AC 2008-691: SUSTAINABLE SOCIETIES: THE SUSTAINABLE ENGINEERING DESIGN CURRICULUM AT JAMES MADISON UNIVERSITY

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Sustainable Societies: The Sustainable Engineering Design Program at James Madison University

I. Introduction

A sustainable society possesses the ability to continue to survive and prosper indefinitely, not just with respect to environmental resources and economic development, but also with respect to quality of life as it pertains to conditions that promote sustainable human prosperity and growth (e.g. opportunity, economy, privacy, community, education, and health).

In August 2008, James Madison University (JMU) will enroll its first engineering students into a unique engineering product and process design program focused on *sustainable societies*. A significant component of this integrated program is the six semester 10-credit design laboratory sequence that stretches from the sophomore year to graduation. We present a divergence from the generally accepted approach to sustainability (normally referred to as "sustainable engineering" or "environmental sustainability") and include instruction in creating sustainable societies.

Students graduating from the program will demonstrate competencies in product and process design along with significant emphasis on and rigorous coverage of technical skills that facilitate ABET accreditation as well as prepare students for the Fundamentals in Engineering Exam – General Engineering.

This paper will address the following non-traditional topics in the design curriculum in the Sustainable Societies Program:

Environmental Sustainability: An approach to the engineering of processes, products, and structures which has, indefinitely, a less negative, neutral, or benign effect on all environmental systems.

Creative and Critical Thinking, Decision Making, and Assessment: Established critical analysis and evaluation instruction has been limited to linear forms of thinking. How a designer thinks, the actual cognitive processes a designer employs to generate an idea or solve a problem, will be central to design instruction.

Aesthetics of Design: Logic is not the central or only factor in the design of a product; a product must speak to culturally and historically accepted norms of beauty, value, balance, harmony, proportion, and natural body movement.

Economic, Cultural, and Social Contexts: Understanding the far-reaching influence design has on the individual, communities, geographic regions, and cultures is central to instruction. Topics of instruction include sustainable economic and business

practices, cultural sustainability, social contexts in sustainable societies, human prosperity, and community well-being.

Design Ethics: Design ethics in the JMU program go beyond environmental issues and include instruction in the consequences design has on human and social contexts, especially the environment, the conditions under which humans work and live, profit, marketing and advertising, and the equitable use of global resources.

The Design Program is interdisciplinary and will utilize faculty from business, art, and social science disciplines; and employ a variety of innovative instructional methodologies.

II. Rationale

Declining environmental, economic, and social conditions world-wide require a response from the engineering community since many of the solutions to these problems are related to engineering design. Quite literally, engineering as a discipline has to evolve to meet our growing understanding of global, domestic, and local conditions related to the environment and as well as its influence on a variety of issues related to human well-being. Engineering is a creative and integrated discipline; however, it is only in the last two decades that academicians have realized the profound and growing influence engineering, and engineering design especially, has on all sectors of society. We have come to understand well that the greatest and most immediate sustainability problems humans face are related to our relationship with the natural world. This fact places a great deal of responsibility on a discipline that, heretofore, has taken too little responsibility outside its own sphere of technical influence.

As engineering becomes an increasingly integrated discipline, engineers and engineering faculty need to determine the appropriate integration of a variety of social science and artistic disciplines. In short, we need to redefine the discipline to meet the needs of an increasingly technological society that accepts few boundaries related to a global standard of living. While it might go too far to say that engineering needs to become a humanistic discipline, it clearly does need to be a *more* humanistic discipline, quite simply because so many of our human activities are related to and dependent upon products and processes engineers design and develop. As we have no doubt learned, and as is reflected increasingly in academia and industry, the answers to many human problems are not to be found in specific and discrete disciplines. We need to determine which disciplines need to be integrated into engineering practice as we continue to address critical problems facing our planet and people. This is a profound obligation and an exciting challenge, especially for higher education.

Sustainability is a controversial topic because it appears to be an expensive alternative to our "quarterly driven, just-in-time" profit-motivated approach to the business and manufacturing cycle. Benefits that accrue in the future, or those affecting the environment, do not appear to be sufficient motivation for industry to make the necessary changes required to embrace a new philosophy. While successful and profitable sustainable businesses are appearing regularly, the movement has yet to capture the interest and imagination of the corporate sector in general. Unfortunately, the motivation to make large-scale and expensive business changes (both cultural and economic) is currently insufficient to drive these changes. As a test bed for sustainability solutions, engineering programs bear a great responsibility for pioneering analysis and evaluation, materials, processes, and methodologies that will preserve and improve a global standard of living. Academicians and professionals active in engineering and related technical disciplines, as well as those in the social sciences, need to understand the interconnectedness of all disciplines, especially as related to sustainability.

