THE CONTEXT IN ENGINEERING EDUCATION

Edward F. Crawley
Massachusetts Institute of Technology

Cha Jianzhong
Beijing Jiaotong University

Johan Malmqvist
Chalmers University of Technology

Doris R. Brodeur
Massachusetts Institute of Technology

Abstract
Context is the cultural framework, or environment, in which technical knowledge and skills are learned. The culture of education, the skills we teach, and the attitudes we convey should all indicate that C-D-I-O is the role of engineers in their service to society. It is important to note that we believe that the product, process, or system lifecycle should be the *context*, not the content, of engineering education.

In this paper, we highlight models that, while different from CDIO, serve as the context for engineering education in disciplines that do not necessarily build products. One example is the *Measure-Model-Manipulate-Make* approach in biological engineering. This approach simulates the processes that biological engineers follow in their work. In other words, it is what engineers do. The rationale for teaching engineering in context is clear and compelling. It is based on theories and best practices of contextual learning as applied in engineering and higher education.

Finally, the paper concludes with a discussion of the broader societal need for adopting an appropriate context, and more effectively training engineers. The case of development of engineering education in China is highlighted, and parallels are drawn to educational needs in Sweden and in the United States.

Keywords: *Context, Engineering education, Contextual learning, The CDIO approach, The need for engineers in China, Sweden, and the United States*

Introduction
The objective of engineering education is to prepare students who are deeply knowledgeable of the technical fundamentals and broadly prepared with the pre-professional skills of engineering. [1] Over the past several decades, many outside the university, have challenged engineering educators to do a better job at meeting this objective, often by stating lists of the desired attributes of graduating engineers. [2] Within the CDIO program, we identified a statement of the underlying need: it is that we need to educate students to understand how to Conceive-Design-Implement-Operate complex value-added engineering products, processes and systems in a modern, team-based environment.

Three premises, capturing the vision, goals, and pedagogical foundation are fundamental to the CDIO approach:

1) The underlying need is best met by setting goals that stress the fundamentals,

while at the same time making the process of conceiving-designing-implementing-operating products, processes, and systems the *context* of engineering education

2) Learning outcomes for students should be set through stakeholder involvement, and met by constructing a sequence of integrated learning experiences, some of which are experiential, that is, they expose students to the situations that engineers encounter in their profession
3) Proper construction of these integrated learning activities will cause the activities to have dual impact, facilitating student learning of critical personal and interpersonal skills; and product, process, and system building skills, and simultaneously enhancing the learning of the fundamentals [1]

The objective of this paper is to elaborate and explain in more detail the meaning, background and evidence of effectiveness of this first point - the need to make conceiving-designing-implementing-operating the context of engineering education. This point is so central that it is captured in the first CDIO Standard, or principle of effective practice.

Standard One – The Context
Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving-Designing-Implementing-Operating -- are the context for engineering education

Note that the standard does not explicitly require "conceiving-designing-implementing-operating" to be the context, but rather the more general framework of product, process, and system lifecycle development and deployment, of which conceiving-designing-implementing-operating is an example.

The paper is divided into three sections. The first outlines the context of professional engineering practice, that is, the circumstances and environment in which modern engineers practice. This is a necessary precondition to understanding the essential features of context that should be captured in engineering education.

The second section discusses the specific context of engineering education, and gives examples. Placing the education of engineering students in context facilitates contextual learning, a well-developed educational model upon which we are building. A brief background in contextual learning is presented, with explanations of its important features and benefits. This section concludes with a more detailed presentation of CDIO Standard One, its interpretation, and evidence of its implementation.

Finally, the paper concludes with a discussion of the broader societal need for adopting an appropriate context, and more effectively training engineers. The case of the development of engineering education in China is highlighted, and parallels are drawn to educational needs in Sweden and in the United States.

The Context of Professional Engineering Practice

Before addressing the context of engineering education, it may be worth considering the meaning of *context*, and the specific context of modern professional engineering practice.

What is context?

Context is defined as "the words, phases or passages that come before, or after, a particular word or passage of text that help to explain its full meaning". The definition has two important parts: a) the sense of surrounding, and b) of using surrounding to understand meaning. Our use of the word *context* is listed as a second definition, as "the circumstances or events that form the environment within which something exists or takes place". The sense of surrounding is present, and the use of that surrounding to help understand meaning is implicit. An architect would be using this second definition of context in saying that to understand a building, one must examine the context of the neighborhood. Another example might be the need to examine the issues and forces that form the *context* in which to interpret the decisions of an organization. It is this meaning of context -- circumstances and surroundings that aid in understanding -- that we use. In order to understand the context of engineering, we must next examine what constitutes engineering.

