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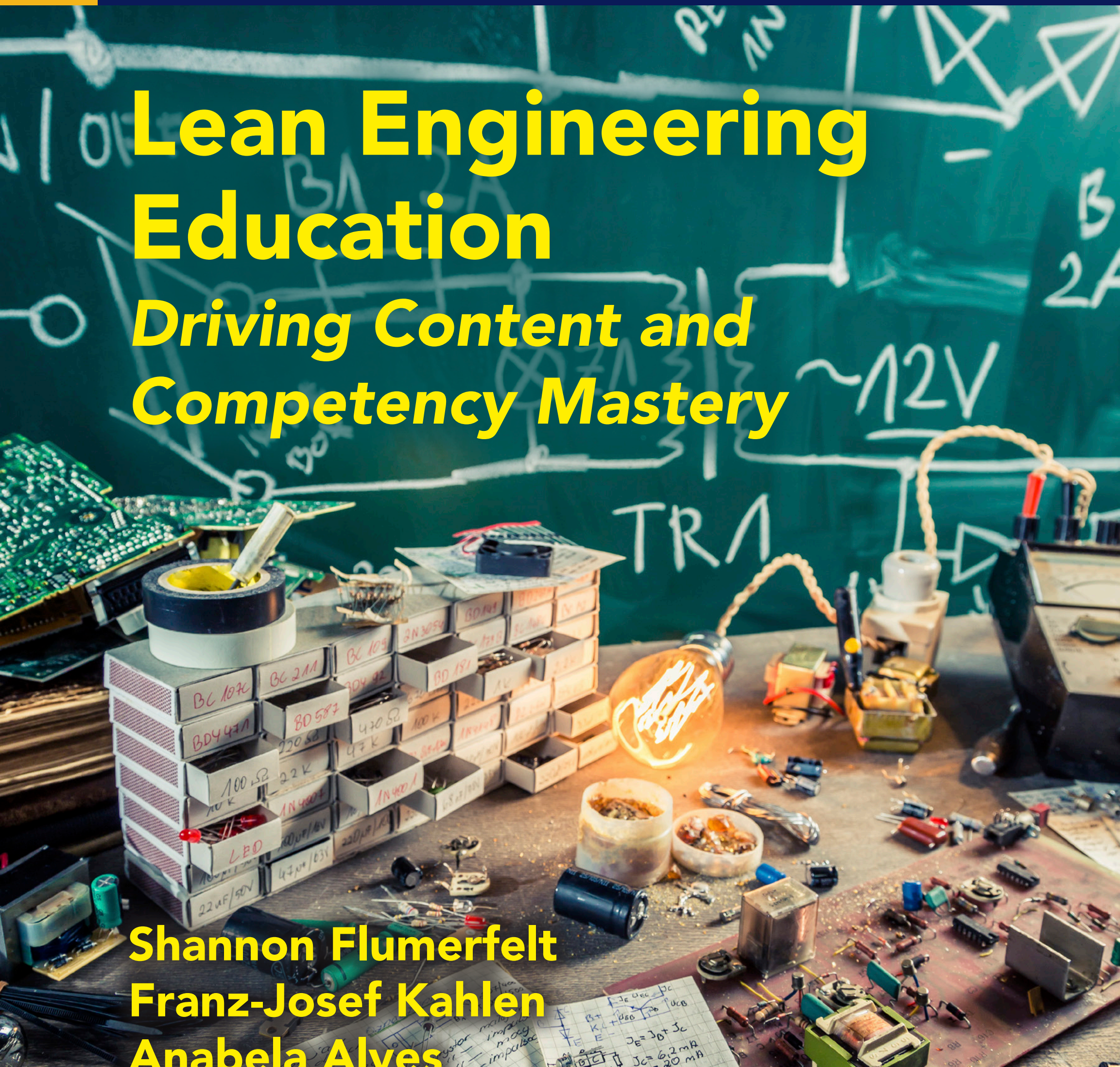

Lean Engineering Education

Driving Content and Competency Mastery

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MOMENTUM PRESS
ENGINEERING

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Preface

The role and scope of the mechanical engineering discipline and profession continues to evolve rapidly. The undergraduate mechanical engineering curriculum, the engineering student experience, what mechanical engineers do in practice, and how they do it, has been changing not only as a result of technological innovations that expand the scope and reach of the discipline, but due to the emergence of engineering practice, engineering education, and standards of quality on an increasingly global scale.

The ASME's ongoing *Vision 2030: Creating the Future of Mechanical Engineering Education (V2030)* program, operating under the auspices of the ASME Board on Education, has four primary goals:

1. to re-examine the engineering practice perspective and broadly define the engineering knowledge, skills and competencies that mechanical engineering graduates should have to successfully launch into engineering practice and progress in their early professional years;
2. to provide recommendations for the development of professional skills and competencies in the engineering graduates that will produce the leadership required for developing and implementing the technology and policy that will bring new solutions for the challenges facing local and global industry, governments and society;
3. to provide recommendations and exemplary approaches to the mechanical engineering education curricula that effectively produce the desired results in alignment with degree program accreditation standards; and
4. to move to change degree program accreditation standards as needed in response to Vision 2030 research findings and recommended actions.

The specific ASME V2030 recommendations are based on a rich set of data from over 2,500 contributors drawn from the experience of engineering managers and early career engineers in industry, university mechanical engineering department heads and faculty, and education leaders in ASME. In addition the work has been informed by exemplary work done by the National Academy of Engineering (NAE, 2005) –

Grand Challenges for Engineering; *Engineer of 2020*; *Educating the Engineer of 2020*; and *Changing the Conversation* – the National Science Foundation/University of Michigan (5XME Project) and scores of other individuals and institutions who have been a part of the meetings, workshops and conference sessions used in the process vetting and extending of the original V2030 concepts since 2009.

Current Context of ME Education and Practice

Blurring disciplinary boundaries. The earliest engineering disciplines, civil, mechanical and electrical, have given rise to distinctive engineering specialties and application-based disciplines, such as aeronautical, chemical, biomedical, environmental, industrial and nuclear engineering. A classic definition of mechanical engineering is that it embodies the generation and use of thermal energy and power and the design and use of tools and machines to produce products.

In the past, mechanical engineering problems were defined as those dealing with energy and mechanisms, i.e., bending, breaking, heating, cooling, and moving. Today, the range of applications of the mechanical engineering discipline has expanded greatly to include biological and information-based systems, advanced materials, micro/nano-devices, and many others. Currently, the types of problems and products that mechanical engineers work on are not easy to categorize, and they often include elements of other engineering disciplines and the basic sciences. Many contemporary engineering problems are considered to be multidisciplinary in nature and require systems thinking in problem formulation and solution. It is clear that we must educate engineering students for a technological era of increased scope, scale and complexity – while assuring competency in the application of fundamental, foundational principles and helping students move from the conceptual, to the imagined, to the simulated, and ultimately to the real.

Diversity and retention. In the US, for example, with mechanical engineering having the largest enrollment of the engineering disciplines, and also the largest number of undergraduate women, the percentage of women and of other underrepresented of minority groups in mechanical engineering has remained essentially constant at about 15% over the past decades. Despite significant and continuous growth in ME enrollments and efforts by government, industry and universities to increase awareness of scope and opportunity in the field, the current mechanical engineering educational process is not yet attracting and retaining enough women and minorities. Our principal concern is for the future vitality a profession that does not reflect the society in which it exists and for whom it serves.

Value added engineers. As discussed above, corporations have the ability to source their engineering expertise worldwide, e.g., the 24/7 design processes that have been adopted in the automotive and computer industries. If the mechanical engineering profession is to remain viable, it will depend on the ability of its workforce to provide value to their employers in this around the clock, around the world work environment. Engineering expertise will be required at a higher intellectual level than currently if value is to be added to the engineering and the business processes. For example, expertise related to communication, innovation, and leadership will be required to a much larger degree in accelerated product development. Topics such as these are typically not a significant part of the mechanical engineering curriculum.

Greater sophistication, often at the interface between basic science and engineering and at the systems level, and leadership for innovation also exert their influence on the kinds of engineering skills needed in the work force. Consequently engineers, while always faced with an increased need to continually learn and sometimes reinvent themselves over their careers, must continue to reinvent themselves for technology, systems and influential roles not in place a decade ago. Therein also lie some implications for re-thinking aspects of undergraduate engineering education. Whether change takes the form of curricular restructuring, change in the content of degree programs, or both is the task ahead for educators.

Innovation and leadership. These elements will be paramount to a thriving industrial base, a global reach, and sustainable resolutions of the challenges facing the planet. As the economies become more sophisticated and developed, there emerges a greater dependence on the creative power of the engineering workforce, the process of bringing new ideas to market and, just as importantly, the global cooperation needed required to resolve the truly big sustainability challenges.

Creative invention by engineers is essential to innovation, but so to is leadership. The transformation of an invention into an innovative product or process requires personal leadership skills that produce and strategic and critical-mass collaboration. Truly sustainable solutions are needed in companies and they need enabling public policy. Sustainable growth for companies, countries and the planet should be foremost in our graduates' thinking – and preparation. The technical breadth and impact of a mechanical engineering education must result in graduates are practically adept in the short term but are also prepared to see the "big picture" systemically.

Curricular outcomes that stress systemic design/build skills combined with big picture context and impact awareness could lead to a broader environmental, economic and political role for engineers if professional skills, particularly communications and leadership, are more fully developed. These areas have major implications for degree programs, their content, and their approach to teaching that content.

