Strategic Design of Engineering Education for the Flat World

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Abstract

We believe that two critical success factors for an engineer in the flat world are an ability to adapt to changes and to be able to work at the interface of different disciplines. Instead of educating traditional domain-specific and analysis-oriented engineers, we believe that the focus should be on educating and graduating strategic engineers who can realize complex systems for changing markets in a collaborative, globally distributed environment.

In this paper, we identify three key drivers that are foundational to future engineering design education programs. These drivers include a) emphasis on strategic engineering, b) mass customization of courses, and c) utilization of IT-enabled environments for distributed education. Strategic engineering is a field that relates to designing and creating complex systems that are adaptable to changes. Mass customization of courses refers to adapting the course material to educational goals and learning styles of different students. IT enabled environments bring distributed students and instructors closer in the form of a virtual classroom. These three drivers are discussed in this paper with examples from the Georgia Tech Regional Engineering Program (GTREP).

I Motivation and Background

In his recent book, *The World is Flat* [1], Thomas L. Friedman showcases Georgia Tech's approach to education in the 21st century. "*What the Georgia Tech model recognizes is that the world is increasingly going to be operating off the flat-world platform, with its tools for all kinds of horizontal collaboration*," writes Friedman. In the chapter "*The Right Stuff*," Friedman describes how Georgia Tech has worked over the last 10 years to attract and retain more students with more wide-ranging interests, with the thought that these students are more flexible and able to adapt and work across disciplines. According to Friedman, "*Georgia Tech is producing not just more engineers, but the right kind of engineers*". These future engineers will be intellectual leaders that are prepared for success in an era that demands flexibility, creativity, experimentation, and teamwork across traditional boundaries.

Georgia Tech Savannah seeks to be a technology-enabled academic enterprise of diverse students, faculty and staff that is globally recognized for *innovation in engineering-centric education, scholarship and economic development.* In order to comprehend the Woodruff School

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Savannah's response to globalization: '*innovation has no boundaries*'; one needs to be in harmony with a particular mindset regarding engineering innovation. Quoting George Bernard Shaw (Back to Methuselah, Part 1, Act 1, 1921), '*You see things; and you say, "Why?". But I dream things that never were; and say "Why not?"*', we always articulate the following innovation enabling question: "Tell me why things cannot be done?" In addition to this, we strive to live up to what Wayne Gretsky once answered to the question about the secret behind his success as a hockey player was: "*I skate to where the puck is going to be, not where it has been*".

In order to respond to globalization and produce the right kind of engineers for the flat world, our focus at the Woodruff School of Mechanical Engineering in Savannah is on developing ***strategic engineers.*** These are *engineers who know how to realize complex engineered systems for changing markets in collaborative, globally distributed environments thereby safeguarding the economic viability of the companies they represent and hence fostering the prosperity of our country* [4]. Such strategic engineers are also:

- great collaborators, i.e., engineers who can build global supply chains
- great leverages, i.e., engineers who can leverage technology so that one person the do the job of twenty
- great synthesizers, i.e., engineers who can take "A" and "B" to make "C"
- great localizers, i.e., engineers who can create a small business locally, and
- great adaptors, i.e., engineers who can adapt to rapid and large changes.

However, in order to educate strategic engineers having the capabilities outlined above, engineering education has to undergo radical change to accommodate and finally meet the requirements emerging from continuously progressing globalization. Three key drivers have been identified to form the basis of a strategy for design engineering education programs tailored for the flat world. These are:

- From a technical point of view, an emphasis on **strategic engineering**,
- From an educational perspective, the realization of **mass customization** of courses, and
- From a technology-centric perspective, the development of **IT-enabled environments** for globally distributed education without any boundaries whatsoever.

An overview of these strategic drivers as well as concrete corresponding approaches and piloting activities pursued at Georgia Tech Savannah are presented in this paper.

II Education of Strategic Engineers for the Near Tomorrow

In 2004, the National Academy of Engineering published a report summarizing visions of what the engineering profession might be like in the year 2020 [2]. They had deployed so-called scenario-based strategic planning to develop their prediction of the future. A year later, they published a follow-up report on how to educate the engineer of 2020 [3]. In brief, they made clear that engineering education has to be adapted to the challenges of the future, particularly with regard to globalization. In order to realize a new form of global distributed engineering education for which it is envisaged to get rid of any boundaries, new educational models encompassing the design of programs and courses, novel ways to deliver them, new IT-infrastructures, as well as solutions for a number of other issues, such as accreditation, credit transfer etc. have to be developed. In light of this, the term *strategic engineering* can be understood in two ways. Firstly, it refers to the development of strategies for realizing engineering education as required in the year 2020 settings. Secondly, it refers to the development of new strategic role models, paving the way for a new kind of engineer, capable of combining various scientific fields. These engineers will be characterized by their competencies, which refer to knowledge, skills and attitude. All that is needed to become a new kind of (design) engineer, capable of tackling the complicated multidisciplinary questions our society is facing.

