2006, the interdisciplinary graduate design program at the University of Michigan offers a Ph.D. in Design Science with 8 students enrolled for the fall semester of 2009. The program graduated its first Ph.D. in December 2009. Described as the study of "the creation of artifacts and their embedding in our physical, psychological, economic, and social environment" by Dr. Papalambros, the program is housed within the University of Michigan's Rackham Graduate School and is supported by faculty from several different departments in the Schools of Art and Design, Business Administration, Psychology, and Engineering. Since faculty are not hired directly as Design Science professors, this program exhibits many of the challenges described in Section 3.2 in that faculty interest drives any affiliation with the Design Science program and time spent with the program must be delicately balanced with the promotion and tenure requirements of a faculty's home department. However, some of the interdisciplinary barriers are mitigated by the unique structure of the university, where the Rackham Graduate School—not a department—houses the graduate degrees offered throughout the university. The program, now in its third year, requires a student to have a Master's degree prior to becoming a Ph.D. candidate and to have two dissertation advisors from two distinctly different disciplines (i.e., advisors from two different engineering departments would not be acceptable). Funding graduate students is another common challenge, and students are required to have secured funding for two years prior to being admitted into the Design Science program. The corresponding morphological matrix for the Design Science Program is given in Table 2. To learn more about the Design Science program, visit: http://designscience.umich.edu/.

4.2 Segal Design Institute, Northwestern University

The Segal Design Institute at Northwestern University offers undergraduate design courses and certificates in engineering design but does not grant undergraduate degrees (see: http://www.segal.northwestern.edu/). The Institute is affiliated with three full-time graduate-level degree programs: (1) a management program in design and operations (MMM) that offers a combined Master of Business Administration (MBA) degree with a Master of Engineering Management (MEM) degree, (2) a Master of Science in Engineering Design & Innovation (EDI), a one-year program focusing on a human-centered approach to engineering design, and (3) a Masters of Product Development (MPD) for professionals still working in industry. Housed within the Robert R. McCormick School of Engineering and Applied Science, the institute, supported by a $5 million private donation and stands independent of all engineering departments. Classroom, meeting, and studio space for these programs is available in the new Ford Engineering Design Center where the institute resides.

Table 1. Morphological Matrix for Designing Interdisciplinary Graduate Design Programs

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
Resources	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
Resources	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
Resources	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
Faculty	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
Students	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
Pedagogy	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other
Pedagogy	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Table 2. Morphological Matrix for University of Michigan's Design Science Program

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
Resources	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
Resources	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
Resources	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
Faculty	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
Students	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
Pedagogy	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other
Pedagogy	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Table 3. Morphological Matrix for Northwestern University's MMM Program

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
Resources	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
Resources	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
Resources	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
Faculty	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
Students	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other (MEngr-Mgmt)
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
Pedagogy	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other (Human-Center-Design)
Pedagogy	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Table 4. Morphological Matrix for Northwestern University's EDI Program

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other (Lecturers)
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other (Human-Centered Design)
	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Table 5. Morphological Matrix for Northwestern University's MPD Program

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other (MPD)
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other (Prod. Mangament)
	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Table 6. Morphological Matrix for Stanford University's d.school

	Challenges:	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5	Solution 6
Resources	Getting admin buy-in	Industry letters	Letters/models other univ.	Admin mandate	Faculty advocacy	Student advocacy	Prior activity
	Funding program	Allocation/ Tuition recov.	On-line courses	Exec Ed	Masters program	Angel funding	Industry
	Funding students	RA/TA	Company supported	University/dept fellowships	NSF IGERT or fellowships	Self-funded	Angel funding
	Space	Dept space	Co-located space	New building	Rent building	Buy building	No space
Faculty	Home dept for faculty	Affiliated faculty from other depts	Dedicated lines	Adjunct faculty	Joint appointments		
	Tenure-ability of faculty	Tenure in home dept.	Tenure in design dept.	No tenure track	Prof. of the Practice	Clinical Faculty	Other
Students	Advisor structure	Individual advisor from design dept	Co-advisor from design & other dept	Non-design dept advisor	Co-advisors from different depts	Individual advisor from program	
	Degree(s) granted	PhD	MEng	MS	MFA	MBA	Other (None)
Pedagogy	Curriculum architecture	Use existing courses	Cross-list design course	Dedicated design courses			
	Core course areas	Engineering (ME, IE, etc.)	Business (Finance, Mktg, Mngmt)	Industrial Design	Psychology	Media	Other (Jrnl, CS, Medicine, Perf Arts, ...)
	Instructional delivery	Studios	Lectures	Case studies	Problem-based	Project-based	Co-taught