Global issues. Attention to global issues in engineering practice will become more important to design, product development, and engineering services. Global grand challenges include the scarcity of potable water, developing alternative sources of energy, renewing infrastructure, and assuring sustainable development. Engineers must play and increasing role in fostering cooperation among countries, industries, and educational institutions if we are to respond effectively to these global challenges.

Sustainable economies. Economic decisions must be driven not only by short- but also by long-term perspectives in all areas of professional activity, especially engineering as applied to product development and in the innovation process. In an increasingly commercial, market-driven world, this is a challenge. Mechanical Engineers must occupy prominent, influential roles toward a more sustainability-driven economic future. Sustainable, not unlimited, growth is central to future solutions. Engineering educators, industrial leaders and public leaders must work in concert to address this issue.

ASME V2030 Action Agenda - Creating the Future of Mechanical Engineering Education

What type of curriculum, or curricular change, is needed? By what processes shall institutions determine how to further refine their mechanical engineering programs? Excellence comes from a blending of standardization and innovation and in doing so under constraint — economic, political, physical, institutional, etc. Institutions vary and the vitality that comes from balanced standardization and diversity needs to be systemically embraced. But with any change, core legacy, contemporary engineering fundamentals, and the problem conceptualization and solving abilities of mechanical engineering graduates must be retained.

The ASME Vision 2030 team envisions a more flexible, holistic, and more practice–oriented undergraduate curriculum with a strong, integrated, professional skills component. The curriculum should include major active, discovery-based learning opportunities such as a design spine or other experiences. The curriculum should emphasize problem definition, solving and impact and include systems level experiences. Breadth is most important, with depth possible in a particular area of the student's choosing or the department's professed strengths.

What should Mechanical Engineering education look like as we move towards 2030? Seven aspects of the educational landscape emerge as target areas for curricular evolution on mechanical engineering undergraduate degree programs.

RICHER PRACTICE-BASED EXPERIENCE

Action: Offer more authentic practice-based engineering experiences such as the design spine or design portfolio approach throughout the undergraduate program.

Among the greatest concerns noted among current ME graduates by their employers, as well as the early career engineers themselves, are – simply put – a lack of practical experience in how devices are made and work, a lack of familiarity with industry codes and standards, and a lack of a systems perspective and approach to the design and product development process.

STRONGER PROFESSIONAL SKILLS

Action: Develop students' professional skills to a higher standard.

Both industry supervisors and early career engineers emphasize that graduates need stronger professional skills, e.g., interpersonal skills, negotiating, conflict management, innovation, oral and written communication, and inter-disciplinary teamwork. To meet this need, a systematic focus on integration of such skills into curricula must approach the priority given to technical topics. Incorporation of a multi-year design spine, or portfolio approach, which incorporates such skills development integrated with technical competency development into curricula, is urged.

MORE FLEXIBLE CURRICULA

Action: Create curricular flexibility and efficiency with core requirements and specialization options.

To enable students to develop understanding of mechanical engineering fundamentals but also offer greater strength in context and realization of design, a better systems perspective, and the possibility of focus in an area of interest, there is a need for greater flexibility in the degree path. Thus, the model of a required ME "core" set of fundamental classes, followed by a concentration area is suggested, echoing recommendations of earlier studies.

Action: Modify ABET mechanical engineering degree program accreditation criteria to allow more flexibility.

To enable curriculum change and encourage more flexible curricula, modify ABET ME program criteria to no longer requiring equal thermal and mechanical competencies, but preparation for professional work in one and/or the other, with significant exposure to the area not emphasized.

GREATER INNOVATION & CREATIVITY

Action: Create a curriculum that inspires and enables innovation and creativity.

The chance to produce practical and technical innovation to solve real-world problems and to be of greater value to society is one of the most inspiring aspects of the profession. Developing student creativity and innovation skills, through explicit curricular components that emphasize active, discovery-based learning — such as a design spine or portfolio, or other authentic extracurricular engineering experiences – can also enhance motivation, retention, and serve as a potential launching pad for a next generation of innovators.

TECHNICAL DEPTH SPECIALIZATION

Action: Focus on post graduate education for specialization.

Additional technical depth and specialization in mechanical engineering topics, plus increasingly sophisticated professional skills, will be required in many aspects of industry, according to both the ME department heads and industry managers. Increasing the availability of professional Master's degrees provides increased opportunity for graduates and practitioners to meet such a need.

NEW BALANCE OF FACULTY SKILLS

Action: Increase faculty expertise in professional practice.

To produce graduates with the practical and professional skills described above, diversification of faculty capabilities is required. Employing more faculty members with significant industry experience and creating continuous faculty development opportunities for exposure to current industry practice is urged. Faculty with experience in product realization and innovation, project management and business processes, with understanding of the use of industry codes and standards in different contexts will impart a greater and more authentic sense of the world of practice to students. The institutional expansion and industry support of full-time, tenure or long-term contract faculty positions such as the Professor of Practice or Clinical Professor is urged.

Action: Advocate the modification of ABET criteria for faculty numbers and qualifications.

ABET Criteria should address metrics for minimum faculty size and student to faculty ratio to ensure program quality in design and also address measures that increase the proportion of significantly practice-experienced faculty.

Constrain – and Re-engineer – the Undergraduate Program

It is not necessary to add courses or content to a nominal 120–128 semester hour, four year baccalaureate degree program. However, there must be more effective use of existing technical content, the general education program, technology based instructional methods and even the employment of co-curricular activities. Recognizing that the four-year engineering education program containing all of the attributes previously described may not contain as much technical content in some ME sub-specialty areas, we suggest that undergraduate programs be designed with the expectation that most in-depth technical specialization will come later. Strong articulation with graduate programs is warranted as the nature of graduate education may change due to a differently educated undergraduate entering a graduate program.

The ASME Vision 2030 team has recognized that there is no single approach to addressing and executing the desired changes in mechanical engineering education, but has laid out a number of interventions that should be taken together. What is of particular concern is the degree of industry manager consensus on the shortcomings in graduates' skills and competencies, in areas that ME programs often believe are a core strength of their programs. The Vision 2030 task force therefore has recommended that engineering education be re-thought significantly, with a renewed focus on practice-oriented skills and competency development.

The concept of Lean Engineering Education as explored by the authors of this book offers a tantalizing vision of addressing some of the shortfalls of current mechanical engineering education, particularly the skills and competency deficiencies, and to reconcile content and competencies in mechanical engineering programs.

Although engineering disciplines have specialized further from their roots of civil, mechanical and electrical engineering into a multitude of engineering specialties, they have remained strong in conveying the engineering sciences. However, with the organization of suppliers within the Tier structures, when content has to be applied to develop a more evolved machine, manufacturers have to resort to systems engineering as a way of integrating or adapting components or sub-systems.

While systems engineering by its nature is content-focused, lean engineering is focused on workforce development, in the form of competency development. From the first days of its conception, lean engineering's primary goal was the further qualification and training of employees, to enable and empower them to carry out their daily tasks while giving them the freedom to self-organize and authority respond to production defects. In order to achieve this goal, workforce development had to focus on the development of competencies such as systems thinking, recognizing cause-effect chains and networks, and working in teams, to name just a few. Because of its focus on developing these competencies, lean engineering seems to be a logical complement to systems engineering, thereby complementing content with competency.

It is in this spirit of bringing together content and competency that this work opens the doors for new thinking in mechanical engineering education. ME programs of the future must provide for content and competency at the same time; a focus on content alone will not suffice. The ASME Vision 2030 study has shown that content without integrated competency does not serve the needs of engineers, industry and society, neither today nor in 2030. The readers are strongly encouraged to consider the contents of this book in their own environment, and to be inspired in adapting their curriculum.

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1. Planning for the future to improve mechanical engineering education

Is it worthwhile to *know the future*? Perhaps it is, for knowing the future could help to avert a range of negative outcomes, from avoiding small embarrassing situations to preventing major catastrophic disasters. Unfortunately, knowing the future is a competency that escapes (most) humans. We cannot overcome the consequences of unknown potential problems simply because we cannot know the future.

While knowing the future is beyond human capacity, *anticipating the future* is an activity that people can conduct. Anticipating the future cannot overcome the shortfalls of knowing the future, but it is highly regarded practice and it does provide benefits. In fact, anticipating the future by *planning for the future* is an engagement that consumes a good share of human activity. Consider, for instance, what accountants do as they develop for stakeholders budgets designed to meet goals of either alleviating or increasing risk. Budgeting is an act of planning that requires a substantial allocation of time and resources within the fiscal year. And although knowing the future is not possible through this accounting activity, budgets are acts of planning for the future. Scientists hypothesize and then test their theories considering what might happen as a result of variable changes and interactions. And as they do this, they discover new information. Experimenting is an act of planning that forms the basis of classical scientific inquiry. It often requires a large and substantial allocation of time and resources to conduct. Although knowing the future is not possible through research and development work, scientists can explore unknown possibilities that may materialize into invention. Scientific inquiry is in this sense an act of planning for the future. Even politicians work to leverage ideas, alliances, and resources in preparation for future consequences. They do this by producing current benefits for constituents in exchange for support at a later time. Politicking is an act of planning that requires emotional, cognitive and monetary investment by supporters interested in effecting the results of decision making processes. Knowing the future of such political endeavors is not possible, but the act of planning for the future is a key deliverable of both authorities and partisans.