The Woodruff School of Mechanical engineering at Savannah seeks to develop rigorous, innovative, experiential educational programs that integrate disciplines and that engage students in the excitement of learning, motivate their passion for positive societal impact and develop leaders for the future.

Strategic engineering education seeks to foster design as a basis to create value for the economy (Figure 1).

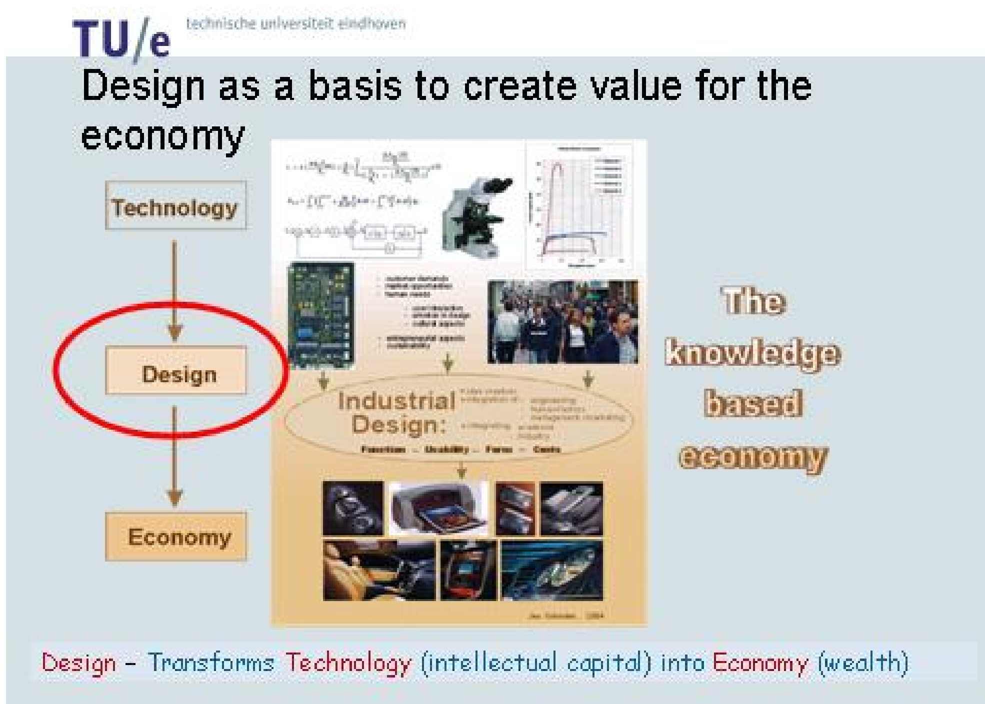

Figure 1: Design as a basis to create value for the economy

In other words, design transforms technology, i.e., intellectual capital into economy (wealth). Core elements of such a program have to incorporate design methods, technology, business processes, and users (Figure 2).

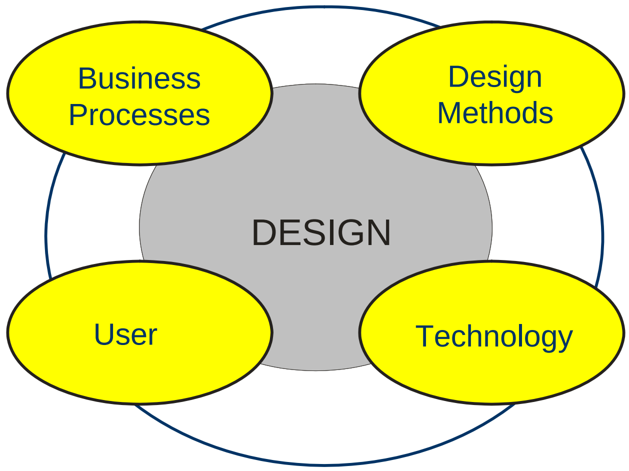

Figure 2: Core elements of a strategic engineering design program

Some related example applications that allow innovating at the interface between disciplinary emphasis (e.g., fluid mechanics, materials, heat transfer and manufacturing) and system realization (e.g., design, manufacturing, life-cycle activities) in distributed engineering environments include:

- Design methods for complex engineered systems - product families and architectures, the design and analysis of knowledge and information flows.