What is engineering?

The central task of engineering is to design and implement solutions that have not previously existed, and that directly or indirectly serve society or segments of society. Engineering is distinguished from science by the process of creation. Noted engineer Theodore Von Kármán once said that scientists discover the world that exists, while engineers create the world that never was. [3] An important aspect of engineering is the use of natural materials, applied science, and technology to create this "world that never was." *What it is* that engineers create varies widely depending on field. In the CDIO approach, we use the terms *products, processes, and systems* to designate what engineers create. In this phrase, products are any tangible good or objects that can be transferred, while processes are actions or transformations directed toward an aim, and systems are combinations of objects and processes with some desired outcome. This phrase *products, processes and systems* is a shortened list of more detailed descriptions of what various engineers identify as the solutions they create. Manufacturing, civil and chemical engineers talk of plants, products, and projects. Bioengineers create new molecules, while materials engineers create new materials. Software and systems are outcomes of computer scientists and engineers.

Regardless of the sector, central to the role of engineering is the design and building of these solutions. Desirably, engineers are also involved in defining the solution, which involves understanding the needs of the customer or society, identifying new technologies that might be infused, and creating the high level requirements and strategy for the solution. In the CDIO approach, we designate this as *conceiving*. At the other end of the spectrum, almost all solutions must be operated in order to deliver value. Sometimes operation is by the customer, as is the case in cars, home appliances, and sporting goods. More complex systems are usually operated by professionals, including engineers who also have a role in repairing, upgrading, evolving and retiring the systems.

Even for solutions that do not involve engineers in operations, the design engineers must be sensitive to the issues of operations. In the CDIO approach, we call this entire post implementation phase *operating.* The span from conceiving to designing, implementing and operating is the product, process or system lifecycle referred to in Standard One above, which we use as a designator for the domain of engineering.

The evolution of professional engineering context

Engineering activities and the engineering profession exist within a context that is constantly evolving. It is interesting to note the features that are relatively stable in this environment, and those that are more rapidly evolving. [4]. The contextual elements that have not materially changed in the last 50 years include:

- A focus on the problems of the customer and society. Engineering from ancient times has been outward looking, motivated to understand and "solve" these problems
- The delivery of new products, processes and systems. The ultimate outcome of engineering is the transfer to someone of the "solution", which when operated acts to meet the needs of the customer or society
- The role of invention and new technology in shaping the future. The aqueduct, the windmill, the railroad, aircraft, and the internet, all developments of engineers, helped shape the era in which they were developed, and all subsequent time.
- The use of many disciplines to develop the "solution". Engineers focus on the "solution", and use whatever disciplines are necessary to deliver it. Almost 200 years ago, steam engineering required fluid mechanics, solid mechanics, controls, thermodynamics, combustion and manufacturing. The term *interdisciplinary* is a recent invention when those who focus on disciplines rediscovered the need to work together to produce solutions
- The need for engineers to work together, to communicate effectively, and to provide leadership in technical endeavors. Engineering is not a lonely profession, but is one that is inherently social, requiring interaction with other engineers and non-engineers to deliver the product, process or system
- The need to work efficiently, within resources and/or profitably. In public works, engineers strive to deliver on time and schedule. In private industry, they must also deliver profitably

Perhaps the boundary event of the 20th century that marks the transition from an unchanging context of engineering to a more rapidly evolving context is the more explicit linking of engineering to their underlying sciences. This linkage is not new; the steam engine of 200 years ago used the exact same thermodynamics as the one of today. It is the use of the scientifically based analysis, and the influence of new technology development on synthesis that is relatively new. With these changes, engineering education was reframed, basing it on engineering science.