Planning for the future is an act of widespread practice because it is connected to promise. In spite of the challenges and shortfalls inherent in not knowing the future, planning for the future is an activity that represents a buffer against not knowing the future. That is why a good portion of what the workforce does involves planning for the future. This is because our existence is consistently based on uncertainty or tension about a possible or known event, problem or consequence. In this regard, therefore, it can be stated that planning for the future is generally considered iterative work. And in this context, it is valued activity, normally leading to the decision to act or not to act. For instance, if budgets indicate monetary shortfalls, then administrators make decisions about how to increase revenues or reduce expenses. If scientific inquiry leads to clearer understandings of the impact of a new technology, then the new technology is applied with added caution or freedom. If political coalitions weaken because of internal or external conditions, then realignment of rationale, aims and strategies are taken. In other words, the act of planning for the future is a precursor or guide to potential future action or inaction.

This book is focused on mechanical engineering. It would be wonderful if one could know the future of mechanical engineering practice. While such prowess is not realistic for mechanical engineering apologists, it is possible to anticipate and plan for what engineers of the future will have to know and be able to do. By prompting thought about possible options for engineering education in the context of job opportunities, hiring standards, induction procedures, and work environments of early practice of the future, the imagination can be stretched and new paradigms can be captured. Therefore, planning for the future of mechanical engineering is proposed as a viable activity of educational work as it will help engineering educators and employers alike to estimate what future actions will be most useful for their students and employees. While planning for the future is approached cleanly by ethical accountants, politicians and scientists with protocols rooted in professional codes of conduct or societal mores, planning for the future is presented in the same manner for engineering education. Planning for the future of mechanical engineering is designed for discussion purposes in order to formulate future actions for mechanical engineering preparation for the betterment of mankind.

Planning for the future or planning in mechanical engineering can be approached in many ways. For this book, it is described as a generalized four step process. These four steps in Planning are, 1) *Establish a Statement of the Theme*, 2) *Describe the Core Background Elements*, 3) *Analyze the Current Condition's Shortfalls*, and 4) *Select Statement(s) of the Problem*. These four steps in Planning are described in detail as:

1. *Establish a Statement of a Theme.*
   A Statement of the Theme creates the scope, focus and tenor for Planning. It serves as a label for Planning and establishes initial understanding and nomenclature. For instance, there are differences in these two Statements of a Theme as "Engineering Education Prepares for the Future," and "Engineering Education Ponders the Future." The first Statement of a Theme is more forward-focused, proactive, and positioned to act. The second Statement of a Theme is more present-focused, reflexive and positioned to examine. These are both valid Statements of a Theme, but they are very different, and therefore, these variations will impact the remaining three steps of Planning in different ways, eventually impacting decision making and action.
2. *Describe the Core Background Elements.*
   The Core Background Elements provide a succinct historical perspective that leads to the present state. The narrative of the past does impact in some way both the current and future conditions, so this aspect of Planning identifies and respects this essential feeder information. For instance, based on the Statement of the Theme, "Engineering Education Prepares for the Future," the Core Background Elements might be:

   a. Studies indicate that current graduates and early engineers are missing competencies and knowledge needed for engineering practice.
   b. The global demand for engineers is rising.
   c. Employers are requesting better collaboration between higher education and the workplace in the preparation and induction of engineering graduates.
   d. Futurists state that global needs for engineering solutions founded in sustainability solutions will continue to rise.

   As a part of Planning, these four statements (a–d) are culled from the larger body of history to represent the most critical facts relative to the previous Statement of the Theme.
3. *Analyze the Current Condition's Shortfalls.*
   The Current Condition's Shortfalls highlight why Planning is useful as they set up a gap analysis, as discussed in NAE (2005),

Duderstadt (2008), Sheppard et al. (2008), ASCE (2009), UNESCO (2010), ASME (2011), Graham (2012). The Current Condition's Shortfalls are in-depth examinations of needs highlighted in the Core Background Elements. Many analytic tools can be used to identify these gaps in the present state, ranging from statistical analysis to qualitative assessment to visual diagramming, or even using combinations of these as mixed methods. For instance, an Ishikawa or root-cause visual diagram can be used to understand the gaps in Core Background Element a above and this item could be additionally supported using mixed methods of statistical data from a national survey (see Figure 1-1).

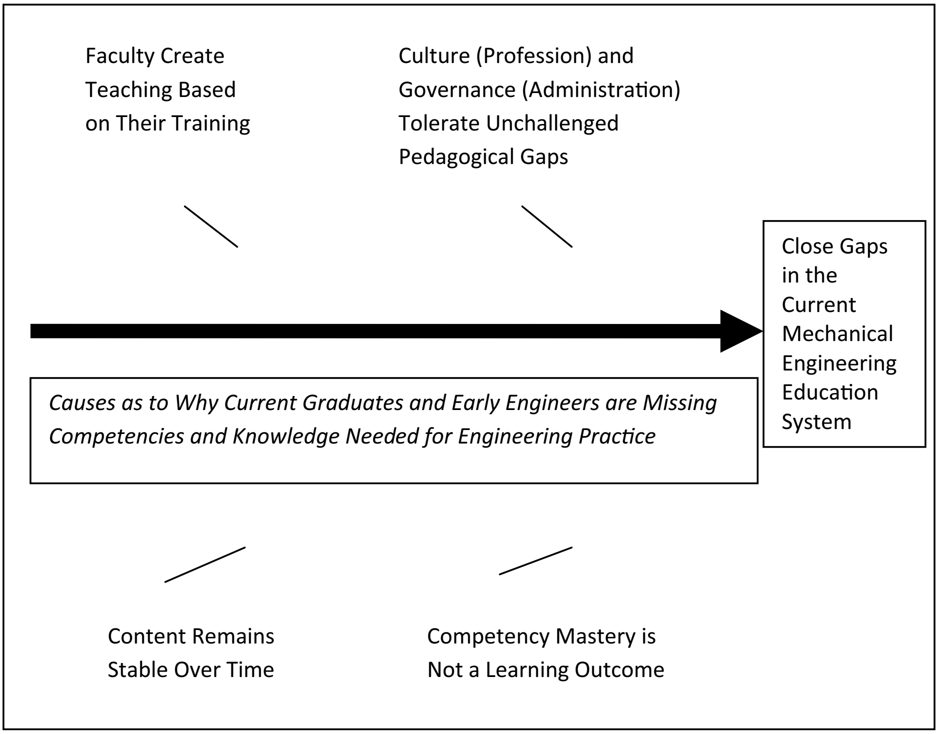

Figure 1-1 Current condition's shortfalls for core background element a.

As a part of Planning, the Current Condition's Shortfalls create the dynamics for current problems to be prioritized and addressed in the future.

4. *Select the Statement(s) of the Problem.*
   As Planning proceeds from the gap analysis in the Current Condition's Shortfalls, problems may become evident. Hence, the fourth step in Planning is to select any Statement(s) of the Problem that may exist. These Statement(s) of the Problem can catapult Planning work into future oriented, needs-based improvement. In the Figure 1-1 above, there are four contributing problems identified causing gaps in current mechanical engineering education. They are identified as: 1) Faculty Create Teaching Based on Their Training, 2) Culture (Profession) and Governance (Administration) Tolerates Unchallenged Pedagogical Gaps, 3) Content Remains Stable Over Time, and 4) Competency Mastery Is Not a Learning Outcome. From these four contributing problems of the Analysis of the Current Condition's Shortfalls, previously derived from the four Core Background Elements, and based on the initial Statement of Theme of "Engineering Education Plans for the Future" an overall Statement of the Problem can be selected as:

   The training, professional codes and administrative oversight of mechanical engineering education allow for engineering education to be delivered without ensuring the identification and renewal of curriculum with relevant content and without providing for critical competency development (i.e., communication skills) of engineering students.

In summary, this exercise in Planning for the Future of Mechanical Engineering consists of four elements described in Figure 1-2 as: 1) Establish a Statement of the Theme, 2) Describe the Core Background Elements, 3) Analyze the Current Condition's Shortfalls, and 4) Select Statements of the Problem.

Based on the four elements presented above of Planning, this leads to action formulation and more informed benchmarks of success or enriched target conditions. Planning, therefore is not an end in itself, but, rather, the first essential step in an improvement process.

Planning for the Future of Mechanical Engineering

1. Establish a Statement of the Theme
2. Describe the Core Background Elements
3. Analyze the Current Condition's Shortfalls
4. Select Statement(s) of the Problem

Figure 1-2 The four elements of planning for the future.

As Planning is promoted and explored for mechanical engineering education in this book, the following series of three scenarios are presented to insinuate what may occur in emerging and early career engineering practice as interview and induction processes, job opportunities and work environments in 2030. The use of scenarios is a viable method in creating vision for the future. Vision serves as a both a prompt to and a plan about a new benchmark of action. Figure 1-3 depicts the use of scenarios as a viable source of data in Planning for the Future.

These scenarios are presented, therefore, as a means to enrich data sets and understandings in Analyzing the Current Condition's Shortfalls and in Selecting a Statement of the Problem.

Mechanical Engineering Scenario 1-
What a mechanical engineering graduate may experience in the interview process in 2030,

Mechanical Engineering Scenario 2-
What a mechanical engineering graduate may experience in job opportunities in 2030, and

Mechanical Engineering Scenario 3-
What an early practicing mechanical engineer may experience in the work environment in 2030.