  Example research: investigations that result in simulation-based, distributed engineering of complex engineered systems.

- Design, analysis, and fabrication aspects of products that employ ambient intelligence (are context aware, adaptive, and anticipatory); embedded sensors, sensor networks that facilitate automated reconfiguration.
- Rapidly reconfigurable business processes including supply and value chains and e-commerce.

  Example research: investigations that are embodied in network/graph theory and that result in reconfigurable, dynamic chains.

- User observation methods and customer needs analysis relevant to product creation, development and testing.

  Example research: investigations that lead to symbiotic collaboration between humans and technology.

- Affective engineering techniques to design more satisfying products.

III Mass Customization of Courses

Engineering courses are currently mainly focused on the aspects of analysis. In addition to the analysis skills, a strategic engineer must possess critical thinking skills, abstraction, and synthesis skills. Critical thinking allows them to observe a situation and frame the problem, abstraction skills are required to identify the crux of the problem, whereas synthesizing skills are important for utilizing available information to solve the problem.

In order to facilitate learning of these skills, a paradigm shift is required in the manner in which engineering courses are taught. Williams and Mistree [6] present a model for teaching engineering design courses, which relies on mass customization of courses for students' interests and learning styles. In other words, the emphasis is on *offering a course to the individual in a group setting*. The mass customization model of a course relies on creating an environment for active learning rather than passive one way flow of information. The professor acts as an *orchestrator* who architects the course content, motivates the students and provides the necessary scaffolding to facilitate learning. The orchestrator uses various tools to customize the course content for different individuals through various modes for managing student learning variety. These modes include tailoring of lectures, presentation style, examples, in-class discussions, learning essays, assignments, and evaluation to suit the individual's educational needs. The orchestration tools used in such a setting encourage active involvement of students in taking control over their own learning. Hence, the students learn the process of creating their own knowledge, i.e., learning how to learn. We discuss these orchestration tools in the context of a graduate level course "ME6102 - Designing Open Engineering Systems" offered at Georgia Tech.

The first step in offering a customized course is gaining an understanding of the goals of the students for the semester. The students are asked to identify and prioritize their personal learning goals in Assignment 0, which is handed out during the first day of the class. These learning goals are centered on the general theme of the course and the manner in which the course is orchestrated. Examples of personal goals include "learning how to design open systems", "learning how to design for changing requirements", "learning how to validate a design method", "learning how to formulate design problems", "leaning how to design for environment", etc. These goals are utilized by orchestrators to customize the lectures and examples, and to provide individualized feedback. Further, defining their own goals at the start of the course makes the students proactive towards their own learning.

The students are introduced with the Observe-Reflect-Articulate paradigm of learning and are encouraged to represent their work using these steps. With an understanding of the manner in which learning takes place, the students are empowered with the ability to provide customization at their own level. It also brings out the process of individual learning and helps the orchestrators to understand the learning process of each student.

During the first lecture, the students are also given a Question for the Semester (Q4S). The answer to this question is due at the end of the semester and all the activities throughout the semester are targeted towards answering this Q4S. The Q4S for ME102 is as follows: *We imagine a future in which geographically distributed engineers collaboratively develop, build, and test solutions to design-manufacture problems encountered in the product realization process. In this* *context, we want you to provide a method to support the realization of mass customized industrial products for a global marketplace through distributed design and manufacture*. In order to answer this question, the course is partitioned into three phases – a) defining the world of 2020, b) understanding the world of today and identifying gaps, and c) developing the design method for 2020. The lectures and assignments are used to scaffold students' answer to the Q4S.

In the first phase, the students are asked to identify the changes that will take place by 2020 and describe the environment in which they will be working. Depending on students' interests and research field, they highlight different aspects such as collaboration, globalization, environmental considerations, outsourcing, etc. This provides significant opportunity for students to personalize the Q4S and identify specific aspects of the world of 2020 that they want to focus on. In the second phase, the focus is on analyzing existing design methods that are used today and identify the shortcomings of current methods to address future needs.