In the last 50 years, we have seen changes in the context of engineering. Some of the evolving factors include:

- A change from mastery of the environment to stewardship of the environment. In 1828, the U.K. Institution for Civil Engineers stated that engineering is "the art of directing great sources of power in nature for the use and convenience of man". [5] Today, we would recognize the need to conserve and sustainably utilize the resources of the planet, rather than direct them

- Globalization and international competition. Until recently, engineering solutions were largely generated locally or nationally. Now, efforts increasingly move to locations where they can be completed most competently and efficiently
- Fragmentation and geographic dispersion of engineering activities. As a complement to globalization, it is now increasingly true that on any given project, engineers must work across geographic, national and cultural boundaries
- The increasingly human-centered nature of engineering practice. As the understanding of human needs and cognition increase, and the cost of customization decline, processes and products that continually re-interpret the world of the customer, such as, ubiquitous computing, will become more prevalent
- Increasing service-oriented industries, with decreasing manufacturing industries
- Shortened lifespan of product and technologies. Current engineering graduates will need to be prepared to re-train many times during their careers. In addition, companies want their new hires to be productive from the first day on the job. So, future engineers also need to be quick learners

Summarizing this discussion, we conclude that the fundamental nature of engineering is unchanged over time, and the context of engineering has many long enduring features, with relatively fewer features that are evolving due to contemporary forces in our world. Engineering educators should be aware of, understand, and reflect on this context of professional engineering practice, and be prepared to make it the context of engineering education.

The Context of Engineering Education

Having established the context of professional engineering *practice*, it is now desirable to define an appropriate context for engineering *education*. In education, once again, *context* is the surroundings and environment that help establish meaning and understanding. Educational context includes the experience base of the students, factors that motivate learning, and projections to the ultimate applications of the learned material, informed by professional practice.

If we are to base the context of education on the context of professional engineering practice, the implications for engineering education are relatively clear. We should set the education firmly in the timeless aspects of the professional context:

- A focus on the needs of customers
- Delivery of products and systems
- Incorporation of new inventions and technologies
- A focus on the solution, not disciplines
- Working with others
- Effective communication
- Working within resources

We should make students aware of the new and evolving elements of context, and incorporate them appropriately "sustainability, globalization, geographic dispersion and the human-centric nature of engineering practice. This is the idea that is captured in CDIO Standard One.

While the context of engineering practice has been largely unchanging in its core features, what has changed in the last 50 years is a pattern of decreasing connection and emphasis in engineering education on the context of professional engineering practice. This loss of connection with practice dates to the advent of the engineering science approach to engineering education, roughly in the 1950's and 1960's. However, the stated intention of the founders of this movement was to strengthen engineering education by enriching it with a firmer scientific and analytic basis. Their intention was not to displace the context of practice, but to provide additional content.

The intended consequence of this shift was the addition of engineering science content, but the unintended consequence was the loss of engineering context. As the decades of the later 20th century passed, engineering was increasingly taught by engineering scientists, most of whom had never worked as engineers. They thought, worked, and taught in the context with which they were familiar -- the context of engineering research. Engineering research is an important process in its own right, but it became the *de facto* context of engineering education. We began teaching our students to be engineering researchers, not engineers.

CDIO as the context of engineering education

The foundational principle (Standard One) of the CDIO approach is that we should reclaim our heritage, and place engineering education in the context of engineering practice -- the product, process or system lifecycle development and deployment. We do not believe that conceiving-designing-implementing-operating should be the content of the education. Almost all agree that at the university, students should learn the fundamental technical knowledge and approaches of an engineering discipline: mechanical engineering, civil engineering, biological engineering, *etc.* What we assert is that students understand this content better in the appropriate context, and that their learning of personal, interpersonal and system building skills is significantly enhanced by placing them in the CDIO context.

Conceiving-Designing-Implementing-Operating as a context was described above. It is intended to capture a model, not necessarily the *only* model, of the product, process or system lifecycle. The words are chosen to convey the generalized activities of engineers. The most obvious mapping of these four phases is onto the development of discrete electro/mechanical/information products and systems in serial production, such as cars, aircraft, ships, software, computers, and communications devices. Manufacturing engineers would say that they plan, design, realize, and operate the manufacturing processes for these discrete products and systems. Other engineers envision, design, develop, and deploy networks and systems of these devices, including transportation networks and communication systems. In software, engineers envision, design, write, and operate code. In chemical engineering and similar process industries, engineers conceive, design, build, and operate a plant or facility. In civil engineering, similar steps are taken for the planning, design, construction, and operation of a single project. Although different words are used, all of these engineering sectors follow some variant of conceiving, designing, implementing and operating.

Alternative lifecycle contexts
There are alternatives to choosing CDIO as the context of engineering education that reflects professional practice. Some would argue that design, by itself, is the central activity of engineering. While design activities are certainly important, focus on them as the exclusive context tends to exclude the important role that engineers have in identifying new products and systems, developing new technology, implementing, and in operations when the value of the product, process or system is delivered. We would argue that the entire product, process or system lifecycle, encompassing all of the activities of engineering, is a more appropriate context for engineering education.