As these three scenarios are presented as anticipated engineering venues for 2030, each one is followed by **Mechanical Engineering Education Planning Steps** presented as the four step process for Planning as described above:

Mechanical Engineering Education Planning Steps for Scenario 1-
What higher education might do to prepare an engineering graduate for the interview process in 2030,

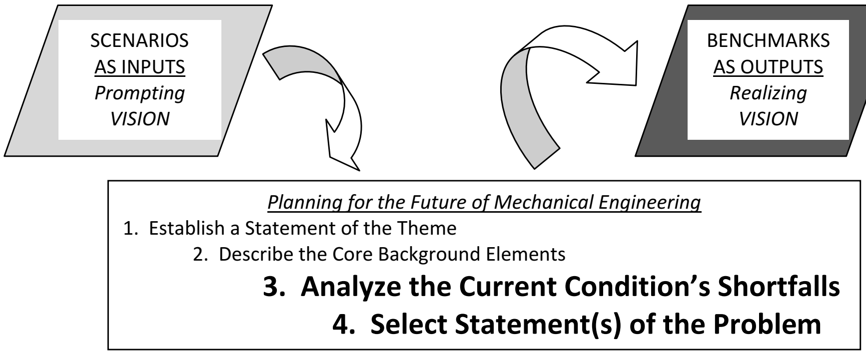

Figure 1-3 Scenarios as valued data inputs to planning.

Mechanical Engineering Education Planning Steps for Scenario 2- What higher education might do to prepare an engineering graduate for job opportunities in 2030, and

Mechanical Engineering Education Planning Steps for Scenario 3- What higher education might do to prepare an early practicing engineer for the work environment in 2030.

These scenarios are not predictions, but are imaginative possibilities for what could occur. They are presented as a starting point way to leverage the current corporate intelligence of the engineering community to assist in planning for the future of mechanical engineering.

Mechanical Engineering Scenario 1-

What an engineering graduate may experience in the interview process in 2030:

Jasmine was thrilled to receive a call back for a third interview for the next week on July 12 with the Rebuild Division of Generalized Solutions Inc. She had just finished her bachelor's degree in engineering in May 2030 and was ready to enter the workforce. This call back meant that she was a top candidate for the position of Design Engineer, a plum job that was at the top of her list. In her job search prior to graduating, Jasmine had found that Generalized Solutions Inc. was listed as one of the "Best Places to Work in 2030" and she wanted to be a part of this international cooperative more than any of the other options she had pursued.

As Jasmine nervously entered the room at the Serbian office, five managers were there to meet her. Three managers stepped forward first and shook Jasmine's hand as they introduced themselves as the Director of Human Resources, the Team Development Director and the Plant Director. Two of the managers were represented as holograms in the room, the Chief Engineer and the Cultural Engineer from the headquarters in Bangladesh and Jasmine stepped up to shake their hands as well. As she was directed to have a seat at the table, Jasmine took a deep breath, sat down and smiled. This interview was a critical moment she had prepared for and hoped she had prepared well for.

The Director of Human Resources began the interview, "Jasmine, we have had a chance to review your digital portfolio of mastery knowledge and competencies and subsequently have asked you here for two previous interviews. The first interview was an observation by the Team Development Director and Plant Director of you leading a team through a problem solving exercise. The second interview was a group interview of five possible employees you would supervise if you were hired."

Jasmine nodded, "Yes, I have had chance to work as a team leader for a project at the university and also have mastery demonstrations of communication and interpersonal skills in my portfolio. I hope that you found my abilities in the first two interviews aligned with your needs for the Design Engineer position."

The Director of Human Resources continued, "We did review your digital portfolio carefully on these two fronts, so we were hoping that you would handle this part of the interview with some acumen, which you did. In addition, the Chief Engineer has reviewed your knowledge credentials and is impressed by your achievements in core content as well."

"Thank you," Jasmine said. "I appreciate the opportunity to be here and to present myself to you for this position."

The Director of Human Resources gestured to his four colleagues at the table, "Today my colleagues and I would like to talk with you, ask you some questions and give you a chance to ask questions. Are you ready?"

This scenario prompts a critical question for engineering education, "What will engineering graduates in the year 2030 have to convey in the interview process regarding what they know and can do?" In this scenario of the future, Jasmine's engineering education will either help or hinder her. In fact, there may even be correlations to Jasmine's ability to meet the expectations of Generalized Solutions Inc. in this interview process and the eventual pace and direction of her career path at the company should she obtain the position. She will soon find out if her mechanical engineering education and preparation is valuable or not in this regard. By connecting this engineering graduate interview scenario to higher education engineering preparation, the question is posed, what should be done to prepare Jasmine for this interview process in 2030? Keeping in mind, that knowing the future is not possible, but that planning for the future is. And Scenario 1 both focuses and extends Planning by adding data inputs of key stakeholders of mechanical engineering education.

Mechanical Engineering Education Planning Steps for Scenario 1-
What might higher education do to prepare an engineering graduate for this interview process in 2030:
Jasmine's interview with the Rebuild Solutions of Generalized Solutions Inc. provides many angles to consider in planning for the future in higher education. The four step Planning process described earlier is used to prompt, suggest and guide considerations for mechanical engineering education in 2030:

1. *Establish a Statement of the Theme-*
   "Engineering Educators Need to Prepare Their Students for New and Different Types of Job Interviews."
2. *Describe the Core Background Elements-*
   a) Students want to align their interests and abilities to appropriate job opportunities. They have choices based on the estimated soaring demands for engineers and the unfilled capacity to meet those demands.
   b) The expansion of international enterprise development and emerging collaborations and structures provides students with different work settings and roles.

c) Students are expected to have high levels of multicultural acumen, ethical development, a team orientation, and project-based learning experiences.
d) Student achievement is quite transparent and accessible, with digital portfolios and demonstrations of mastery in simulated or real workplace environments available for examination.
e) Interview processes may include virtual arrangements, simulated work, and iterative cycles of examination of student candidates.

3. *Analyze the Current Condition's Shortfalls-*
   a) Students are not exposed to entrepreneurial approaches and do not know how to leverage their talents in the marketplace.
   b) Students are not taught about organizational culture, structure and roles and do not know how to function effectively in both collaborative and competitive cultures.
   c) Students are not required to have multicultural experiences, to work on a team in different roles, or to participate in project-based learning.
   d) Students do not have educational lifecycle management technology with semantic continuity which charts learning pathways (rather than requiring courses), recognizes and digitally documents mastery (rather than simply recording academic achievement), and allows for collaboration and sharing (rather than privatizing student learning outcomes).
   e) Students are not prepared for various iterative interview requirements which are prone to work-embedded performances, rather than just formal interviews.
4. *Select Statement(s) of the Problem-*
   Mechanical engineering education is not challenged to prepare students for the environment of interviewing and the variety of interview processes of the future.

Jasmine's interview scenario infers what engineering recruits in 2030 may encounter. **Mechanical Engineering Scenario 1** highlights how organizations will rely on recruiting and interviewing processes to find candidates who present themselves with current knowledge and capacity to be immediately effective in highly complex environments. In fact, Spears (2011) describes the heightened expectations for employees of the future as needing to be ready to operate in dynamic environments, possessing abilities to think systemically and creatively, carrying work competencies honed from team-based learning paradigms. This means that the effort and time to develop this knowledge and capacity must occur before the interview and during the educational process for engineering recruits.

The interviewing processes of the future are designed to vet engineering candidates who are acclimated to a different culture of manufacturing. According to the National Research Council (1998) this culture for 2020 is based on six key drivers as the need to: 1) achieve concurrency in all operations, 2) integrate human and technical resources to enhance workforce performance and satisfaction, 3)"instantaneously" transform information gathered from a vast array of diverse sources into useful knowledge for making effective decisions, 4) reduce production waste and product environmental impact to "near zero," 5) reconfigure manufacturing enterprises rapidly in response to changing needs and opportunities and 6) develop innovative manufacturing processes and products with a focus on decreasing dimensional scale.

With transference in the manufacturing sector away from traditional ways of doing business to valuing new results, to demanding new challenges and to seeking new technologies, the mechanical engineers of the future will likely encounter interviews that are equally aligned with these goals. In planning for the future of what mechanical engineering education might do to prepare graduates for interview processes, therefore, it is reasonable to assume that changes are needed in higher education engineering education to prepare students for new and different interview processes in 2030.

Mechanical Engineering Scenario 2-

What might mechanical engineering education do to prepare mechanical engineering graduates for job opportunities in 2030?

Consider the following scenario of the early engineer working in entry level practice in 2030:

> Harry and Sally are two entry-level engineers. Harry is an electrical engineer and Sally is a mechanical engineer. They are twins and studied engineering at a university in Europe. Making use of the opportunities presented to them during their studies, they utilized the Erasmus program for semester-abroad studies since

> global awareness is needed in practice. Sally complemented her studies at her home institution by taking two courses at a French university while Harry went to Singapore at the same time for a research visit at one of their national research institutes.
>
> After they completed their studies, Harry started working for a large corporation with global field offices and manufacturing sites while Sally started her own consulting business, focusing on the needs of small and medium size enterprises in the global economy. While their individual jobs kept them busy and on the road, they make an interesting observation every time they get back together and share experiences.
>
> They realized that they could not be successful in their jobs if they did not recognize the diversity of their working environment, the needs and acclimations of the people they interact with, and the interdependency of their employer's and customers' interaction with the local and regional staff. They found that the driving competency that enables them to work with such a diverse global spread of people and cultures is their ethical foundation. They discovered quickly that being an engineer is in itself not good enough to be successful in engineering; they relied on their education to prepare them holistically for engineering.