In the third phase, various approaches and methods for designing systems for 2020 are discussed. The design methods discussed in the course are from the standpoint of designing Open Engineering Systems. The definition of Open Engineering Systems used in the course is "Open Engineering systems are systems of industrial products, services, and/or processes that are readily adaptable to changes in their environment which enable producers to remain competitive in a global marketplace through continuous improvement and indefinite growth of an existing technological base"[5]. Examples of approaches for designing Open Engineering Systems include modularity, robustness, product architectures, standardization, handling uncertainty in design, validation, distributed design, mass customization, and strategic design.

Every week, the students are asked to write an essay on learning. In these learning essays, the students get the opportunity to articulate how the content covered in the class relates to their goals. The students are not provided any fixed structure for learning essays. The essays enhance students' creativity and allow them to focus on aspects that are more important to them. Hence, learning essays provide an avenue for personalizing students' learning.

The learning essays are complemented by various assignments that are heavily scaffold towards answering the question for the semester. The students are provided broader assignments that can be customized by the students based on their individual interests. As opposed to learning essays, the assignments have a well defined structure so that the students can follow the process of Observation, Reflection and Articulation. The orchestrators provide flexibility in terms of submission dates of assignments to allow the students to learn at their own pace. Collaboration with other students is a key ingredient in the course. The students are provided best practices from other students who are either in the class or have taken the course previously. These best practices encourage students to learn from their peers. Using the best practices, the students are able to build on the work done by other students in order to create value. The orchestrators provide personalized feedback to the students on learning essays and assignments. The feedback is provided to guide the students on the next steps. The students' submissions are not graded until the end of the semester. Hence, the students take greater risks without being constantly concerned about getting a good grade. Finally, at the end of the semester, the students create their own grading scheme based on their learning goals. Using this grading scheme, they evaluate their learning throughout the semester. By evaluating their own learning, the students identify their strengths and weaknesses and are able to identify the possible avenues for improvement. Ability of self evaluation paves their way for lifelong learning.

In summary, mass customization of the course aids and empowers students both in their internalization of course content and their development of critical analysis, abstraction, and synthesizing skills that in addition will help them become lifelong learners. We believe that this is a step towards preparing our students for the flat world.

IV IT-Enabled Instruction and Virtual Classroom

Significant advances in IT facilitate real-time collaborations and have great potential to change the current learning environment. Key advantages of using latest IT advances in distributed education include extension of the reach of education, adaptability to changing lifestyles and demanding schedules, and the availability of a richer diverse learning environment. A key challenge in distributed education is achieving a right balance between the synchronous and asynchronous aspects of communication to maximize individual learning.

Georgia Tech Savannah is incorporating novel distributed education tools such as electric whiteboards and advanced video teleconferencing systems into geographically distributed courses offered within the Georgia Tech Regional Engineering Program (GTREP). The purpose of GTREP is to provide increasing access to engineering education for southeastern Georgia students with the partnership of three institutions - Armstrong Atlantic State University, Savannah State University, and Georgia Southern University. In this section, we discuss academic factors for advanced distributed education methods, which can support real-time feedback and team project collaboration, along with the technical overview of our current system configuration. In addition, we discuss the challenges we are facing with balancing the synchronous and asynchronous aspects of learning and some of the approaches we have adopted to effectively use IT enabled instruction.

Balancing the Synchronous and Asynchronous Learning Environment

The traditional learning style, namely synchronous learning through face to face interaction between faculty and students, is still the main approach of the education. The weakness of the traditional synchronous environment is distance and time constraints for instructors and students. To overcome the obstacles of the traditional institutional norms, alternative methods are required. Advances in new technologies, such as 3D visualization, simulation, and networking, provide new learning experiences. Asynchronous Learning Networks (ALN), that employ information technology, include the self-study learning methods (i.e., computer-based learning, viewing tapes, reading, etc.) and asynchronous people-to-people interactions as shown in Figure 3. Accordingly, ALN represents the idea that people can learn at different times and different locations; namely anywhere-anytime learning networks [8].

