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Educating Engineers for a Flat World*

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This paper encompasses and extends remarks made at the opening of a workshop on engineering and design education in a flat world by the workshop's organizing committee's chair. Held at Harvey Mudd College in May 2007, and supported by Mudd's Center for Design Education, Mudd Design Workshop VI brought together engineers and designers—in their roles as educators, researchers and practitioners interested in learning and in design—to identify and articulate important flat world issues in design and engineering education. The remarks detailed below were intended to highlight some of the issues that arise due to globalization and a developing flat world, as well as to raise some questions about what engineering educators might do that could be addressed by the workshop's presentations and discussions. While some aspects of these remarks may well have been in the vein of preaching to the converted about issues of design teaching, it is also noted herein that the many benefits associated with teaching design—which are increasingly seen as meeting many of the primary goals of engineering education—are equally relevant—if not more so—in the context of engineering education in a flat world.

Keywords: design pedagogy; design practice; globalization; flat world; design research

INTRODUCTION

> The engineer is concerned with how things ought to be—ought to be, that is, in order to attain goals and to function.
>
> Herbert A. Simon

WE ARE HERE, at this sixth Mudd Design Workshop, to figure out what ought to be the goals toward which we should strive in our engineering curricula in the face of unprecedented changes in the worlds in which we teach and in which our graduates will practice. First and foremost, at least for this discussion, are the changes due to globalization. Thomas L. Friedman, the noted foreign affairs columnist of *The New York Times*, has brought globalization to the forefront of the public's attention, in both clearly explaining its development [1] and successfully detailing how India, China other countries became part of the global supply chain of both manufacturing and services [2]. In so doing, Friedman has also made the phrase flat world a staple of our daily discussions of topics as varied as economics, foreign policy, and education. The sixth Mudd Design Workshop (MDW VI) was intended to extend the reach of prior workshops [3–7] to explore the impacts of globalization and the flattening of the world—or, to borrow another Friedman metaphor, the levelling of the playing field—on engineering education in general and on design education in particular. (Of course, for those of us who believe in Simon's dictum that design is the central feature of engineering [8], the general and the particular are the same.) Thus, we go on to articulate some of the signposts that indicate how the educational environment is being changed by the flattening of our world.

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SIGNS OF A CHANGING, FLATTENING WORLD

There are many indicators that point to changes in the environments in which we engineers (in particular) live, are educated, and practice. Some indicators reflect the vast growth of knowledge, which itself often seems to follow Gordon Moore's famous heuristic about the doubling of computer processing capability. One such indicator that will certainly appeal to academics is a simple count of journals over, say, the last forty years. If we look just at three major professional societies (the American Society of Civil Engineers (ASCE), the American Society of Mechanical Engineers (ASME) and the Institute of Electrical and Electronic Engineers (IEEE)), we can find the data shown in Table 1. These data show significant increases in the number of journals, without showing similar increases in the numbers of pages published by these journals, and without listing at all the hundreds—if not thousands—of proprietary journals that simply did not exist forty or fifty years ago.

We can identify another set of indicators of the changing environment in the several *qualitative changes in the technologies* that drive much of our individual and our societies' activities:

- We have far more devices and artifacts in our lives than any of us would have been imagined in the era immediately after World War II. Exam-

Table 1. Growth in journals published by selected professional societies

	1962	2002
ASCE Journals	17	29
ASME Journals	5	20
IEEE Journals	39	87

ples include computers, ranging from micro and handheld to super, wireless communication devices, surgical robots, nanoscale devices, genetically engineered drugs, and more.

- We also have many more processes and tools for representing and disseminating information, which has led in turn to both the dispersal and democratization of knowledge.
- The dispersal and democratization of knowledge has produced, in parallel, both the empowerment of individuals and the commoditization of tasks.

These technological changes and their consequences provide the foundations for Friedman's triple convergence [2] of forces and activities that characterize the flat world under discussion. In fact, Friedman tells an iconic story that is familiar to any frequent flyer, and especially those of us who routinely fly on Southwest Airlines. In the not-too-distant past, we would call or visit a travel agent or an airline to arrange a trip—and from whom we would obtain 'real', 'hard-copy' tickets. Friedman terms these (good?) old days as Globalization 1.0. The next stage, Globalization 2.0, emerged when we could call the airline and book our tickets over the phone. We would then retrieve them at the airport, shortly before flight time, by inserting our (identifying) credit cards into electronic ticketing kiosks. Friedman then describes how he arrived at an airport well in advance of—one and one-half hours before—a Southwest flight in order to ensure that he would get a prized 'A' boarding pass. Much to his consternation the kiosk issued only a 'B' boarding pass. While standing in the 'B' line both puzzled and irritated at his misfortune, Friedman noted that many of the passengers in the 'A' line had tickets printed on full-size pieces of paper, rather than the cardboard pass produced by the kiosk. This observation inspired Friedman's realization that we had entered Globalization 3.0: We are each our own travel agents, as which we not only make reservations and pay for our tickets over a web interface, we actually print them out ourselves!