Aside from the issues noted just above, a serious threat to the U.S.-educated engineer-in-training (as well as to domestic engineering as a discipline) is the rapidly increasing practice of outsourcing. While U.S. corporations continue to profitably outsource engineering work to India and China, U.S. institutions of higher learning are attempting to cope with an uncertain economic future for their graduates, one few academicians anticipated or imagined even 20 years ago.

Engineering programs need to address this dilemma which involves revising curricula in established programs and developing new programs that focus on skills not easily (or profitably) outsourced. Because academic disciplines (the sciences and engineering especially) are no longer discrete, new programs need to focus on the future of engineering disciplines rather than on the still rather stable conditions that characterize current engineering work. Many engineering programs have introduced limited instruction in creativity and innovation, entrepreneurship, collaborative work, ethics, and design process into curricula. Traditional programs, however, still struggle to revise curricula in the face of faculty who do not understand or accept, or simply resist, the conditions that soon will influence most all engineering and technical disciplines.

In addition to the topics noted above, an understanding of the social sciences, human behavior, and sustainability will soon become requirements for engineers who wish to compete in the world market. Engineering programs that do not respond to the problems created by outsourcing may find themselves competing with India and China, especially in terms of professional compensation, when ten years ago they were competing with us.

One area in which we are not yet at risk of serious competition (although this will most certainly change in the next two decades) is in innovation and creativity. The U.S. still holds the edge in design innovation, and it is here that academic programs must adapt. Failure to do so will change the future and nature of engineering education and practice, as well as the economic well-being of our country. Innovation and creativity that support the instruction in and practice of sustainability are at the center of this

controversy. While engineering sustainability has become an increasingly popular topic in engineering, few programs provide significant instruction in the subject, especially design for sustainability.

Beginning in the early 1990's, but specifically during the last few years, engineering educators have been modifying engineering curricula by initiating courses and projects that foster in their students advanced thinking skills and an understanding of the creative process. The educational modes in these "new engineering classrooms" are both diverse and experimental, crossing disciplines, and involving processes once reserved for artists and writers. The topography of progressive engineering programs varies dramatically from university to university, as professors draw inspiration from non-traditional sources including the social sciences, philosophy, business, architecture, and art.

The future of engineering education and practice is now largely the responsibility of university programs that must respond flexibly to market and technological conditions. New engineering programs offer the most efficient and innovative response to the rapidly changing landscape of engineering practice. While traditional programs will still fill a critical need, innovative instruction in new and progressive engineering programs will likely be the source of developing innovative responses to global human and technological challenges as well as helping the U.S. maintain its leadership in the discipline.

III. Literature Review

Creative engineering design instruction is at the center of our efforts to design for sustainability. In the past two decades, engineering design instruction has evolved into an integrated and cross-disciplinary endeavor. While many engineering programs have developed design courses and programs to better reflect the needs of society and the environment, perhaps one of the first academicians to note the interdependence among technical engineering skills and the arts and social sciences is Duke University Professor of Civil Engineering Henry Petroski. Although much of his work has addressed the role of failure in design, Petroski was one of the first to consider engineering an integrated discipline. In what many consider his seminal work, *To Engineer is Human*, Petroski refers to engineering practice as a *human* endeavor, a practice of both science and art, one that is "part of our human understanding and experience."[1]

Petroski is particularly referring to working in an interdisciplinary manner, especially integrating artistic skills into the design process, stating that "…the *conception* of a design…can involve as much a leap of the imagination and as much a synthesis of experience and knowledge as any artist is required to bring to his canvas or paper."[2]

Others, including Joseph Bordogna, former deputy director of engineering for the National Science Foundation, agree: "The engineer must be able to work across many different disciplines and fields—and make the connections that will lead to deeper insights, more creative solutions, and getting things done."[3] William Wulf, President of the National Academy of Engineering (NAE), and George M.C. Fisher, former chair and CEO of the NAE council, call for a "major shift in engineering education's center of gravity" toward creative design and cross-disciplinary teaching practices.[4] In addition, the ABET 2000 "a-k" criteria confirm these conclusions and require an increasingly design-based and interdisciplinary approach to engineering education.[5]

Current trends in engineering design education in academia and industry over the past decade have continually stressed the importance of innovation, writing and communications skills (especially for team-based projects), and interdisciplinary collaboration skills. The topography of progressive engineering programs varies dramatically from university to university, as professors draw inspiration from non-traditional sources including the social sciences, philosophy, business, architecture, and art.