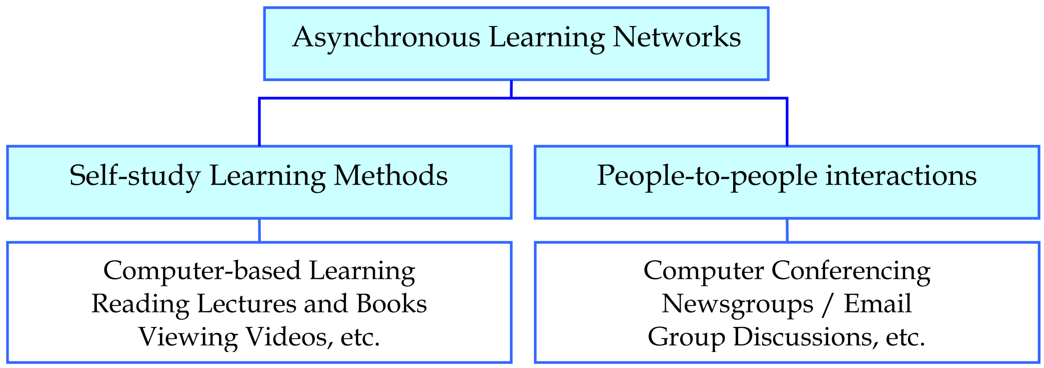

Figure 3: Components of the Asynchronous Learning Networks

Although ALN shows the clear advantages for distant and local education in terms of the learning time and learner's performance, it requires extensive preparation and planning for the development of the class materials to make ALN as good as the traditional learning environment [7, 8]. Thus, a combination of ALN and modest synchronous mechanisms can be an optimal solution for the higher education, especially for off-campus learners. In the following subsection, we discuss a test-bed for understanding the balance between synchronous and asynchronous aspects of the learning environment.

Integration of the IT-enabled Instruction Tools into a Geographically Distributed Course

Important advances in IT-enabled instruction tools, such as Tablet PC and video teleconferencing technologies, can facilitate real-time collaborations and have great potential to change the current learning environment. Georgia Tech Savannah (GTS) is incorporating these new technologies into geographically distributed courses. The students of the partner institutes attend classes through the distance-learning connections under the GTREP; namely, a teacher and students are physically distributed in multiple campuses. In a selected course, *ECE2025: Introduction to Signal Processing*, the faculty members are exploring the usefulness of the Tablet PC for various learning activities of the geographically dispersed groups including scientific visualization, data exploration and analysis, engineering design procedures, and team projects. During the class, students work in groups for class projects/questions and demonstrate the efficacy of the Tablet PC to the applications of dynamic systems. The multi-campus student group will prepare and present their project work in class and orchestrate the ensuing class discussion via Tablet PC technology. This kind of problem-based learning is identified as one of the best pedagogical practices for improving learning of design concepts.

GTS has identified the efficacy of the IT-enabled instruction tools to enhance the teaching and learning environment of undergraduate and graduate engineering classes in which a teacher and students are physically distributed to multi-campus. This test-bed effort can be a role model for geographically distributed courses which should be able to support real-time feedback and team project collaboration through IT-enabled instruction tools. The long term goal of the current effort is to establish a virtual and collaborative learning environment that increases student motivation and success in education through advanced IT technologies. GTS currently pursues a new education program that integrates engineering and business or education and prepares students for careers in IT-enabled engineering. It is expected that the identified results of the current GTS's IT-enabled learning environment will contribute to construct a teaching/learning role model for geographically dispersed courses.

V Initiatives at the Woodruff School of Mechanical Engineering in Savannah on Engineering Education in the Flat World

V.A GTREP: A Collaborative Engineering Program

As mentioned in Section IV, the Georgia Tech Regional Engineering Program (GTREP) is an academic collaboration between Georgia Tech and three partner institutions: Armstrong Atlantic State University and Savannah State University in Savannah, and Georgia Southern University in Statesboro. During the first and sophomore years of the undergraduate program, students are enrolled through one of the three partner institutions. These universities offer all of the mathematics and science courses and some of the engineering courses required in the first two years of the Georgia Tech engineering curricula. Prior to their junior year, students apply for transfer admission to Georgia Tech and complete their degree program as a Georgia Tech student. During the junior and senior years, the students are taught by Georgia Tech Savannah faculty supplemented by distance learning connections. Non-engineering portions of the degree program continue to be offered by the partner institutions during the junior and senior years. Currently, GTREP offers undergraduate degree programs in civil, computer, electrical and mechanical engineering. Students graduating from GTREP receive a Georgia Tech degree with the designation Regional Engineering Program.

V.B A Global Product Creation Network

Recently, Georgia Tech Savannah, Technical University of Eindhoven (the Netherlands), and the Indian Institute of Technology, Kharagpur have developed a shared vision and decided to jointly realize a premier global network for product creation, focusing on the development on innovative methodologies, processes and technologies. The mission is to create and nurture leaders and pioneer knowledge in product creation to fuel sustainable economic growth through continuous innovation.