Dr. Don Norman discussed some practical issues that limit the effectiveness of the institute's mission to train students in the process of design from conception through production, largely focusing on issues stemming from the dependency on faculty affiliations with the institute to support teaching and research related to design. Since all faculty affiliated with the institute must first be hired within a traditional engineering department, exceptional candidates for the institute are often dismissed because their proposed research is viewed as too "soft" to match the goals of the department. If a new professor with a design focus is hired, there is often concern that the goals outlined for the tenure process do not reward the new faculty for the time commitment required to also support the institute's goals. The inability to hire faculty directly and the reliance on affiliations mostly from tenured faculty again emphasizes a theme from the workshop that success in these programs is often fueled solely by the dedication and energy of the faculty supporting them. Dr. Norman stated, "What we are trying to do as practical designers does not fit within a university," and later highlighted the need to better recognize work in design. Other challenges raised include problems faced with balancing the teaching expectations of engineering and business students and the necessity of developing quantitative views of the general principles being applied in order to create the academic depth required for a new discipline and to receive greater funding. The corresponding morphological matrices for the MMM, EDI, and MPD graduate programs at Northwestern are shown in Table 3, Table 4, and Table 5, respectively.

4.3 Hasso Plattner Institute of Design at Stanford

The Stanford d.school, officially The Hasso Plattner Institute of Design at Stanford, was created five years ago by an interdisciplinary group of faculty. The hallmark of the d.school is interdisciplinary collaboration by both faculty and students. It uses project-based education in order to actively engage students in the process of learning and creating. The main strength of the program is the dedication of the entire community (students, faculty and staff) to the development of a culture that thrives on defining and solving meaningful design problems, and to producing working solutions to real problems using a group of processes known as "Design Thinking". The concepts that define design thinking are different from the usual thrusts of engineering education. The greatest emphasis is on interdisciplinary teaching teams and student teams learning by doing. The courses use little formal lecturing or textbook learning; instead, students are encouraged to move to a state of complete immersion in a problem, with the goal of quickly creating empathy for the user and moving rapidly into the ideation phase by use of sketches, lists, and prototypes. The d.school offers course that are taken by mainly graduate students. Students come from all of Stanford's schools (Business, Earth Sciences, Engineering, Humanities and Science, Law and Medicine). The d.school courses are taken as electives in students' normal degree programs. Consequently, the d.school does not offer a degree; students obtain their degrees from their home departments.

The d.school's design courses often turn out to be the transformative experience of a student's life at Stanford—it is not uncommon for students to change their career trajectory after a d.school experience, and there have been many successful project outcomes. For example, the *Entrepreneurial Design for Extreme Affordability* student teams have designed products that have improved the lives of hundreds of thousands of people in Myanmar, India, Nepal, and Ethiopia. The student teams in the *Creating Infectious Action* course have influenced policy at Walmart, Disney, Jet Blue and several financial institutions. Teams from the *Boot Camp* class and the *Media* class have changed programming at New York Public Radio. There are also ongoing projects (called labs) that are not tied to courses. The two largest ones are the K-12 Lab and the Environments Lab. The teams in the K-12 Lab have designed classroom spaces and curricula for teaching design thinking and creative problem solving to students in elementary schools. The d.school has a strong presence in three elementary schools in the San Francisco Bay Area, in the Henry Ford Museum in Dearborn Michigan, and in some elementary schools in Bhutan and in India. The Environments Lab devises ways to use physical spaces to run multiple design classes, and designs and builds special furniture to support d.school unique teaching and project activities. The d.school's web page is a good source for more information: http://d.school.stanford.edu.