However, CDIO is not the only possible lifecycle model. It tends to be interpreted as a "top-down" model, in which conceiving new products and systems is driven by customer or societal needs. Often, conceiving is enabled by invention and new technology, which is then matched to societal or customer needs. For example, in the emerging field of biological engineering, educators at MIT have constructed a lifecycle model called MMMM for *Measure-Model-Manipulate-Make*. [6] These are thought of as the essential activities on the pathway to a new biomolecule. First, you measure what nature already gives us as building materials, then you model them. With a model, you can devise. and then execute, manipulations of the building blocks to create new "solutions". This is an encompassing description that establishes a professional context for students, and distinguishes the role of biological engineers from biologists.

It is possible to construct context statements that are more encompassing than conceiving-designing-implementing-operating. Group T in Leuven Belgium describes five "E" terms around which their program is built. The first three *E*'s represent the roles engineers play in society.

- ENGINEERING -- making things
  Integral engineers create by making use of technology and the underlying sciences. They are familiar with a multidisciplinary approach.
- ENTERPRISING -- getting things done
  Integral engineers have vision. On this basis, they define a mission around which they gather others. Through innovation, daring and leadership they effectively get things done.
- EDUCATING -- developing oneself and others
  Integral engineers are capable of coaching themselves, others and teams. Their ideal is the development of each and everyone.
- ENVIRONMENTING -- embracing all elements
  Integral engineers are conscious of the influence of technology on the world, and vice versa. This is why they take into account the impact of their actions on ethics, ecology, aesthetics and economics within a globalizing and ever-evolving world.
- ENSEMBLING -- transcending and including

> Integral engineers see the coherence of things. By differentiating and integrating, and approaching all things from different angles, they achieve deeper insights and arrive at ever-richer experiences. [7]

Whether it is explicitly conceiving-designing-implementing-operating, a variant such as measuring-modeling-manipulating-making, or an extension such as engineering-enterprising-educating-environmenting-ensembling, it is important that we place the education of students in the context of product, process, and system lifecycle development and deployment.

Rationale for adopting the product, process, and system lifecycle as the context
The rationale for adopting the principle that the system lifecycle -- conceiving, designing, implementing and operating -- is the appropriate context for engineering education is supported by the following arguments:

- It is what engineers do
- It is the underlying need and basis for the skills lists that industry proposes to university educators
- It is the natural context in which to teach these skills to engineering students
- It better supports the learning of the technical fundamentals [1]

The first three of these points are discussed quickly in this section, and the fourth, a far more encompassing point, is discussed in the next.

The first of the four points -- modern engineers engage in some or all phases of conceiving, designing, implementing, and operating -- has been argued above. Students come to us wanting to be engineers, and understand that these are the essential activities of engineering. We actually disappoint them, and reduce their motivation and dedication by not immersing them in the lifecycle context. If we set the engineering education in the context of practice, we reflect to our students what engineers actually do to serve humanity.

The second point is evidenced by the widespread, consistent and organized reaction from industry, which has led to calls for skills that students should possess. Beginning in the late 1970's and early 1980's, and increasingly in the 1990's, industrial representatives began expressing concern about the skills and attitudes possessed by graduating engineers. They articulated the need for a broader view that gives greater emphasis to the skills actually used by engineers in the professional context. The Finiston Report of 1978 in the United Kingdom is an early example of this reaction. [8] A few years later in 1984, Bernard M. Gordon, the inventor of the analog-to-digital converter, stated bluntly that "society around the world is not entirely pleased with the current state of general [engineering] education". [9]. In the 1990's, the Boeing Company in the United States set forth its list of desired attributes of an engineer [2]. This was a coherent reaction to what industry considered a major threat to its human resource flow from universities. What these and other commentaries by industrialists have in common is that they enumerate the knowledge, skills and attitudes that reflect the professional practice of engineering, always underscoring the importance of engineering fundamentals, but then going on to list a wider array of skills that typically include design and manufacturing, communications and teamwork, and other personal skills and attributes.

The third point is more subtle. In principle, it is possible to teach students the skills and attitudes of engineering while they work by themselves on engineering theory, but this approach may not be very effective. What could be a more natural way to educate students in these skills than to set the education in the context of product and system development and deployment, that is, the very context in which students will use the skills?

Pedagogic rationale for the lifecycle context

The fourth point in the rationale for adopting the product, process, and system lifecycle as the context for engineering education is related to more effective learning of technical fundamentals. Learning is more effective when teaching and learning experiences are set within an environment or surroundings that help with understanding and interpretation. In education practice, this is called *contextual learning.*

What is contextual learning?