From a university perspective, this network seeks to further design science and educate design engineers who create high value added products and processes that efficiently *and effectively accommodate:*

- Dynamic global markets and associated customer requirements
- Dynamic global business processes
- Technological innovations
- Collaborative, distributed, multicultural, international environment

There will also be industrial partners involved. From their perspective, the product creation network seeks to further design science and educate design engineers who create high value added products and processes *that drive and sustain the economic viability* of companies in an industrialized world thereby sustaining the economic and ecological well-being of the global community.

VI Closure

In this paper, we share our thoughts on how to strategically re-design engineering education in order to position the Woodruff School of Mechanical Engineering for what lies ahead in terms of meeting the challenges of a flat world, rather than waiting for time to pass and then trying to respond. A number of associated issues regarding the development of future engineering curricula and programs, ways to adapt them to the flat world, the customization of engineering education, as well as the utilization of IT to enhance student learning in distributed educational settings are discussed.

We recognize that much remains to be done and that what needs to be done cannot be done by us alone. Accordingly, we invite you, our colleagues, to join us in identifying what needs to be done and how we can have *fun in defining the emerging science-based discipline of design. Fun in providing an opportunity for highly motivated and talented people to learn how to achieve their dreams.* Collaboratively, we can live up to what Joel A. Barker once said: "*Vision without action is merely a dream. Action without vision just passes the time. Vision with action can change the world*".

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Dr. Dirk Schaefer is an Assistant Professor in the George W. Woodruff School of Mechanical Engineering at Georgia Tech Savannah, USA. His research interests are focused on the high-impact interdisciplinary area of Information Engineering for Complex Engineered Systems. Prior to joining Georgia Tech, Dr. Schaefer was a Lecturer in the School of Engineering at Durham University, UK. He has published around fifty papers on Computer-Aided Engineering and Design in conference proceedings, journals and books. Dr. Schaefer is a member of several professional affiliations including The American Society of Mechanical Engineers (ASME), The Institute of Electrical & Electronics Engineers (IEEE), The Association for Computing Machinery (ACM), The American Society for Engineering Education (ASEE), The Institution of Engineering Designers (IED), and The British Computer Society (BCS). Furthermore, Dr. Schaefer is a registered professional European Engineer (Eur Ing) and a Chartered Engineer (CEng), a Chartered IT-Professional (CITP) and a Fellow of The Higher Education Academy (FHEA) in the United Kingdom.

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Dr. Seung-Kyum Choi began at Georgia Tech in Fall 2006 as an Assistant Professor in the George W. Woodruff School of Mechanical Engineering. Prior to joining Georgia Tech, Dr. Choi was a research assistant at Wright State University, conducting research on uncertainty quantification techniques for the analytical certification of complex engineered systems. His research interests include structural reliability, probabilistic mechanics, statistical approaches to design of structural systems, multidisciplinary design optimization, and information engineering for complex engineered systems. Dr. Choi is a member of the American Society of Mechanical Engineers (ASME), the American Institute of Aeronautics and Astronautics (AIAA), and the American Society for Engineering Education (ASEE).

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Dr. Farrokh Mistree is a Professor of Mechanical Engineering, Associate Chair of the Woodruff School of Mechanical Engineering and Associate Director of Georgia Tech, Savannah. His design experience spans mechanical, aeronautical, structural, and industrial engineering. His teaching experience spans courses in engineering design, naval architecture, solid mechanics, operations research and computer science. His current research focus is on learning how to manage design freedom in multi-scale design (from molecular to reduced-order models) to facilitate the integrated design of materials, product and design process chains. He is committed to developing a design pedagogy that is rooted in Decision-Based Design and adaptive action learning. It is in this context that he enjoys experimenting with ways in which design can be learned and taught. Dr. Mistree has co-authored two textbooks and over 350 technical publications. Dr. Mistree was recognized for his research and teaching in 1999 and 2001, respectively: ASME Design Automation Committee's 1999 Design Automation Award and 2001 Jack M. Zeigler Woodruff School Outstanding Educator Award. He served as Secretary-Treasurer of Pi Tau Sigma Mechanical Engineering Honor Society (1995-2007)and served as a reviewer for ABET. He is a Fellow of ASME, an Associate Fellow of the AIAA, a Member of ASEE and the Society of Naval Architects and Marine Engineers. *And what does Farrokh Mistree want to do in the future? He wants to have fun—fun in defining the emerging science-based discipline of design. Fun in providing an opportunity for highly motivated and talented people to learn how to achieve their dreams.*

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