The need for innovation in teaching engineering design has been noted in educational and industrial sectors for years;[6,7,8,9] some university educators have lamented the fact that too many colleges of engineering have become complacent in teaching design, creating an "unfortunate gap that too often exists between industry and academe."[10] Progressive engineering educators and industry leaders both stress that critical and creative thinking skills are at the center of design instruction, and are key to the continued success of American industry.[11,12,13] Noted author and product designer Robert G. Cooper sums up the dilemma well, stating that "most companies lack much in the way of effective product innovation and technology strategy, and worse yet, seem at a loss for developing such a strategy."[14]

Obviously, universities are, at least in part, as much responsible for this problem as they are for the solution. The Accreditation Board for Engineering and Technology recognizes this shortcoming in engineering programs, and has clearly outlined the technical and non-technical skills necessary for success in an increasingly complex and interdisciplinary workplace environment.[15] Teaching design skills, communication and team working skills, ethics, global awareness, and environmental awareness now punctuate, and temporarily overshadow, teaching the technical skills engineering educators have long thought to be the most central pedagogical issue in engineering education.

Noting the important role university and industrial training programs have in addressing this dilemma, Penn State Professors Salamon and Engel suggest that design instruction cannot be successful without academic instruction that "exercises student creativity and other non-analytical talents."[16] Several authors and educators note the importance of colleges and universities teaching effective writing skills, interpersonal communications, and collaborative working skills as a necessary foundation for learning effective design skills.[17,18,19]

Responding to the needs well-expressed by industry, some engineering programs have begun teaching problem solving,[20] critical writing skills,[21,22] interpersonal skills as related to creativity, [23,24] perception skills[25] and reflection[26] over the past few years.

Increasingly, the competencies noted above are being included in instructional programs to address specific environmental problems related to environmental sustainability and the inevitable influence these problems have on creating sustainable communities.

Sustainability in engineering has its roots in two engineering disciplines: green engineering and environmental engineering. In general, green engineering has focused on design that is in greater long-term harmony with the environment while environmental engineering has addressed the deleterious effects engineering design (or, sadly, lack of design) has had on the environment. Sustainable engineering is, in many ways, more related to green engineering as it focuses on design that requires fewer natural resources, produces less (or no) waste, and reuses or recycles waste products. In the last few years, environmental and green engineering programs have been moving towards a focus on environmental sustainability and, in a few cases, social and economic sustainability as well.

The Brundtland Report of the United Nations World Commission on Environment and Development first expressed concern over sustainable engineering at its 96th plenary meeting (December 11, 1987), noting a concern "about the accelerating deterioration of the human environment and natural resources, and the consequences of that deterioration for economic and social development…"[27] The Commission's report defined sustainable development as "a form of development that meets the needs of the present without compromising the ability of future generations to meet their own needs." [28] Three areas of sustainability define the Report's broad concept of sustainability: environment, economy, and society.

What is, perhaps, most notable about the Report is a definition of sustainability that includes more than environmental sustainability and the opinion that the environment, the economy, and society compose a complex system, and that a change in one factor of sustainability will likely cause change in others.

Other definitions of sustainability often mirror the Commission's Report. In *Cradle to Cradle*, McDonough and Braungart view sustainability from the point of view of balancing environmental, social, and cultural concerns through a "triple bottom line" based on balancing the "tripod" of ecology, economy, and equity.[29] The authors suggest that every sustainability problem can be analyzed and evaluated through this approach.