4.4 Program Similarities and Differences

As we can see from these tables, there is clearly no single solution that suits everyone—the launch (and sustainment) of interdisciplinary graduate design programs depends on a variety of factors, many of which are specific to the university and its surrounding environment. The degrees offered by these five programs range from a Ph.D. (in Design Science), to M.S. and professional Master's degrees (MBA, MPD), to no degree (in the d.school). Programs have been successfully driven from the top down (administrative mandates at Northwestern) as well as from the bottom up (faculty advocacy resulting from previous collaboration at Michigan). It is no surprise that alumni and Angel investors can play a key role in program formation (Plattner's contributions formalized the d.school at Stanford, Segal's contributions formalized the Segal Design Institute at Northwestern); however, other programs (e.g., Design Science) have found ways to accomplish their goals with some university support. Faculty affiliations and tenure concerns exist across all these programs, and the best solution depends heavily on the university structure (e.g., department vs. institute affiliation). Despite these differences, there is a large consensus that interdisciplinary design programs should emphasize: project-based (active) learning, co-taught lectures and studios, teamwork, interdisciplinarity, and systems thinking to name a few. Finally, while the monikers we use may differ (Interdisciplinary Design vs. Design Science vs. Design Thinking), we all agree that design—in the broadest sense—provides unique opportunities to engage, impassion, and ultimately transform students' educational experiences.

5. CLOSING REMARKS AND RECOMMENDATIONS

In a frequently cited quote, *The Economist* claimed that "Innovation is now recognized as the single most important ingredient in any modern economy" [9]. Meanwhile, Commerce Secretary Gary Locke recently declared that our nation's innovation system is "broken" and stated that "the United States has not adjusted to a new global marketplace where foreign countries and foreign companies have the ability to outpace their American counterparts. It's not tenable for the United States to continue with the status quo. In a world where innovation is critical to U.S. competitiveness, we must do everything in our power to optimize commercialization that stems from our nation's vast research investment"[2]. There has never been a clearer imperative to improve the creativity and innovative mindset of U.S. graduates from all disciplines.

We assert that design lies at the heart of innovation, and interdisciplinary graduate design programs such as those involved with these workshops are uniquely positioned to provide the educational opportunities to revitalize the nation's innovation ecosystem. The Design Workshop Series sought to arrive at a clearer understanding of ***who*** these new graduate programs should serve and ***what*** they should entail. Participants found the talks from the "thinkers" (academic leaders representing different design themes in the workshops' panels) as well as the design "doers" (award-winning design practitioners who spoke in, for example, "Design:Chicago") were stimulating. The barriers and challenges to creating (and sustaining) these programs were discussed at length, and many feel that now is the time for action.

The Design Workshop Series catalyzed an interdisciplinary research community that shares a passion for design. Descriptions of innovative design courses have been posted by workshop participants and are available online along with additional teaching material developed by the d.school[3]. An online community, DesignWIKI[4], was recently established by participants to share and disseminate work. One participant shared his experiences at the workshop with *BusinessWeek* and was subsequently included as one of the panelists[5] in their assessment of the "World's Best Design Schools"[6]. Several participants also reported that their involvement in the Design Workshop Series spurred the development of new interdisciplinary graduate design programs at their institutions (e.g., Iowa State, University of Illinois Urbana-Champaign), and faculty at Sheffield Hallam University in the UK created a new Design Leadership programming that united Engineering, Computing, Art and Design and Media Arts. Finally, faculty at

[2] Secretary Locke's speech is available online at: http://www.commerce.gov/NewsRoom/SecretarySpeeches/PROD01_008812

[3] http://www.stanford.edu/group/dschool/nsfdesignworkshop/

[4] http://designnetwork.wetpaint.com/

[5] http://www.businessweek.com/innovate/content/sep2009/id20090930_821020.htm?chan= innovation_special+report+--+design+thinking_special+report+--+design+thinking

[6] http://images.businessweek.com/ss/09/09/0930_worlds_best_design_schools/index.htm?chan= innovation_special+report+--+design+thinking_special+report+--+design+thinking

the University of Michigan are considering a M.S. in Design Science, and faculty at Penn State have started to offer cross-disciplinary design courses with the goal of establishing a new interdisciplinary graduate design program.