This scenario prompts a critical question for engineering education, "What kinds of job opportunities will engineering graduates in the year 2030 have to do to prepare?" In this scenario of the future, Harry's and Sally's engineering educations will either assist or block them. In fact, there may even be correlations to Harry's and Sally's abilities to understand the job opportunities as early career engineers and the eventual pace and direction of their career success. They will soon find out if their mechanical engineering educations and preparations are valuable or not in this regard. By connecting these engineering graduates job opportunities scenario to higher education engineering preparation, the question is posed, what should be done to prepare Harry and Sally for these job opportunities in 2030? Keeping in mind, that knowing the future is not possible, but that planning for the future is. And Scenario 2 both focuses and extends Planning by adding data inputs of key stakeholders of mechanical engineering education.

Mechanical Engineering Education Planning Steps for Scenario 2- ***What might higher education do to prepare an engineering graduate for job opportunities in 2030:***

Harry's and Sally's job prospects provide many angles to consider in planning for the future in higher education. The four step Planning process described earlier is used to prompt, suggest and guide considerations for mechanical engineering education in 2030:

1. *Establish a Statement of the Theme-*
   "Engineering Educators Need to Prepare Their Students for New and Different Types of Job Opportunities."
2. *Describe the Core Background Elements-*
   a) The expansion of international enterprise development and new collaborations and structures provides students with different work settings and roles.
   b) Students are expected to have high levels of multicultural acumen, ethical development, a team orientation, and project-based learning experiences.
   c) Student achievement is quite transparent and accessible, with digital portfolios and demonstrations of mastery in simulated or real workplace environments available for examination.
   d) Job opportunities for early engineering graduate are interdependently linked, yet vary widely.
3. *Analyze the Current Condition's Shortfalls-*
   a) Students are not exposed to entrepreneurial approaches and do not know how to leverage their talents in the marketplace.
   b) Students are not taught about organizational culture, structure and roles and do not know how to function effectively in both collaborative and competitive cultures.
   c) Students are not required to have multicultural experiences, to work on a team in different roles, or to participate in project-based learning.
   d) Students do not have educational lifecycle management technology with semantic continuity which charts learning pathways (rather than requiring courses), recognizes and digitally documents mastery (rather than simply recording academic achievement), and allows for collaboration and sharing (rather than privatizing student learning outcomes).

e) Students are not prepared for various interview requirements which are prone for work-embedded performances, rather than just formal interviews.

4. *Select Statement(s) of the Problem-*
Mechanical engineering education is not challenged to prepare students for the job opportunities of the future.

Harry and Sally's job prospect scenario infers what engineering recruits in 2030 may encounter. **Mechanical Engineering Scenario 2** highlights what is needed for success in early engineering practice and it provides several clues for engineering education. Initially, both early practicing engineers, although in different job settings, are drawing from the same set of knowledge, technical expertise, and competencies, the transversal or "soft" competencies, desired in their positions. Global awareness, systems thinking, sustainability awareness and ethical development are examples of transversal competencies that they are needed for their work.

Transversal competencies are developed in engineering education graduates through student-centered learning methods. According to Jonassen and Land (2000), this implies three fundamental shifts in thinking about traditional engineering education methods: 1) from an external process of knowledge transmission to an internal process of making meaning, 2) from restrictive dynamics of individually-held perceptions to the open-ended dynamics of constructing meaning through social interactions, and 3) from learning through the visual and audio transmission of information to including making meaning through characterlogical development with social relationships and through experiential understanding through tactical experiences with physical artifacts, models and theories.

Weimer (2000) described how student-centered learning promotes a shift of power from the teacher to the student. In fact, as the responsibility for learning shifts to the teacher, the teacher is responsible for facilitating the process of learning through active learning methods, such as hands-on simulations, case studies or field projects. McManus, Rebentisch, and Murmanand-Stanke (2007) explained how hands-on simulations have been explored to promote understanding of complex subjects in a deep and intuitive ways. Alves and van-Hattum (2011) informed this point further by describing that student-centered learning involves stimulating students to apply learned concepts from previous years' curricular units in a varied ways, preparing students for different roles in their professional futures through themed training sessions applied to different work environments, and promoting creative thinking through teams-based projects. Eurydice (2010) stated that such active and cooperative learning methodologies have been adopted by many universities all around the world through external entities like in the Bologna process in Europe. In planning for the future of what mechanical engineering education might do to prepare graduates for job opportunities, therefore, it is reasonable to assume that changes are needed in higher education engineering education to prepare students for new and different positions in 2030.

Mechanical Engineering Scenario 3-

What an early practicing mechanical engineer may experience in the work environment in 2030.

> Maria is an engineer in an multinational company which dismantles electronic products like cell phones, televisions, compute, wash-machines and other domestic appliances. Her day starts early in the morning with a fifteen-minute video-conferencing meeting with her interdisciplinary team spread around the world.
>
> This meeting's protocol is succinct because employees apply continuous improvement and have been trained in the use of tools that enable these daily focused improvement meetings. The fifteen-minute meeting's purpose is to discuss output targets, productivity indices, and, most importantly, new uses or applications for the dismantled components at an environmentally and sustainable cost among others.
>
> "Sustainable" production in Maria's company requires energy efficiency with minimal environmental impact, compliance to the regulatory constraints and fulfilling the safety and health requirements, in addition to attaining profitabilty for economic growth. Maria knows this information well and comprehends its meaning and implications for her work. In her company, Maria is challenged every day with tons of products that do not attend to this requisite and she must find ways to change these wasteful components into sustainable products. Transforming rubber from cars'

tires into kids' playground equipment and developing keyboards from old computers into suitcases are successful examples stemming from over two decades ago that she learned about in engineering school. However, she is faced with the problem that not all products are created and made under sustainability guidelines.

The concern of Maria's company is to determine how to dismantle the products used by consumers and how to create new eco-efficient products from the old ones using eco-efficient processes to do so. Everyone in her company has to think creatively about new applications for these used components and about ways to reduce the environmental impact of the recycled materials. Hence, "Old Products into New Eco-Friendly Products" is the mantra of the company and Maria is serious about upholding it in all aspects of her work.

In the interdependent world of the third millennium, social, technological, environmental, economical and political factors have created massive problems with significant consequences. Therefore, several complex factors have to be conceptualized as a system as Marie creates solutions. She has to be aware of multiple challenges such as, the globalization of world economies, accumulating climate change, the scarcity of strategic raw materials, the needs of centers of growing overpopulation, changing employment demands, the security of energy supplies, the needs of a large aging population, the public concerns about health for all, increasing poverty and social exclusion, the loss of bio-diversity, increasing waste volumes, soil loss and transport congestion.

In this setting, Maria's company has strict rules in place about the materials supplied from suspected sources. Energy intensive materials are not permitted in the company; all stakeholders have knowledge of this.

In order to be successful in this environment, the company hires engineers with ethics, sustainability knowledge (footprint analysis, product lifecycle management, energy intensive, carbon neutral systems) and systems thinking. These were the reasons why the company hired Maria. As an early practicing engineer, she was required to demonstrate clearly her positions on such issues. For instance, she was asked in the interview to create a defense for the environment against river water pollution. In her new position, she was required to demonstrate how she would appeal to consumers to behave in a more eco-friendly manner. Maria's confidence and assertive attitude helped her in the interview and with her work duties.

Because she had the chance to work in teams at her university and develop projects, such as designing a mechanism for recovering oil from ocean oil disasters. In this team-based project, Maria had to examine why these problems occurred. The causes stemmed from many issues like negligence of a petroleum ship's cleanness or from lack of proper maintenance. In her first year of study at her university through project-based learning experiences, Maria came to conceptualize the impact of environmental disasters.

Since her company was strategically invested in adding value to its knowledge base, it used ICT-enabled intelligent manufacturing and high performance manufacturing in order to achieve sustainable and competitive growth and wealth. In this environment, Maria was the right person to be leader of the interdisciplinary team trained in these skills. Besides possessing technical skills, she had the transversal skills to manage projects and teams, to employ empowerment tenets to her team through shared responsibility. Maria had a good sensibility and awareness of the work environment themes promoted by her organization.

Additionally, Maria and her team of colleagues from around the world, focused not only on results, but in engaging in learning. Their understandings about the dismantling of products to reduce waste were acquired through a Lean approach. Occassionally, Maria and her team are subsequently asked to train other company teams in how to use lean tools and tenets in advancing green agendum. She and her team have helped others to understand how to improve processes, how to understand what is value-added and what is wasteful, and how to accomplish results collectively in a positive work environment. Maria's company are then were better able to create new products that possess created sustainability value and eliminate waste. Company production has become more energy efficient, giving off less process emissions (dust, air, water, noise, waste, etc.). Maria's company relies on paradigms about recycling or dismantling. Maria's company disseminates information about new materials that are low carbon and green materials, and, consequently, encourages employees to execute socially responsibility and eco-sustainability as a reflection of the conscience of the company.