Charles L. Redman, director of Arizona State University's School of Sustainability defines sustainability as "Sustainability is an awareness of the connectivity of the world and the implications of our actions. It is finding solutions through innovative approaches, expanding future options by practicing environmental

stewardship, building governance institutions that continually learn, and instilling values that promote justice."[30]

The University of California Los Angeles Anderson School of Management offers a multidisciplinary approach to sustainability from an economic point of view: "'Sustainability' (loosely defined as the simultaneous consideration of economic, environmental and social factors) has become a key element in decision making in many areas of business and public policy. By definition, sustainability requires a multi-disciplinary perspective."[31]

Roseland focuses on a wide variety of issues related to sustainable community development, such as integrating environmental, economic, and social objectives, and concepts of "natural capital and social capital, whether (and if so, how) they are linked, and explores their implications for sustainable development at the community level…" including those related to individual well-being.[32]

Since the Brundtland Commission and others defined sustainability for the future, engineering programs have responded. Engineering programs at a variety of universities have embraced the concept of sustainability, though only a few with much vigor or through design instruction. Most efforts appear to be in the development stage. Perhaps the most notable effort to date that includes a focus on social and economic sustainability, as well as environmental, is Carnegie Mellon University's Center for Sustainable Engineering which is a partnership with the University of Texas Austin, Arizona State University, the National Science Foundation, and the Environmental Protection Agency.[33]

Efforts at other institutions that include a focus on issues broader than environmental include University of Massachusetts Boston,[34] University of Maryland College Park,[35] University of New Mexico,[36] Illinois Institute of Technology,[37] Cambridge University Engineering Department—Center for Sustainable Development,[38] UK Centre for Materials Education,[39] Rensselaer Polytechnic Institute,[40] and The University of Western Ontario.[41]

The link between sustainability and design is clear, not only in engineering programs but in the social sciences and business as well. Sustainable engineering programs must take into account the complexity of the problems we now face. In short, the technical problems we face, especially as related to the environment, are truly *human* problems that affect our communities, our standard of living, and our ability to secure the well-being of future generations.

II. Design Program Description

Defining "sustainability" for sustainable societies is tricky business and depends entirely upon one's perspective (or perhaps, investment). Rather than attempt to define sustainability per se for the current JMU effort, we offer instead the following description:

> A sustainable society possesses the ability to continue to survive and prosper indefinitely, not just with respect to resources and economic development, but with quality of life as it pertains to conditions that promote general human prosperity and growth (e.g. opportunity, safety, privacy, community, education, and health). A sustainable society meets these needs simultaneously, and in the context of human respect and the ability to negotiate differences.

> Our program is integrated and interdisciplinary, and we expect, over the first few years, to determine the disciplines and the degree of integration that will be appropriate for our needs. In this way, our efforts will pioneer innovative topics *as well as* instructional methodologies and be a test bed for other programs wishing to focus on this broader concept of sustainability and design. Design, for our purposes, falls into the following two categories:

> *Product Design*: process engineering that includes designing, developing, implementing, evaluating, and revising a process to manufacture a product or material. This includes the sequence of design steps, operations, and the selection of tools and materials to manufacture a product.

> *Process Design*: may refer to designing the process flow (people, materials, money, information, testing, and marketing) associated with manufacturing a product or material. This term is sometimes referred to as business process engineering or "management of technology," approaches that enable an organization to define and understand its business processes, organization, strategies, and technologies to achieve improvements in operating results.

All the following instructional topics in the design curriculum are taught in the context of sustainability:

A) Environmental Sustainability

Briefly stated, designing for environmental sustainability is an approach to the engineering of processes, products, and structures which has, indefinitely, a less negative, neutral, or benign effect on all environmental systems. Sustainable engineering design

tends to produce designs in which nature is not subject to continual 1) increased use of natural resources, 2) increases in substances produced by society, and 3) increases in waste products and the effects of their degradation.

Often, design for environmental sustainability has traditionally required trade-offs among market forces, resource availability, and technology—and may include the consideration of *some* human factors—but may ignore or deemphasize issues related to the economic, social, and cultural well-being of a population.

It would appear that determining the sustainability of a product, process, or human community depends upon the careful and complete *assessment and evaluation* of a range of technical and human factors that may (or may not) be influenced by a particular design. This approach is central to our efforts, but it is an approach about which little has been written or practiced. One tool especially valuable to this challenge is life-cycle analysis. While there remain countless unknowns of how to apply this tool to complex systems in manufacturing and business, as well as how to integrate human factors into the analysis, it creates a pioneering opportunity for our students to define the terms with which they and others will apply such analyses. For our purposes, life cycle analysis includes societal factors, not simply those related to the environment or life of a product or process.