Contextual learning is a proven concept that incorporates much of the most recent research in cognitive science. According to contextual learning theory, learning occurs when students process new knowledge in such a way that it makes sense to them in their own frames of reference. This approach to learning and teaching assumes that the mind naturally seeks meaning in context, that is, in relation to the person's current environment, and that it does so by searching for relationships that make sense and appear useful. [10]

Characteristics of contextual learning

Drawing on its roots in constructivist learning theory, as well as theories of cognition and learning, contextual learning has the following characteristics:

- New concepts are presented in real-life situations and experiences that are familiar to students
- Concepts in problems and exercises are presented in the context of their use
- Concepts are presented in the context of what students already know
- Examples include believable situations that students recognize as being important to their current or possible future lives
- Learning experiences encourage students to apply concepts and skills in useful contexts, projecting students into imagined futures, *e.g.*, possible careers, and unfamiliar locations, *e.g.*, workplaces

The rationale for adopting a contextual learning approach is persuasive. This approach encourages students to choose specific careers and remain in their respective career preparation programs. Learning environments and experiences set in professional contexts open students' minds, enabling them to become more thoughtful, participative members of society and the workforce. Moreover, a contextual learning approach assists students in learning how to monitor their own learning so that they can become self-regulated learners. [11]

Benefits and examples of contextual learning
Contextual learning approaches offer several benefits to engineering education. In addition to those already mentioned, this approach

- Increases retention of new knowledge and skills
- Interconnects concepts and knowledge that build on each other
- Communicates the rationale for, meaning of, and relevance of, what students are learning

A few examples of contextual learning may help to illustrate the benefits of con textual learning.

At the course level.

1. The study of thermal conductivity might be applied in experiences that measure how the quality and amount of building insulation materials affect the amount of energy required to keep the building heated or cooled
2. Biology, chemistry, and mathematics courses might collaborate in the study of basic science concepts by studying the spread of contagious diseases that follow a global natural disaster, or the ways in which agriculture suffers from, and contributes to, environmental degradation

At the program level.

1. Field work in a hospital research laboratory can provide a stimulating context and rationale for the design of medical devices in a biological engineering program
2. Soliciting requests for innovative products and services from community nonprofit organizations can give meaning and relevance to design-implement experiences in engineering programs

Contextual Learning and CDIO Standard One
Contextual learning is the basis for adopting the product, process, and system lifecycle as the context for engineering education. This approach underlies our belief that when engineering students acquire knowledge and skills that are relevant to the engineering profession, they are more motivated to learn, learn more effectively, know how to apply what they have learned in meaningful ways, and are encouraged to remain in engineering careers. For these reasons, the adoption of the product, process, and system lifecycle is the first of the standards of best practice that characterize the CDIO approach to engineering education.

> **Standard One – The Context**
> *Adoption of the principle that product, process, and system lifecycle development and deployment -- Conceiving, Designing, Implementing and Operating -- are the context for engineering education*

Rationale. Beginning engineers should be able to *Conceive--Design--Implement--Operate* complex value-added engineering products, processes, and systems in modern team-based environments. They should be able to participate in engineering processes, contribute to the development of engineering products, and do so while working in engineering organizations. This is the essence of the engineering profession.

Evidenc*e*. Evidence of a program's adoption of CDIO as the context of engineering education is found in:

- Its mission statement, or other documentation approved by appropriate responsible bodies, that describes the program as being a CDIO program
- Faculty and students who can explain the principle that the product, process, and system lifecycle is the context of engineering education [1]

In summary, engineering education is more effective when it is set in the context of engineering practice. We have adopted the *Conceive-Design-Implement-Operate* approach, but there are other models of product, process, and system lifecyle development and deployment. The rationale is based on education research and practice in contextual learning. In the final section of the paper, we highlight the need for improved engineering education to address current challenges in engineering practice in China, Sweden, and the United States.