This scenario prompts a critical question for engineering education, "What kind of work environments will engineering graduates in the year 2030 have to prepare for? In this scenario of the future, Maria's engineering education will either enable or inhibit her. In fact, there may even be correlations to Maria's abilities to understand the work environment as an early career engineer and the eventual pace and direction of her career success. She is finding out if her mechanical engineering education and preparation are valuable or not in this regard. By connecting this engineering graduate work environment scenario to higher education engineering preparation, the question is posed, what should be done to prepare Maria for this work environment in 2030? Keeping in mind, that knowing the future is not possible, but that planning for the future is. And Scenario 3 both focuses and extends Planning by adding data inputs of key stakeholders of mechanical engineering education.

Mechanical Engineering Education Planning Steps for Scenario 3- ***What might higher education do to prepare an engineering graduate for the work environment in 2030:***

Maria's work environment provides many angles to consider in planning for the future in higher education. The four step Planning process described earlier is used to prompt, suggest and guide considerations for mechanical engineering education in 2030:

1. *Establish a Statement of the Theme-*
   "Engineering Educators Need to Prepare Their Students for New and Different Work Environments."

2. *Describe the Core Background Elements-*
   a) Students want to align their interests and abilities to work environments. They have choices based on the estimated soaring demands for engineers and the unfilled capacity to meet those demands.
   b) The expansion of international enterprise development and new collaborations and structures provides students with emerging work environments.
   c) Students are expected to have high levels of multicultural acumen, ethical development, a team orientation, and project-based and green learning experiences.
   d) Student achievement is quite transparent and accessible within new work environments.
   e) Work environments for early engineering graduates are focused on results, learning and leveraging human capital for societal good.
3. *Analyze the Current Condition's Shortfalls-*
   a) Students are not exposed to learning experiences that develop desired talents in the work environment.
   b) Students are not taught about organizational culture, structure and roles and do not know how to function effectively in both collaborative and competitive cultures.
   c) Students are not required to have multicultural experiences, to work on a team in different roles, to create sustainability platforms, or to participate in project-based learning.
   d) Students do not have educational lifecycle management technology with semantic continuity which charts learning pathways (rather than requiring courses), recognizes and digitally documents mastery (rather than simply recording academic achievement), and allows for collaboration and sharing (rather than privatizing student learning outcomes).
   e) Students are not prepared for work environment requirements which are prone to systems approaches, creativity and concern for others.
4. *Select Statement(s) of the Problem-*

   Mechanical engineering education is not challenged to prepare students for work environments of the future.

Maria's work environment scenario infers what early practicing engineering in 2030 may encounter.

Mechanical Engineering Scenario 3 highlights what is needed for success in early engineering practice and it provides several clues for engineering education. According to Poon (2011), engineering education should, besides giving students the traditional competences, prepare students to: 1) think globally and innovate about the future, 2) act by contributing, taking the initiative and demonstrating integrity, 3) adapt and embrace changes as the find their feet in unfamiliar places, 4) be sensitive to and tolerate opposition and cultural differences by managing expectations, 5) be aware of sustainability on social, economical and environmental levels, 6) communicate effectively, and 7) inspire others. To achieve this, Poon (ibid) concludes that higher education and industries should collaborate further to develop the next generation of engineers.

This vision is shared by McCormick (2011) who advocated for collaboration by teams of faculty to integrate coursework within programs. He and others authors such as Kirkpatrick and Danielson (2011) emphasizes a need for practical learning, an emphasis on professionalism and a commitment to the work, an understanding of and experience with leadership, a fundamental technical competence, a creative spirit, and a dedication to teamwork. To leverage the job opportunities faced by early career engineers in 2030, Rokkjae, Nørgaard, Jensson, Schinner, Appold, Byrne, Nolan, Polman, Schut, Bayard, and Areskoug (2011) described that more global dialogue and collaboration are called for so that a better match between needs of the work environment and the competencies acquired through engineering education occurs for early career engineers.

Some are planning on engineering practice to change dramatically by the year 2030. This is because the main concern of engineering work product until the present was to design, build, assemble and implement new products without having to consider the end of product lifecycle. In addition, not only is the scope and impact of the life cycle a new focus, but so is planning how the product or system will be dismantled or recycled after its active life. DeGrasso and Martenilli (2007) boldly outlined these implications for the work environment of the practicing engineer as,

> In this evolving world, a new kind of engineer is needed, one who can think broadly across disciplines and consider the human dimensions that are at the heart of every design challenge. In the new order, narrow engineering thinking will not be enough. (p. B8)

Additionally, because design will continue to be an important activity of engineers, products and services will be prioritized around eco-efficiency and sustainability metrics.

According to the Delphi study, Visionary Manufacturing Challenges for 2020, published by the National Research Council (1998), it will be important to attain seven key metrics in the work environment of the future. They are to: 1) innovate processes to design and produce new materials that will minimize waste and energy consumption, 2) design adaptable equipment and systems that are easily reconfigurable, 3) rely on biotechnology for manufacturing; product and process design methods that address a broad range of product requirements, 4) enhance human-machine interfaces, 5) synthesize systems by modeling and simulation for all manufacturing operations, 6) apply technologies to convert information into knowledge for effective decision making, and 7) utilize software for intelligent collaboration systems and new educational and training methods that enable the rapid assimilation of knowledge.

In the midst of these emerging manufacturing changes, there exists an even more critical and rising concern. There is considerable imminence given as to how to preserve and distribute existing resources to reach all people in the planet. This concern of sustainability is dependent on a significant paradigm shift in manufacturing practice from wasteful consumption of materials in some regions to stewardship of resources by more careful and more equitable distribution of these resources. So, in order to create a conscience toward sustainability and to educate the mechanical engineer of the future, it will be necessary, more than ever, that engineering education is strongly based in ethics and systems thinking. Mechanical engineering education must also accompany the trends of current and evolving engineering practice and to incite sustainability mindfulness in all future engineers is called for. According to Boyce (2011), this means being increasingly multidisciplinary, interdisciplinary, deeper, broader, integrated, innovative, team-based and connected to world challenges. In planning for the future of what mechanical engineering education might do to prepare graduates for the work environment, therefore, it is reasonable to assume that changes are needed in higher education engineering education to prepare students for new and different work environments in 2030.

These three scenarios focus on the interview process, job opportunities and work environments of early career engineers and posit much about the future of mechanical engineering practice and education. Each scenario utilized a planning for the future approach to analyze implications for decision making in mechanical engineering education. While each scenario had a slightly different Statement of the Theme, the Core Background Elements, the Analysis of the Current Condition's Shortfalls, the Statements of the Problem, were very similar in all three. In other words, when asking why gaps exist between the current educational practice and the possibilities of what the future engineer needs in preparation for practice, the conclusion is that the engineering education remains somewhat unchallenged. It is the intention of this book to provoke a challenge to think more deeply, to vision more proactively, to dialogue more intently and to engage in more improvement action than ever before.

The point of the three scenarios, planning steps and discussion is to point out the critical need for mechanical engineering education to closely align with the essentials of engineering practice of the future. The future of engineering professional practice in 2030 cannot be fully understood since no one knows the future. But, by creating and examining viable scenarios of the future as the basis for planning for mechanical engineering education, a position is created that asks for decision making by mechanical engineering educators to improve pedagogy, curriculum, instruction and assessment.

To guide in the challenge for improvement, this book explores and examines change options for the mechanical engineering educator. Since it is predicted that the interview process, job opportunities and work environments for engineers in a few decades will be quite different from current practice, the manner in which engineers are educated today will have to be different for the year 2030. For Jasmine, Harry and Sally, and Maria as early practicing engineers in the year 2030, their futures are initially tied to the relevance, quality and scope of their engineering educations. And not only are their futures reliant on their engineering educations, so is the future of the planet.

2. What is needed from mechanical engineering education in the future?

Planning for the future is a key activity promoted in Chapter One as the foundation for improving mechanical engineering education. Once critical and thoughtful educational planning has occurred, then it is possible to deliver educational programming by design. In the process of Planning, themes of educational development are established, background information is explored, current conditions are analyzed, and core problems are identified. Scenarios are used to better inform understandings to *Analyze the Current Condition* and to *Select Statement(s) of the Problem*. The examination of what is possible against what is present informs Planning so that improvements can be envisioned, developed, deployed and re-examined again at a later time.

All planning is for naught, however, unless the Planning process is positioned from the perspectives of educational stakeholders. These critical stakeholders are the early career engineers, employers, faculty and the elements of society impacted by the work product of mechanical engineers (see Figure 2-1). The use of scenarios as described in Chapter One provides essential perspectives for planning. To further enhance Planning work, statistical data from needs-based data arranged thematically by stakeholders provide another source of information for the Planning process.

In this chapter, the perspectives of these mechanical engineering stakeholders are examined. This is done so that planning for the future can be approached as a need-based process, connected in a meaningful

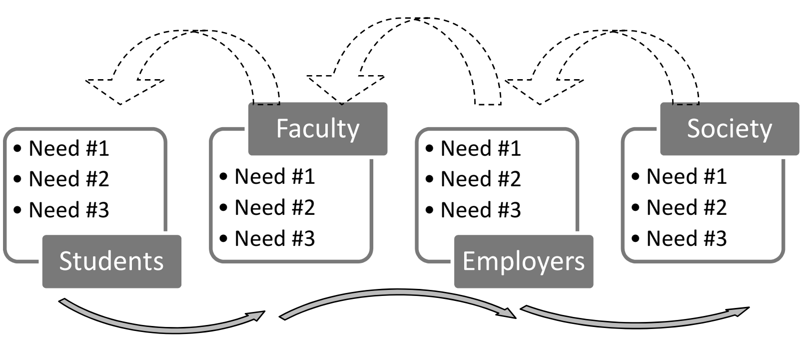

Figure 2-1 Mechanical engineering education stakeholders.

way to these stakeholders. This examination is presented for positive reasons, to jump start possible discussion points of improvement. It is not intended to inclusively represent all data from these stakeholders, but to serve as an example as to how to embed *Planning for the Future of Mechanical Engineering* in informative gap analysis.