This little story embodies the triple convergence of economic forces that Friedman identifies as the basis of the flat world, of the new and level playing field [2]:

- We see the emergence of new flattening forces that are heralded by the emergence of a knowledge society in which value is created horizontally, rather than vertically. The power of these flattening forces are both enabled and reinforced by "steroids" in computer usage at all levels. In the case of Friedman's story, these forces are clearly evident in the roles of both computers and the world-wide web.
- We see also the development of new business habits wherein both individuals and companies respond to the emerging flattening forces. In Friedman's parable, Southwest Airlines develops a new relationship with its customers by exploiting computational capabilities and the accessibility of the world-wide web.
- And, consequently, we witness as well populations of new players in China, India and the former Soviet empire. Similarly, we also note that this is the wave of an almost certain future trend in which still more new populations of players will also appear on the world economic stage. Friedman points to the widespread adoption by US customers of Southwest's new business model that presaged the emergence of new populations once the new capabilities for capturing and applying knowledge began to propagate over our once-round globe.

John H. McMasters has identified a perfect storm of forces that also reflect major changes in the environment, albeit at a somewhat different level of abstraction than Friedman's analysis. McMasters' perfect storm, which we might also call a quadruple convergence, identifies the following four major components that are also depicted in Fig. 1 [9].

- global warming (and the role that human activity plays in fostering it), which is now, apparently (and finally?) accepted and understood as the major—and in some sense perhaps the—environmental challenge facing the world;
- a rapidly growing world population and its concomitant demographics, as a result of which many countries and regions are faced with disproportionately large populations of young people who need not only food and shelter, but also education, and for whom jobs must be provided in economies that are not growing nearly fast enough;
- our increasing awareness of the finite supply of natural resources such as oil, water (especially potable water) and a variety of minerals (including soil); and
- that many of our institutions and cultures are either unable or unwilling to change or to otherwise respond positively to the other three converging trends of this perfect storm.

Some of the indicators of the extent to which the changed environment in which engineering is both taught and practiced and changed are quantitative and have emerged to capture our attention in the wake of both the economic forces described by Friedman [1, 2], but also in the initial reactions by various institutions that are concerned with engineering, technology and science within the United States. Thus, the National Academy of Engineer-

Fig. 1. McMasters' depiction of the perfect storm [9].

ing (NAE) has published two studies on the future of engineering education in the US [10, 11] and the National Research Council (NRC) has published a study that examines more broadly the impact of the changes on the future of the US economy [12]. (Some of the premises underlying the NRC study have recently been called into question [13].) Without responding directly to any of these studies and findings, it does appear that they are consistent in presenting some numbers that seem simply startling, including:

- the number of U.S. bachelor's degrees in engineering (BSEs) as a share of total US baccalaureate degrees and in absolute counts has dropped from 7.8% (77,572) in 1985 to 4% (72,893) in 2004;
- China graduated more than 200,000 (44% of its total baccalaureates) in 2004 and is planning to increase that total to 1,000,000;
- of 2,800,000 first degrees in engineering and/or science granted world wide in 2004, 1,200,000 were awarded in Asian universities, 830,000 in Europe, and 400,000 in the US; and
- Asian universities produced eight (8!) times as many BSE degrees as do their American counterparts.

Now, as already noted, some of these numbers have already been questioned or challenged, for example, on the grounds of quality of the institutions and their respective programs, and even on the very accuracy of the numbers cited because of a lack of uniformity of counting standards [13]. And it is not our present purpose to either affirm or deny these findings, but only to note that they are part and parcel of present perceptions of the environment in which engineering education is taking place.

To bring this portion of our discussion to a close, we follow Friedman's lead [2] and observe that we, as engineering educators, must face that fact that we are preparing our graduates as future professionals who will practice engineering on a new, level playing field that is characterized by the facts that:

- there is geographically dispersed engineering talent that is almost instantaneously available across the world, and with whom our graduates must work and with whom they must also be able to compete;
- many engineering tasks have become commodities that can be outsourced to this geographically dispersed talent, as it already is to engineers in China, India and the former Soviet empire;
- US firms will retain engineers and engineering tasks stateside only if their results add value and if they can be used to differentiate themselves in the marketplace.