B) <u>Creative</u> and <u>Critical</u> <u>Thinking</u>, <u>Decision</u> <u>Making</u>**,** and <u>Assessment</u> and <u>Evaluation</u>

Critical to effective and innovative design are the thinking practices that go into the analysis and evaluation of a problem as well as conception of a product or process that will address a problem. Instruction in design focuses on cognitive processes that constitute the "conceptual" component of a design. In the past, design in engineering has primarily focused, oddly enough, on the "construction" phase of the design process. Critical assessment and evaluation, while traditionally a component of the design process, have been limited to established and very linear forms of thinking. *How* a designer thinks, the actual cognitive processes a designer employs to generate an idea or solve a problem, has occupied no or very limited instructional time in established engineering curricula. Perhaps this is because engineering design instruction has not moved across disciplines until the last decade.

Thinking skills in engineering design grow out of two disciplines: art and psychology. The creative thinking *processes* artists use to create a "product" are no different than those employed by creative engineering designers. At the same time, the very individual cognitive skills learned and practiced by artists emerge largely from the metacognitive strategies studied and practiced by psychologists.

There is less mystery and confusion here than many believe. While the products of artists and psychologists are likely quite different from those of engineering designers, the methods used in these disciplines that focus on *thinking processes* yield innovative ideas and designs, as well as solutions to problems in virtually any discipline.

Instruction in developing *the intentional and directed intellectual processes and habits that foster effective thinking* is a foundational skill upon which all innovative design skills are ultimately dependent, especially when human factors, and the inevitable problems they create, are integrated into the technical design equation.

C) Aesthetics of Design

Aesthetics is that which can be perceived through the senses. Individuals respond very personally to what they consider aesthetically appealing and what is not. All one's senses, cultural and historical norms, and personal notions of harmony and "appropriateness" are employed in determining the aesthetic quality of a design.

As an integral component of design, effective aesthetics invites and supports use, as well as augments the psychological benefits of a design. Aesthetic design is a form of communication and is the link between technical and commercial feasibility (product appeal and marketability). Designs that do not take these factors into account risk rejection by the user.

Instruction in aesthetics is more than adjunct to design conception, especially if a device or product is to be marketed to, or used by, the public and need not be sacrificed for function. Logic is not the central or only factor in the design of a product; a product must speak to culturally accepted norms of beauty, value, balance, proportion, and natural body movement.

Engineering students at JMU will study aesthetics from a conceptual and functional point of view in order to understand how successful aesthetic design invites sensible and practical use that is not divorced from the properties related to cost, usability, durability, and manufacturability…lest it hinder or sabotage the design. For this reason, our design curriculum will include instruction in human factors in design, and those related to economic viability and product testing.

According to Alaistar McDonald, head of Product Design Engineering at the University of Glasgow / Glasgow School of Art, before developing aesthetic content for any product, it is important to understand the following:

- the factors affecting product use and choice;
- the prospective users' needs, preferences, and expectations; and
- the environments in which the product is bought and used.[42]

It is important for students to understand the role aesthetics plays in the design process including 1) the scope and analysis of factors going into a design, 2) the success of a design (usability), 3) the role of the user in the design and testing process, and 4) the criteria that determine user satisfaction.

In short, aesthetics influences user interface—how a user feels about a product or process—and helps determine if, how, and how often a product is purchased or used, or a process employed successfully. Designing for sustainability need not sacrifice aesthetics for function, practicality of construction, or economics (costs or marketing). The aesthetics of a product or design (e.g. the style with which a process is implemented in an organization) is not divorced from the sustainability: that which meets the natural aesthetic favor and functional ease of a user is more likely to persist and survive.

D) <u>Economic</u>, <u>Social</u>, <u>and</u> <u>Cultural</u> <u>Contexts</u>

Understanding the far-reaching influence design has on the individual as well as on groups of people (communities, professional communities, geographic regions, cultures) is critical to instruction in these contexts. Ignoring or deemphasizing these factors, especially the common practice of considering profit as central to a design, may contribute to design that meets technical and economic needs but not a variety of other needs related to human prosperity and community well-being. Redefining economic factors to include additional contexts (human and community) will tend to produce products and processes that contribute to the general prosperity and sustainability of a community.

While it is nearly impossible to separate economic, social, and cultural factors, for our current purposes, we offer the following brief descriptions (which will be detailed in future articles):

Economic: Beyond the economic policies and strategies related the design and development of a process or product, economic factors in design influence the economic health and profile of communities including the standard of living, the existing business climate, employment, and the productive role of the corporation in the life of a community.