2.1 Early career engineers as stakeholders of mechanical engineering education

The needs of early career engineers, as the most highly valued stakeholders of mechanical engineering education, require critical examination and consideration. Professional associations, such as the Royal Academy of Engineering and the American Society of Mechanical Engineers (ASME), have a history of collecting data on the effectiveness of engineering education on the engineering graduate, early career graduate, and engineering practitioner. These data are extremely valuable in understanding where value has been delivered from the academy to the engineering student graduate as immediate, short term and long term career benefits. A March 2012 Royal Academy of Engineering report by Graham states, "A series of reports from The Royal Academy of Engineering (The Royal Academy of Engineering, 2006, 2007, 2010) has demonstrated that change in undergraduate engineering education is urgently needed to ensure graduates remain equipped for the new and complex challenges of the 21st century." (p. 2) The following gap analysis from the ASME's Vision 2030 project (2010, 2011, 2012, 2013) are presented to further these key themes of improvement for mechanical engineering education.

Overall, 53% of student graduates surveyed declared their education preparation as neutral or as inadequate. While 47% of students were satisfied with their preparation, the majority of students were not. This is a significant gap and is useful in planning for the future by determining where improvements can be made. There are many data from these students which can be examined in several ways. For the purposes of this chapter, the data have been arranged into three themes, the need for systems thinking, sustainability thinking and ethical development (see Figure 2-2). This gap analysis is presented as a demonstration of *Planning for the Future*. It is not identified as an exclusive or exhaustive summary to other needs in mechanical engineering education. The analysis is presented to provide an example as to how to engage in *Planning*.

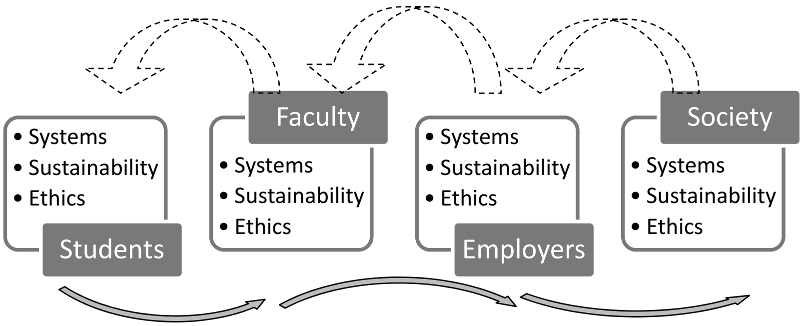

Figure 2-2 Mechanical engineering education stakeholders needs for systems, sustainability and ethics competency.

Students' Need for Better Systems Competency. Student graduates provided insights into systems competencies needed from their educations. Specifically, they cited business process knowledge (69%), project management ability (53%), systems perspectives (31–37%) and interdisciplinary team experience (43%). They reported that experience with delegating tasks was needed. In addition, interesting open-ended feedback was provided regarding more improvement options, such as:

- "Understanding life cycles and how to calculate expected failure is important,"
- "Nuclear safety is a big deal. Understanding how systems interact and could adversely impact operation and safety is important,"
- "Understanding implications of certain failures on design and prove design acceptable for intended use is needed,"
- "Being able to understand and implement a system that allows our company to review the risks in advance to making decisions would be beneficial."
- "Learning not only to be creative, but how to adapt existing ideas to new applications is needed. A lot of the engineers I work with do not see that just because a item was designed for one application does not mean it cannot be used somewhere else,"
- "Understanding manufacturing processes and machine capabilities, and the costs associated with one process over another is important aspect,"

- "Understanding the process for almost all consumer products with mechanical and/or electrical component is needed. Understanding how parts made with the same process can have varying properties," and
- "The further I have moved into my career the more I am dealing with project management and understanding and meeting customer expectations. This requires a better understanding of risk assessment, marketing, and selling the technical aspects of a product."

Students' Need for Improved Sustainability Competency. Student graduates provided insights into sustainability competencies needed from their educations. Specifically, they cited gaps in understanding maintainability (40%), codes and standards (72%), risk assessment and management systems perspectives (26%) and new technical knowledge (59%). Students reported an interest in knowing how to participate in and how to manage processes "to *assure* that the last time I get to touch a product, it will work for next fifty years." In addition, interesting multifaceted feedback was provided regarding more improvement options, such as enhancing experience with:

- "Latest developments, benchmarking best practices."
- "Safety, along with environmental protection in new projects, are the main driving factors in most of the new work we are involved in. I have very little prior exposure to safety. In my case, this is exposure to state and federal regulations governing safety in industrial facilities."
- "Failure analysis, corrosion (materials content)."
- "Setting up, troubleshooting, and conducting tests. I would like to see more engineers familiar with identifying sources of error."
- "Understanding that tests and evaluation are critical that risks, environmental considerations, life cycle cost, etc. are verified (testing)."
- "Lean processes, high yield/low waste production."
- "Working on understanding how what they are doing could affect the environment and if the process/product could be more sustainable."
- "Understand Environmental Impact Assessments"

- "Searching for online tools for potential habitats, cultural sites, landmines, gas pipelines, wetlands, etc."
- "Green Building Design - HVAC and Plumbing areas."
- "Internalizing that every design, maintenance job, operation impacts the environment through waste, leaks, containment. And knowing what the industry standards and law allow. An example is LDAR (Leak Detection and Repair) where you cannot just add a valve or pump without review."
- "Learning about latest technologies and low investment ways to reduce environmental impact of buildings/factories."
- "Introducing the notion that many actions in new construction have an impact on the environment - waste, recycling, repurposing - and how we can think of ways to reduce the carbon footprint by utilizing the byproducts of one process to be mutually beneficial for another while helping to perpetuate the environment."
- "Packaging is a mess that creates more environmental problems than it solves. Packaging materials have already been slimmed to the bone. Biodegradable 'enhancement' using less fiber or plastic content is needed."

Students' Need for Better Ethics Competency. One gap analysis theme accumulates around the issues of the legal and ethical competencies of mechanical engineering education. Students reported the need for more training in: reliability (40%), safety (37%), leadership (32%), conflict resolutions (26%), business ethics (24%), and legal information (22%).

Students also described a need to be able to assess and evaluate data better and to be able to draw reasonable conclusions from those assessments. Qualitative feedback from early engineers highlight the need to make sure that people are safe with "things we design," such as remembering that "what we design will be used by a mother of three." Other needs that graduates had include changing old engrained culture to accept safety as your own personal responsibility instead of it being someone else's responsibility and weighing risk assessment by balancing safety and reliability. Respondents also described the need to be creative and to create value by improving ideas and understandings, not just work product.

These data are presented to indicate where current gaps are occurring, but there is not the claim that the needs of engineering graduates are fully explored here. The intention is to bring awareness to the fact that gaps exist for mechanical engineering graduates in order to promote planning for improvement.

2.2 Employers as stakeholders of mechanical engineering education

From an industry perspective, the deficiencies of engineering education manifest in weak performances of engineering graduates. Industry demands show dissatisfaction with the status quo in mechanical engineering education and the American Society of Mechanical Engineers has worked to understand these shortfalls through their Vision 2030 initiative. Interestingly, shared thinking does not exist among employers, as views vary and are equally split about required changes. For instance, when asked, "Overall, do you feel the undergraduate mechanical engineering education needs greater breadth or depth?", 39% believe that the current balance of material taught is sufficient, while the demand for more breadth (30%) and more depth (31%) is equally strong. However, there are coherent data that provide starting points for understanding where to begin improvement planning. These data are described next under three themes, systems, sustainability and ethics competency.

Employers' Need for Systems Competency. Employer surveys provide data showing that more than half (55%) the engineering graduates lack practical experiences of how engineering products work, and close to half the engineering graduates do not have an overall systems perspective (43%). In addition, close to one third of engineering graduates have difficulties in participating in project management (35%), in problem solving (34%) and in understanding business processes (30%). An increased depth in problem solving and critical thinking, as well as in design was cited by 46% and 4% of respondents as needing improvement, respectively.

Employers' Need for Sustainability Competency. Employers are increasingly interested in and concerned about sustainability competency in the workplace. For instance, engineering codes and standards are either viewed as needing more depth of understanding (40% of respondents) or more breadth of understanding (35% of respondents). And while approximately 50% of respondents reported that technical fundamentals were adequate, 50% reported a concern for either more depth or breadth.

Employers' Need for Ethics Competency. The demand for more ethics competency as indicated by the response for higher leadership ability (with different degrees) was cited by a total of 84% of employer respondents. This is also connected to need for better communication and practical experience at about 50% of respondents.