This is the marketplace that, as design and engineering educators, we face, and that our students must anticipate and be themselves prepared to constructively engage.

DESIGN EDUCATION AS THE WORLD TURNS: ROUND => FLAT

> Schools of engineering . . . are all centrally concerned with the process of design. Engineering schools have become schools of mathematics and physics.
>
> Herbert A. Simon

Simon's two observations about engineering schools appear on the same page in his landmark lectures on *The Sciences of the Artificial* [8]. They reflect a view that is increasingly widely shared, namely, that engineering schools ought to focus on design as their central activity, rather than being schools of applied science, that is, applied mathematics, applied physics, and so on. The foundations of this engineering science approach to the study of engineering has been widely and frequently discussed (e.g. see [14, 15] and many of the references cited in both) and so will not be explored again here. Suffice it to say that the fundamental curriculum model inspired by the Grinter report [16] still obtains almost universally (at least in the US), but in recent years the schools of engineering that offer such curricula have been under what might be termed as a triple convergence of pressures.

The first element of the convergence is curriculum pressures that push toward reducing the number of credit hours required to complete a typical bachelor's programme. For example, over the period 1962–2002 the credit hours required at The Cooper Union and at Harvey Mudd College have declined, respectively, from 143.5 to 135 and from 138 to 128 (see Figs 2 (a, b)). This trend has been fairly common, so that engineering programmes now typically require 128 credits. Further, many institutions have long been discussing the notion of reducing the number of engineering credit hours to the same number typically required for B.A. degrees, that is, 120 hours. Of course, the reasons for these particular pressures may well vary with the institution, but there seems to be a widespread sentiment outside of engineer-

1962			**2002**		
1st Year	F	S	1st Year	F	S
Chemistry I, II	5.5	5.5	Chemistry I, II	3	4.5
Mathematics I, II	4	4	Mathematics I, II, III	6	4
Physics I		5	Physics I		4
English I, II	3	2	Studies in Lit. I, II	3	3
Engrng. Graphics	4.5		Engrng. Design	3	
Surveying		5	Comput. Prog. for Engrs.	2	
Physical Education	1	1			
2nd Year			2nd Year		
Mathematics III, IV	5	3	Mathematics IV, V, VI	4	3
Physics II, III	6.5	4	Physics II, III	5.5	4
Statics & Dynamics I, II	2	2	Engrng., Solid Mechanics	3	3
Civil Engrng. Problems		4.5	Materials Science	3	
Economics	3		Elect. Engrng.		3
Public Speaking	2		Engrng./Sci. Elect. I		3
Civilization I		3	Modern Society I, II	3	3
3rd Year			3rd Year		
Elect. Circuits & Machs.	3		Environ. Systs. Engrng.	4.5	
Mechs. of Materials I, II	4	4.5	Engrng./Sci. Elect. I		3
Fluid Mechanics I	4.5		Fluids, Water Res. Engrng.	3	4.5
Structures I, II	3.5	4.5	Structures I, II	4.5	3
Thermodynamics		3	Theromodynamics	3	
Soil Mechanics		3.5	Soil Mechanics		4.5
Civilization II, III	3	3	Hum. & Soc. Sci. Elect. I, II	3	3
4th Year			4th Year		
Highway Engrng.	2		Structures III	3	
Fluid Mechanics II	3		Urban Transport. Planning	3	
Civil Engrng Design I, II	4.5	4.5	Civil Engrng. Design I, II	3	3
Civil Engrng Projects I, II	1	1	Civil Engrng Projects		2
Atom. & Nuclear Physics	3		Engrng./Sci. Elect. II, III, IV	3	6
Civilization IV	3		Hum. & Soc. Sci. Elect. III, IV	3	3
Sanitary Engrng.		3.5			
Structures III		3			
Social Philosophy		3			
TOTAL CREDITS (1962)	143.5		TOTAL CREDITS (2002)	135	

Fig. 2(a). Cooper Union's B.C.E. curricula for 1962 and 2002 [15].