Sustainable economic and business practices most certainly have an influence on the sustainability of products and industrial processes produced, but as importantly on the internal employee practices that reflect individual well-being, opportunity, and productivity.

In short, businesses need to have a "community and global consciousness," and the awareness necessary to determine how internal and economic policies and practices can promote sustainable communities—local, regional, and global.

Social: Product design influences social context—the roles of individuals, relationships among social groups, the family, collective behavior, social class, race and ethnicity, social control, the role of institutions in society, medicine, and education. The assessment and evaluation of the influence of a design on social structure and norms may influence whether and how a product or process is developed and marketed.

A good example of how technology and design has had an overwhelming influence on social and cultural factors globally has been in the development of new modes of technical communication, but more importantly as related to the *marketing* of communication devices. We are far from understanding these devices' long-term effects on human communications and relationships…quite simply, how we live and work. We may end up regretting forgoing an analysis and evaluation of social effects of these devices before making them the everyday *interface* of our human relations and business practices.

Cultural: How the design and marketing of products tend to change how we live (e.g. communicate, travel, and interact with each others) often requires changes in design to assess and evaluate these human factors and predict the results. An awareness of these factors may drive the decision of whether or not to develop or market a product, or implement a business process. Again, this requires a greater understanding of the tension, reciprocal influences, and ethics between profit and community well-being.

These three factors (and ethics, additionally) influence each other in complex ways, and understanding these contexts requires a consciousness that goes beyond corporate goals and the hypnotic lure of technological advancement. It is quite possible that an economically and environmentally sustainable engineering design will be in conflict with social, cultural, or ethical forces. We have little experience studying the *reciprocal influences* this complex system creates.

This is largely unexplored territory, one that requires much research, experimentation, and speculation. We cannot deny, however, that the sustainability of our economic institutions, social structure, and culture is a necessary component of creating and preserving sustainable societies.

E) Design Ethics

In many cases, ethics in sustainable engineering design has been considered mostly the environmental issues related to material selection and processing, waste and the processing of waste products, public health, and the long-term analysis of the negative environmental effects of these factors.

Ethics in design more broadly defined includes topics related to the consequences design has on the human and social contexts described above, especially the conditions under which humans work and live, profit, marketing and advertising, and the equitable use of global resources (among others).

More specifically, topics that influence design and use may address the following issues related to corporate and university responsibility:

1) Environmental responsibility,

2) Personal and professional values,
3) Professional responsibility,
4) Business ethics,
5) Employee (or student) policies, and
6) Research and publication practices.

Ethics applied to these contexts is a necessary component of sustainable engineering design and must be considered in the overall design process. What will not harm the environment may still result in negative influences on a variety of complex human issues and institutions.

F) Technical Design Skills

Although technical design skills are not specifically considered a "human factor" in design, one's approach to learning and applying technical design skills must reflect a understanding of and sensitivity to the contexts in which these skills will be employed, and products and processes that result.

Competence and practice in technical design include (but is not limited to) skills in the following areas: 1) an understanding and application of the physical design process, 2) heat / mass momentum balance, 3) flow rates, 4) process flow software, 5) CAD, 6) forces of balance, 7) material selection and characterization, and 8) CES software. Other skills are noted is Section IV below.

III. Instructional Methodology

Interdisciplinary instruction in the JMU engineering design program is developmental and includes the following methodologies:

1) Moderate instruction over long period of time in the curriculum

Skills and attitudes students learn and practice over a long period of time (with regular support from and collaboration with faculty) are the habits they will take ownership of and tailor to their own abilities and design habits. Students need to understand clearly that learning by experience and collaboration is a life long endeavor, and instruction (or practice in the studio) they receive in the design program is specifically meant to model long-term professional practice.

2) Liberal faculty-directed practice in the design studio

Student-centered learning in the design studio establishes a model for a professional laboratory; that is, the studio is an open space in which students immerse

themselves, establish a presence, and work and experiment in the studio regularly, not simply when an assignment is due. Immersion is important to design skill development, for an environment of experimentation, creative ideas, discussion among students and faculty, and a high comfort level are important to learning what will likely become a very individualized design process for each student.

The design studio facilitates the on-going relationship between the student and professor, and effective design processes can be developed during this time. Students learn that an understanding and demonstration of effective design processes determines the ultimate value and utility of a product or process.