The Need to Adopt the CDIO Context

Throughout the world, engineering education is straining. In both developing and developed nations, the same concerns and issues are repeatedly being encountered. Among these are:

- The shortage of engineering graduates, and those continuing on to engineering careers
- The need to educate engineers to be more effective contributors and leaders
- The need to educate engineers to work in a more interdisciplinary manner
- The need for more experiential learning and project-based learning
- The need for enhanced university-industry cooperation and knowledge exchange
- The adaptation of engineering education to prepare students for increasing globalization
- Increasing awareness and response to environmental changes

In order to discuss concrete examples, we will focus now on the issues arising in three representative countries: China (representative of large developing nations in Asia); Sweden (representative of the European Union); and, the United States (representative of North America). Interestingly, the first issue, the shortage of engineers, appears in all three narratives. We will indicate how adopting the product, process or system lifecycle of development and deployment as the context of engineering education can address each of these issues.

Engineering Education in China

China's economy has been developing rapidly for twenty years, attributable in large part to the availability of good-quality and low-cost labor for labor-intensive industries. However, this comparative advantage is diminishing, as labor-intensive industry shifts to countries with even cheaper labor resources.

China is now facing the new challenges of upgrading its industries to knowledge-intensive and innovation-oriented service industries with high added-value goods and services. China must be in a position to attract jobs in knowledge-intensive sectors. Multinational companies have adopted new strategic measures to transfer knowledge-intensive sectors of industry to countries with advantages in every aspect. [12] In the future, multinational corporations will make China, India and the United States their locations of choice to set up their overseas research and development institutions, which will create great demands for a large number of quality engineers conducting R&D work and various service–oriented jobs. These talents will be different from the technical talents needed in the existing Chinese fabrication and processes of its manufacturing industries.

For various societal and cultural reasons, developed countries are sometimes short of engineering students, but they have great engineering education capability. In contrast, China, India and Eastern European countries have large numbers of students available for engineering study, but need to improve the quality of engineering education to increase the number of graduates with educations that are important to industry. According to an analysis in the *McKinsey Quarterly*, from 2004 to 2008, foreign companies in China would need 750,000 first-class college graduates, accounting for 60% of the total available resource of university graduates in this period. [13] In some sectors, there is an even greater shortfall. Talent shortages in the software industry is estimated as being more than 500,000 each year in China, and will increase by 20% annually. Chinese software engineering schools can provide only 70,000 graduates each year, augmented by 120,000 graduates from related disciplines. For example, IBM planned to employ 20,000 people in its Dalian facility by 2007, but only 2,100 employees have been hired due to the shortage of qualified IT engineers. Well-qualified human resources have become a severe bottleneck of the further development of the IT industry in China. [13]

The gap between demands for talent and the current supply of qualified students is compelling China to devote great efforts to reforming Chinese engineering education. If China fails to address this issue, it will soon be facing a severe shortage of talent, which will limit its further economic development. Both the number and the ratio of students in engineering majors in China are very high; how to cultivate these students in engineering to be globally competitive is the current emphasis of engineering education in China.

Traditionally, Chinese people have attached importance to science and engineering education, which can be reflected is sayings such as "With good mastery in mathematics, physics and chemistry, you can go wherever you want in the world for jobs, without worry". Large numbers of students seek education in technology in China. In 2000, engineering Bachelor degrees earned in China reached the sum of the numbers of the United States, Japan and South Korea together. In the same year, the percentage of Bachelor degrees awarded in engineering in China was eight times that of the U.S., five times that of the U.K., three times that of Germany, and twice that of Japan. Currently, there are more than 1.8 million high school graduates each year enrolled for engineering study in higher vocational colleges and universities. In 2006, about 70,000 engineering students graduated in United States, while the number in China was about 10 times as large as in the United States.

However, quantity is not necessarily quality. According to the same report in *McKinsey Quarterly* cited earlier, among the 1.6 million young engineers in China, only 160,000 are qualified at the level to work required by multinational companies. [13] Less than10%

of engineering college graduates in China are qualified to be employed by multinational companies, compared with 25% in India, 35% in Malaysia, 50% in Poland, and more than 80% in Belgium and other developed nations. Several multinational enterprises have pointed out common problems with engineers in China. For example, the president of John Deere China, the largest agricultural machinery manufacturer in China, noted insufficient knowledge and skills related to manufacturing among engineers in his company. When commenting on the employees at the Tianjin facility, the company president said that young engineers in China lack: a) practical experience; b) adaptability to the enterprise's culture; c) decision-making ability; d) communication skills; and, e) fluency in English. Overall, the lack of quality in engineering education in China can be attributed mainly to:

- A lack of clarity in the goals of engineering education, that is, most research-oriented engineering universities aim at fostering scientists, not engineers
- A gap between universities and industries, that is, educators don't listen to industry about their needs for engineering talent
- The lack of industrial background and engineering experiences among university faculty
- Engineering curricula and courses biased toward theory, with insufficient practical application of the theory
- Instructional approaches that are teacher-centered and not student-centered
- Evaluation of engineering education quality that does not include industry and other key stakeholders