1962			**2002**		
1st Year	F	S	1st Year	F	S
Chemistry I, II	4	4	Chemistry I, II	4	4
Mathematics I, II	4	4	Mathematics I, II	4	3
Physics I, II	4	4	Physics I, II	2	4
English I, II	3	3	Hum. & Soc. Sci. I, II	4	3
Engrng. Problems III, IV	2	2	Intro. Engrng. Design		3
			Computer Science	3	
2nd Year			2nd Year		
Chemistry III, IV	3	4	Mathematics III, IV	3	3
Mathematics III, IV	3	3	Physics III	4	
Physics III, IV	4	4	Hum. & Soc. Sci. III, IV	3	3
Humanities I, II	3	3	Biology or Free Elective	3	3
Social Sciences I, II	3	3	Intro. Engrng. Systems	3	
			Experimental. Engrng.		3
			Design Rep. & Real.		1
			Continuum Mechanics		3
3rd Year			3rd Year		
Thermodynamics	4		Chem. & Thermal Processes	3	
Elec. Engrng. I, II	4	3	Electron. & Magnet. Devices	2	
Mechanics		3	Computer Engrng.		3
Technical Electives I, II	3	3	Adv. Engrng. Systems I, II	3	3
Mathematics V, VI	3	3	Engrng. Seminar I, II	0	0
Humanities III, IV	3	3	Engrng. Clinic I		3
Social Sciences III, IV	3	3	Technical Elective I		3
			Hum. & Soc. Sci. V, VI, VII	6	3
4th Year			4th Year		
Sol. State Mol. Engrng.	3		Materials Engrng.	3	
Engrng. Lab. I, II	2	2	Engrng. Seminar III, IV	0	0
Engrng. Des. & Anal. I, II	4	4	Engrng. Clinic II, III	3	3
Technical Electives III, IV	3	3	Technical Elective II, III	3	3
Humanities V, VI	3	3	Hum. & Soc. Sci. VIII–XII	6	9
Social Sciences V, VI	3	3	Integrative Experience	3	
TOTAL CREDITS (1962)	138		TOTAL CREDITS (2002)	128	

Fig. 2(b). Harvey Mudd College's B.S.E. curricula for 1962 and 2002 [15].

ing departments that engineering is too demanding a course of study and it should be scaled back to conform to more standard college programme requirements.

Another facet of pressure on the curriculum is the increased interest in having engineers learn and improve their soft skills (which some might call professional practice skills), that is, their communication skills, both verbal and written, their ability to work in teams and their understanding of both ethics and the societal implications of their work. For example, ABET's recently-adopted Engineering Criteria 2000 reflect the importance of these soft skills. This can be seen in a listing of some of ABET's criteria for graduating engineers [17], which are also very similar to the well-known Boeing list of highly desired attributes [18]:

criterion **(c)** states a goal that engineering graduates have 'an ability to design a system, component, or process to meet desired needs,
criterion **(d)** addresses the need to function on multi-disciplinary teams,
criterion **(f)** addresses social and ethical responsibilities,
criterion **(g)** addresses communication skills,
criterion **(h)** addresses global and societal impact.

Emphasis on the ABET criteria produces pressure on the curriculum because, for most engineering faculty, making space for the skills behind these criteria means reducing the number and scope of the *hard* courses that 'everyone must take'.

Still another part of the curriculum pressures are embodied in actions such as the adoption of Policy 465 by the American Society of Civil Engineers (ASCE), which was also recently incorporated into the model law of the National Council of Examiners for Engineering and Surveying (NCEES) [19]. The crux of Policy 465 is a formal recognition that an undergraduate degree no longer provides sufficient depth to provide a basis for professional registration, that is, for a P.E. licence. Instead, registration requirements would be based on (1) a more general (and perhaps less demanding) undergraduate degree and (2) a master's degree in engineering or 30 additional credits of approved upper-level undergraduate courses or graduate courses. While it is likely a long time before this sentiment is formally adopted by all of the engineering schools and all of the professional societies, it is certainly one of the futures envisioned in the NAE study [11].

The second pressure in our triple convergence is that produced by perceived changes in the quality of the mathematics and computer skills of our engineering undergraduates. While it might have been a misplaced sentiment, it was also the *sine qua non* of engineering education that mathematics was the language of engineering. Thus, a major part of the first two years of the engineering curriculum is devoted to mathematics, and most of the courses taught in the last two years are really exercises in the mathematical modelling of solids, fluids, circuits, etc. We have emphasized mathematics both as the means for setting and formulating problems, and as the means by which these problems are to be solved [14]. As a result, prospective engineering students take more advanced (AP) courses in mathematics in high school, and a high score on the mathematics SAT is viewed as a strong indicator of how well an engineering student will fare. Nowadays, on the other hand, many engineering faculty feel that our entering students do not have the mathematical skills and depth that they should, although they are widely credited with a high degree of computer literacy. (This attribute is not an unmixed blessing: far too many students nowadays equate library research with web searches and the consequent citation of web links of dubious provenance.) In addition, it has become commonplace that engineering faculty expect students to do their homework (and even their exams) on a computer. This often fosters a disconnect between the modelling of problems that is done in mathematics and the subsequent computer-based solving of those same problems. All too often, students exercise computer programs without understanding what they can (and cannot) do or the limits imposed on those very same programs by their creators. Thus, while there's no doubt that students and faculty alike widely use computers, it is less clear that students (and sometimes faculty as well) understand the underlying mathematical and physical models that their programs use, or develop the kinds of insights they need to properly interpret the numbers that their programs produce. That is, are students schooled to think about the dimensions and units of their calculations, or about the relative magnitude(s) of their results, or even about the number of significant figures that are meaningful and appropriate?