While significant strides have been made in the past year through the Design Workshop Series, considerable work remains. The following recommendations are offered to NSF to continue providing support and serving as a catalyst to:

1) Improve administrative buy-in through future interdisciplinary design workshops – in order to capitalize on this new-found momentum and interest in design, we need to get department heads, deans, and senior-level administrators involved with these workshops in order to share our passion and help us identify ways to overcome the barriers and challenges outlined in Section 3. Having them participate in Design Thinking activities like we did at the Stanford workshop would also be a valuable experience for many of them.

2) Identify lessons learned among a broader set of interdisciplinary graduate design programs – the morphological matrix introduced in Table 1 provides a clear and concise way to compare and contrast how different interdisciplinary graduate design programs "solved" the barriers and challenges at their respective universities; as such, this matrix should be used to characterize a broader set of interdisciplinary graduate design programs that exist and identify "lessons learned", which can be shared with other faculty and universities to help them avoid the same pitfalls.

3) Characterize the knowledge, skills, and attitudes of students in these design programs – while there is some consensus on *how* courses in these interdisciplinary design programs should be taught (e.g., project-based learning, teamwork, co-taught), there is little agreement on *what* should be taught; programmatic content will vary, but more work is needed to understand the knowledge, skills, and attitudes that T-shaped students need when they graduate from these programs.

4) Expand involvement of business and other design-related disciplines (e.g. industrial design, architecture, human computer interaction design, law, journalism) in these discussions – while each workshop had representation from a variety of disciplines involved with design, we should continue to grow and expand the community to identify best practices in other fields and find synergies with other disciplines. For instance, significant insight could be gained if participants were able to have discussions with a variety of innovative business leaders to both assess their needs and to better understand novel approaches used to facilitate proven innovation.

5) Identify best practices among international interdisciplinary design programs – several international programs were represented and discussed at our workshops; several schools in Europe (particularly in the UK, Netherlands, and France) have created strong design programs, some with Ph.D. programs; in Asia, there is a strong coordinated effort to build design research and education as a cornerstone of their economic engine, with efforts in China, Korea, Taiwan, and Malaysia—the recently launched Singapore University of Technology and Design (joint effort by MIT and the Singapore Government) has a very ambitious agenda that attends to the issues in Section 3, and it plans to enroll several thousand students. We need to work more with these schools and understand their modes of operation better, as they seem more eager to hire our students as design faculty than many of our U.S.-based institutions.

6) Study the role of design in innovation – while there are many definitions for innovation (e.g., translation of creativity to practice), design plays a key role in all of them; therefore, it is in our best interest to understand the role that design plays in innovation so that we can respond to the challenges facing our nation and help "fix" our innovation ecosystem.

7) Improve funding opportunities for interdisciplinary design research and educational efforts – while NSF programs like Engineering Design and Innovation, CreativeIT, and IGERT are supportive, the community could leverage large grant support through programs such as EFRI and create ERCs to strengthen connections with non-engineering disciplines that are involved with design; expanding CCLI-type grants to support graduate course and laboratory development and dissemination would also advance these efforts.

While *any* interdisciplinary graduate program will face many of the barriers and obstacles discussed in Section 3, programs centered around design may be the best suited to navigate these hurdles since design pervades every discipline, and therefore, everyone is a stakeholder. Until there is a Whitaker Foundation[7] for interdisciplinary design, we must rely on NSF and the generosity of the Plattners, the Segals, and the Fords of the world to help us establish such novel programs and infrastructures. In the meantime, we need to use design to our own advantage—if design can transform companies and organizations around the world, then so too can it help us transform the university environment wherein we are educating the workforce of tomorrow.

ACKNOWLEDGMENTS

We thank Shanna Daly (University of Michigan), Liz Gerber (Northwestern), and Micah Lande (Stanford) for their help organizing the workshops and activities at their local institutions as well as Kemper Lewis (University at Buffalo-SUNY) for his assistance codifying the morphological matrix. We thank NSF Program Directors Judy Vance, Sally Wood, Al Soyster, and Christina Bloebaum for their support of the Design Workshop Series, which was funded by NSF Collaborative Research Grants CMMI-0847181, CMMI-0847460, CMMI-0847694, and CMMI-0847104. Any opinions, findings, and conclusions or recommendations in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

[7] In the 1990's, the Whitaker Foundation granted millions of dollars to help several universities institutionalize biomedical engineering programs, see: http://bmes.seas.wustl.edu/WhitakerArchives/glance/history.html

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