With reference to the cross-cutting issues identified at the beginning of the section, and from the perspective of the UNESCO Chair on university-industry cooperation, the goals for the reform of engineering education in China would include:

- Addressing the shortage of engineering graduates, as well as those who continue on to engineering careers
- Educating engineers to be more effective contributors and leaders [14]

The strategies of engineering education reform should have three dimensions. These include:

- Increased experiential learning and project-based learning approaches
- Enhanced university-industry cooperation and knowledge exchange
- Adaptation of engineering education to prepare students for increasing globalization

The adoption of the CDIO context for engineering education can address these goals, and facilitate the strategies for improvement. We would argue that placing the education of engineers in the lifecycle context will:

- Motivate, attract and retain students in engineering, because they will see what engineers really do, and how they apply technology to address the needs of society and the customer
- Prepare students to be more effective contributors, because the context will inform the knowledge and skills that are passed on to the students

- Place students in more authentic and experiential settings, from which they will better understand the fundamentals and develop the skills of engineering
- Provide a natural framework to engage industry in the university, because the university will now be applying the professional context of engineering to education
- Facilitate discussion of the issues of globalization, as students encounter pre-professional issues, such as workforce and economics

Thus, adopting the principle that product, process and system development and deployment should be the context of the engineering education is an enabling step to reforming the educational system of China to meet its needs.

Engineering Education in Sweden

In Sweden, where the situation is fairly representative of the European Union, three major issues dominate the public debate on the future of engineering education: climate change, globalization, and the shortage of engineers.

Climate change is affecting engineering on several levels. On the macro level, national research policies are shifting more research money into environmental research, and new regulations on combustion engine exhaust are driving development in the automotive industry. On the micro level, many more start-ups based on clean technologies are emerging, and are being supported by venture capitalists. This trend is a major opportunity for Swedish and EU businesses. However, it will require a coupling of science-based knowledge of environmentally friendly solutions with the ability to form profitable businesses based on them. Thus, engineering education needs to prepare future engineers for participation in broad-based efforts to improve product sustainability. Even more leverage may come from teaching future engineers how to capitalize on the environmental science base that is emerging.

Globalization is not a new issue in a small and free-trade-dependent country like Sweden. Already in the 1970's, major Swedish firms, such as Electrolux and SKF, had 95 % of their employees abroad, including effectively all production. National production has gradually shifted to more complex systems. However, China and other low-cost manufacturers are simultaneously gaining the capabilities to produce even more complex products and systems. More recently, engineering outsourcing has become a reality. Current products are developed by global teams with members based in Göteborg, Allentown, Lyon, and Bangalore. Effectively competing in these new circumstances requires a renewed and continual focus on rationalizing production and specialization, in order to develop globally unique skills, and the ability to collaborate in multinational environments, sharpening demands on language, cross-cultural understanding and teamwork skills.

It follows from these observations that a country like Sweden is highly dependent on its engineering competence. However, there is already a shortage of engineers, and the recruitment of engineering students is falling. In 1998, there were 1.9 applicants for each engineering seat at Swedish universities. The number has now fallen to 1.2. [15] The enrollment in engineering education has decreased from 12% of Swedish 19-year-olds in

2000 to about 8% in 2008. [15] The situation is aggravated by the demographic situation. From 2008 to 2016, the number of Swedish 19-year-olds will fall by almost 30%. [16] The situation is worst in electrical and chemical engineering. Current 19-year=olds are more strongly attracted to educational programs that emphasize the arts, design, architecture and management. Technical universities have a huge challenge in 1) attracting more students to engineering in general, and 2) balancing the preferences, attracting more students to, for example. electrical and chemical engineering. However, this will likely require changes on many layers, including the overall profile and naming of programs, content, and pedagogy.

Developing strategies to meet these challenges again points to the value of emphasizing the context of engineering, and the product, process, and system lifecycle in engineering education. First, the systematic exploration of all lifecycle phases in the education provides a multitude of realistic situations where sustainability issues can be considered in the context of engineering decision making. An example of this is seen when development teams are faced with decision situations characterized by the need to make trade-offs among multiple objectives, including environmental effects, performance, cost, and reliability. [17] Second, using the professional context to surround the education brings to the fore the need to educate students in teamwork, communication, and cultural understanding as integral parts of the education. Third, the lifecycle context provides a more holistic view of engineers and the engineering process. The creative component in engineering work is highlighted, as well as the circumstances that many engineers, regardless of field, take on leadership roles from very early in their careers.