3) Real-world application

Students engage application through University and community sustainability projects, both those students research and propose as well as those requested by the University and community. Projects related to sustainability are endless in nature and scope, and students will easily find or develop projects that meet their personal interests and professional aspirations. The JMU School of Engineering will solicit student sustainability projects from all sectors of the local community as well as from the Commonwealth.

4) Collaborative design

Assignments in the design program will require, at times, that students work independently in order to develop the individual skills and competencies they desire and need. Collaborative work, however, will occupy considerable instructional time and, as well, characterize a majority of our students' design projects. Successful and rewarding collaborative work requires developing effect communications skills (especially effective listening and conversational skills).

5) Creative problem solving and idea generation

Design *is* problem solving and idea generation, and more specifically, relies upon successful *assessment* and *evaluation*, whether it be addressing an existing design condition or a flaw (as in redesign), or generating an idea from which a new design may emerge. Instruction in assessment and evaluation for problem solving in sustainability is central to our overall program efforts. From our point of view, students can employ a series of design skills they have practiced and "personalized" (adapted to their own thinking and application style, and habits) in order to develop an *individual creative design process* they document in all their studio projects. It is important, however, for students to develop competence in a variety of technical design-related skills including

1) a familiarity and conceptual understanding of design theory, research, and practice;
2) exposure to theory in materials, construction methods, and product testing; and 3) an understanding of business functions, especially project management.

Unique to our program methodology are exercises and assignments that are "dispositional," that is, which take the form of students practicing and integrating specific design, thinking, and communication skills into their daily lives and activities over the course of the semester. This approach allows students to practice and develop long-lasting and highly useful skills in very personal and real-world settings. In short, such skills rapidly become a part of a student's personality and way of working. As well, this approach saves considerable class instruction time.

IV. Assessment of Design Curriculum Competencies

Instruction in design in the JMU School of Engineering crosses literally all the disciplines in the curriculum. Briefly, students completing the JMU Engineering degree will be able to do the following:

1) Apply engineering design skills;
2) Create CAD models and drawings of physical prototypes;
3) Fabricate and test physical prototypes;
4) List and explain the steps of the design/problem solving process;
5) Describe the role that math and science play in design;
6) Describe the role of engineering analysis in design;
7) Select and use effective methods of written and oral technical communication;
8) Use engineering tools and computational software;
9) Develop skills in invention, imagination, and production that inspire, question, and inform action and reflection on one's work;
10) Select, test, and evaluate materials to be used in a design;
11) Research, evaluate, and consider the design history of a product or process to develop a conceptual understanding of a proposed design;
12) Describe the role social contexts play in the conception and construction of a design; and
13) Describe the role ethics (business, environmental, and social) plays in a design.

Assessment will take several forms and is still under consideration and development. We will require students to maintain design journals throughout the three-year design course sequence, documenting not only the progress they make on their design projects, but as importantly, the journals will serve to describe the evolution of students' thinking processes and the development of an "individual design process" as

well as a "collaborative design process." Faculty will read and evaluate students' design journals each semester, respond in writing and confer with students.

The JMU *Center for Assessment and Research Studies* is currently assisting in the development of engineering design-specific qualitative and quantitative tools for assessing design skills. These assessment instruments will include the evaluation of students' studio skills (e.g. the use of engineering design tools and design software) and their understanding of the math and science competencies that underlie the design conception and construction process.

Most central to design skill assessment involves the use of portfolios, not entirely different than those required of art students. Students will be required to document their projects in writing, present to an academic and corporate audience, and display their design projects.

V. Conclusion

We have yet to clearly define the needs and requirements that characterize sustainable organizations, especially those relating to sustainable societies. This fact creates an opportunity for our faculty and students to experiment with and define sustainability in a variety of contexts as they apply to myriad business and industrial operations.

Our students will be partners in this experiment, and they must understand and accept this role if the program is to succeed. There is much to be gained by young engineers who will be equipped to determine the sustainability of a design project, design successfully, and predict accurately the outcomes (a task that is difficult and uncertain, at best). From our perspective, these are the central objectives of the program.

The JMU program in sustainable societies presents opportunities to innovate, test, and evaluate new approaches to engineering design instruction. A progressive group of educators that does not have to confront an established curriculum—and enjoys administrative support as well as the JMU reputation of seeking innovation—may well make a significant contribution to the future of engineering instruction and practice.

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