The last curriculum pressure in this triple convergence is an emerging one whose influence is as yet unclear. While it is increasingly widely understood that engineering practice has changed a lot in recent years, it is not yet clear that engineering schools have integrated this awareness into their curricula in very meaningful ways. The elements of the changes lie partly in the realm of computer practices, albeit in a different sense and at different levels from the computer issues just described above. But they also lie in the phenomenon that Friedman refers to more generally as commoditization [2], and that is in the fact that engineering tasks have also become commodities. This is due in part to the fact that many basic design and analysis tasks have become sufficiently routine that they can be automated to some degree, and so they are readily incorporated into computer programs. But it is also due to the fact that engineering talent spread around the globe is now able to work on parts or all of an engineering endeavor because of new communication capabilities—especially the Internet and the world-wide web, and most notably, that talent can interact with other geographically (and temporally) dispersed engineers, managers, marketers, etc. The challenge to engineering educators is thus to reflect two changes in engineering practice: the kinds of tasks that engineers will do and the teamwork required of engineers working with other talent at sites that are no longer 'just down the hall'.

In the face of these challenges to our accustomed traditions of engineering education, several questions emerge:

- What do we want our engineering students to learn?
- How are we going to teach it?
- Are engineering schools able and willing to change to reflect the new realities?

It is hard to know how to answer these questions and, for the moment, it seems very hard to believe that the answer to the last question is (sufficiently) positive and affirmative. It is a sad fact that engineering curricula are still:

- highly structured, serial course sequences;
- in which the early (and foundational) courses are taught by non-engineers;
- remain institutionalized in a science or reductionist model of engineering.

In fact, Fig. 2 clearly show that at two of the best-known undergraduate schools of engineering, the curricula have hardly changed since the early 1960s. There have been some changes (e.g. the introduction of courses in computer science and in biology), but the first two years of both programmes still embody the same foundational structure embodied in the recommendations of the Grinter report [16]. The preponderance of the engineering science aspect of current curricula is also still (more) evident in Fig. 2(a), wherein in a style more typical of discipline-specific curricula, the balance is clearly tipped more toward analysis (reductionism) than design (synthesis).

In terms of what schools of engineering should strive to teach, one set of ideas is expressed in the following quotes. Consistent with the observations just above about the content of current engineering curricula, McMasters [9] has suggested that 'beyond being "theoretical carpenters" (i.e., who have a good knowledge of the physics and metallurgy of their tools, but have never themselves made anything even of wood), engineers must be able to create or synthesize systems or design'. Wulf [20] has noted that 'engineering is both a body of knowledge and a process'. These quotes reinforce the ideas that engineering education is much more than a list of required subjects. Rather, the engineering curriculum should be viewed as the sum of a set of experiences in which future engineers will participate and a set of skills that they will acquire as a result of those experiences [14]. Then, perhaps, engineering students will learn to think like engineers. However, since the purpose of this sixth Mudd Design Workshop is, in fact, to propose some key ideas for the future of engineering education in this flat world era, we close this part of our discussion by suggesting a few questions that workshop participants might address as the workshop unfolds. These questions include:

- What engineering tasks and jobs are buffered against Friedman's level playing field?
- What roles should graduating engineers (and their mentors and faculty role models!) play in the face of McMaster's perfect storm?
- What should engineering education encompass and emphasize given the forces unleashed in Dym's triple convergence?
- What can we do to persuade our institutions to face and realistically engage all of the above?

CONCLUSIONS

> . . . the engineering curriculum is an artifact, worthy of design.
>
> Clive L. Dym after Lynn Conway and Mark Stefik

The principal conclusion we draw from or about the trends and forces described above is this, which is a modification and extension of the major conclusion of a recent comprehensive survey of design thinking [21]:

> . . . the most important recommendation is that engineers in academe, both faculty members and administrators, seriously address the issues raised by globalization and by environmental changes and work to appropriately design their pedagogy in future curriculum decisions.

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