Engineering Education in the United States

In the first phase of its project, *The Engineer of 2020*, the National Academy of Engineering (NAE) engaged a diverse group of stakeholders to the engineering enterprise in a series of activities to gather facts, forecast future conditions, and develop future scenarios of the possible world conditions for the 2020 engineer. The study suggests that if the engineering profession is to take the initiative in defining its own future, it must

1) Agree on an exciting vision for its future
2) Transform engineering education to help achieve the vision
3) Build a clear image of the new roles for engineers, including as broad-based technology leaders, in the mind of the public and prospective students who can replenish and improve the talent base of an aging engineering workforce
4) Accommodate innovative developments from non-engineering fields, and
5) Find ways to focus the energies of the different disciplines of engineering toward common goals [18]

If the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs, it must prepare for a new wave of change. While there is no consensus at this stage, it is agreed that innovation is the key and engineering is essential to this task; but engineering will only contribute to success if it is able to continue to adapt to new trends and educate the next generation of students so as to arm them with the tools needed for the world as it will be, not as it is today.

Increased globalization of engineering and the growth of engineering education in countries with developing economies challenge engineering programs in the United States to recruit, educate, and retain students in engineering. According to the National Center for Education Statistics, degrees in engineering and engineering technologies were conferred in 2006 on 81,210 students at the Bachelor's level; 35,133 students at the Master's level; and, 7,471 students at the Doctor's level. These numbers represent growth rates since 2001 of 12%, 23%, and 33% respectively. [19] Despite the numbers, there is evidence of gaps in the number of engineering graduates and the needs of engineering, especially in areas of developing technologies.

Summary

The proper context for engineering education is engineering practice, that is, lifecycle development and deployment of products, processes, and systems. We have adopted the *Conceive-Design-Implement-Operate* approach to engineering education, but there are other models that describe engineering practice, which can be used effectively for teaching and learning engineering. There are many challenges that face engineering worldwide, not the least of which is the shortage of qualified engineers in emerging technologies, and in specific areas of the globe. Setting the education of engineers in the context of engineering practice in highly diversified cultural and physical environments is a major step toward addressing these challenges.

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Biographical Information

EDWARD F. CRAWLEY

Edward F. Crawley is Ford Professor of Aeronautics and Astronautics and of Engineering Systems at MIT. He is Co-Director of the CDIO Initiative, and co-authored *Rethinking Engineering Education: The CDIO Approach*. He was formerly Department Head of Aeronautics and Astronautics, and Executive Director of the Cambridge - MIT Institute. He currently directs the Bernard M. Gordon -- MIT Engineering Leadership Program, and can be reached at crawley@mit.edu.

CHA JIANZHONG

John Cha is Professor and Vice Chairman of the Academic Committee, and UNESCO Chair of University-Industry Cooperation at Beijing Jiaotong University. He serves as member of the Board of Directors and guest professor of Group T University College Leuven, Belgium. He has published more than 250 papers in international and domestic academic journals and peer-reviewed conferences, and three books, one of which is in English. Professor Cha has received three awards from the Chinese government for science and technology achievements. He can be reached at jzcha@bjtu.edu.cn.

JOHAN MALMQVIST

Johan Malmqvist is a Professor in Product Development and Dean of Education at Chalmers University of Technology, Göteborg, Sweden. He is Co-Director of the CDIO Initiative, and co-authored *Rethinking Engineering Education: The CDIO Approach*. His current research focuses on information management in the product development process (PLM), development of product-service systems, and curriculum development methodology. He can be reached at johan.malmqvist@chalmers.se.

DORIS R. BRODEUR
Doris R. Brodeur is an Assessment and Evaluation Specialist at MIT. She co-authored *Rethinking Engineering Education: The CDIO Approach*, and designs and conducts workshops on the CDIO approach. Currently, she is conducting evaluation projects and faculty development for the Bernard M. Gordon ñ MIT Engineering Leadership program, and the CDIO Initiative. She can be reached at dbrodeur@mit.edu.

Corresponding Author
Doris R. Brodeur, Ph.D.
Massachusetts Institute of Technology
77 Massachusetts Avenue ñ 37-391
Cambridge, MA 02139
1-617-253-1695
1-617-258-5940 FAX
dbrodeur@mit.edu