While it is clear from the above data that there is industrial demand for further qualification of employees to carry out their assigned jobs, there is no overwhelming demand for further academic qualifications for engineers. In response to the question, "An initial attempt is being made in the United States to increase the educational requirements from a bachelor's degree to a bachelor's degree plus the equivalent of 30 semester hours (this could be a master's degree) to obtain a professional engineering degree, "Do you support this change?" Only about one third of respondents expressed an interest in a professional engineering degree, with more than 50% expressing no interest. In addition, the benefits of hiring engineers with Master's degrees are clearly conveyed in the responses. The technical overwhelmingly acknowledged as strong (90%), as are the engineers' maturity, technical breadth, better communication skills, and overall better preparation for working in a company on the master's level. This means that employers believe that these shortfalls can be addressed within the context of mechanical engineering education planning.

While the industry returns are somewhat murky about what skills and competencies are required for engineers for the next twenty years, there is a lot to be learned about employers' needs of early practicing engineers in the workplace. The data reveal dissatisfaction with current engineering graduates on multiple levels. However, these findings are contextualized by increasingly better opinions of graduate mechanical engineering students over undergraduate students, indicating that higher education is perceived as a viable venue for engineering development. And, therefore, these data serve as a starting point forward for planning for improvement in mechanical engineering education.

2.3 Faculty as stakeholders of mechanical engineering education

The survey of ASME's Vision 2030 (2010) about Mechanical Engineering Education from the point of view of faculty indicated were strong included problem solving & critical thinking, technical fundamentals and oral and written communications skills. These results are also arranged by the themes systems, sustainability and ethics competency.

Faculties' Need for Systems Competency. Faculty recognized the need for systems competency in mechanical engineering education. Some indicated problem solving and critical thinking as strong by 47% of respondents or as strong, but needs even more emphasis by 12% of respondents. In addition, an overall systems perspective was reported as weak and needs improving by 47% of respondents. Business processes were weak as well (39%). Project management fared as being sufficient (44%) and the need for interdisciplinary teams and interpersonal teamwork was reported as strong by 47% of faculty. In addition, some form of design-build or practical experience before graduation was one of the aspects that a high percentage (82%) of respondents believed should be required. For 81% of these respondents this could be accomplished by hands-on design project experiences and approximately half of the respondents (56%) feel this can be accomplished by a cooperation or internship experience.

Faculties' Need for Sustainability Competency. Faculty reported some concerns under this theme. Sustainable technologies were reported by 48% of respondents as weak, along with new technical fundamentals (such as mechanical engineering applications of bio, nano and information technologies) identified as weak by 40% of faculty. Other weaknesses included codes and standards (36% of faculty).

Faculties' Need for Ethics Competency: Faculty identified that ethics competency in leadership in mechanical engineering education is weak (36%). Among other aspects, ethics involves behaviors that impact professional responsibility. These behaviors are reflected in issues like: public safety and welfare; risk and the principle of informed consent; health and environment; conflict of interest; truthfulness; integrity and representation of data; whistle blowing; choice of a job; loyalty; accountability to clients and customers; plagiarism and giving credit where due; quality control; confidentiality; trade secrets and industrial espionage; gift giving and bribes; employer/employee relations; and discrimination. Engineering ethics instruction is present in many programs, especially in the United States according to Herkert (2000). In addition, Herkert, reflected about engineering ethics education and referred that the greatest challenge is the enthusiastic involvement of the engineering faculty in discussing ethical issues and social implications of technology in their courses. Maybe this is the reason why, even today, this theme is absent in many mechanical engineering and is offered as a separate course. Newberry (2004) explored the systemic barriers within academia that contribute to this problem, resulting in superficially effective ethics instruction. These systemic barriers include, among others elements, the lack of expertise and role modeling by the faculty in engaging students in the emotional elements of ethical engineering practice.

It is interesting to note that 75% of the faculty respondents believe that the changes to the curriculum of mechanical engineering will be done through more efficient curriculum planning. This indicates that the current process of planning for improvement does have barriers that create difficulties. Inefficiencies in curriculum planning and design not only create relevancy gaps, but hinder an ability to respond to present needs. In other words, the need to improve the process of planning for the future is widely recognized as a root cause of curriculum shortfalls. This point enlarges the focus of curriculum planning improvement to include not only the final work product of planning, but also the process of planning. In other words, in order to develop a good curriculum, the process of developing that curriculum requires good attributes as well.

2.4 Society as a stakeholder of mechanical engineering education

The needs of society as dependent on the work product of engineers, is a fourth highly valued stakeholder of mechanical engineering education. Therefore, the needs of society related to engineering education and practice require critical examination and consideration. A variety of sources provide data for this next section on societal needs. These data are extremely valuable in understanding where value has been delivered from the academy to the engineering student graduate to engineering practice to society and are arranged by the same themes, systems, sustainability and ethics competency.

Society's Need for Systems Competency. Although Industrial and Systems Engineering have relied upon systems thinking as a basic competency, systems competency is now more widely called for within in all fields, including engineering. The ASME (2011) has identified systems thinking as a major topic of interest in Project: Crowdsourcing, a program designed to inform the field on relevant topics of interest.

What is of critical interest in regard to this competency is that a lack of systems competency produces consequences that may be catastrophic, long term, and irreparable. The costs of systems competency gaps are staggering when the impacts of this type of dysfunction in engineering practice are calculated. In some cases, the losses are explicit, but in other cases, the losses are oblique. A simple cost-benefit analysis of a handful of disasters caused by a lack of systems competency is impetus enough to attack this problem and make the investment needed to foster its development.

Society's Need for Sustainability Competency. There are multiple demands for sustainability competency from society on engineers. For instance, estimates showed that the world's 6.96 billion population as of July 1, 2011 (http://en.wikipedia.org/wiki/United_States_Census_Bureau) is using 1.5 earths to provide the resources humanity uses and to absorb its waste. This means that it now takes the earth eighteen months to regenerate resources and soak up waste generated in twelve months. Moderate United Nations scenarios suggest that if these current population and consumption trends continue, by the 2030's the equivalent of two earths will be needed to support the human race. (http://www.footprintnetwork.org/en/index.php/GFN/page/world_footprint/) In addition, the current estimates show that the global population growth trend will increase. The population is forecasted to grow to nine billion in 2050. If assumed to be consuming at business-as-usual levels, this is problematic.

These concerns by society for sustainability competency are identified within the Global Challenges set out by the Millennium Development Project (http://www.millennium-project.org/millennium/challeng.html) in 2011. In fact, Sustainable Development and Climate Change is the most highly ranked problem facing humanity today while a 2003 report by the US National Council for Science and the Environment noted that baseline information about the status of sustainability education and practice in any nation is largely absent.

The United Nations General Assembly (2002) and the World Federation of Engineering Organizations' Committee on Technology (2002) provides evidence suggesting that despite the increasing dialogue about environmental engineering and science education, there has not been a substantial shift in this direction in engineering curriculum in any country. The Driving Forces-Pressures-State-Impacts-Responses framework are presented below in Figure 2-3 and highlight the origins and status of the system of societal needs around the sustainability competency.

The generally accepted DPSIR framework above is used to define the linkages among the activities of man in society and their effects in the environment. Driving forces are the socio-economic and socio-cultural forces driving human activities, which increase or mitigate pressures on the environment. Pressures are the stresses that human activities place on the environment. State, or state of the environment, is the condition

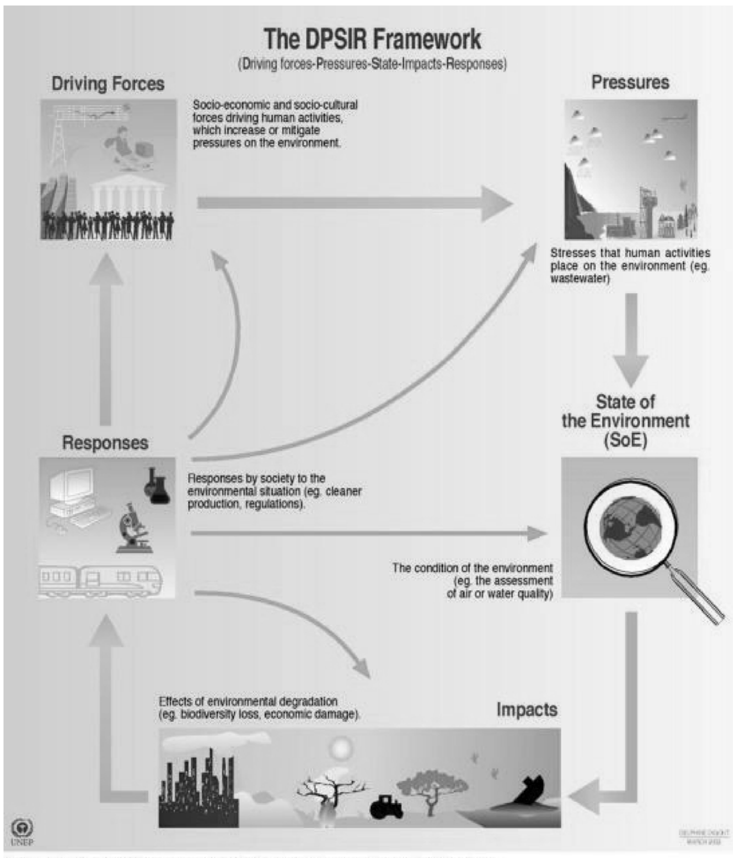

Figure 2-3 The DPSIR framework for sustainability thinking. (Credit Delphine Digout, UNEP/GRID-Arendal, http://www.grida.no/graphicslib/detail/dpsir-framework-for-state-of-environment-reporting_379f)

of the environment. Impacts are the effects of environmental degradation. Responses refer to the responses by society to the environmental situation, also expressed by engineering solutions. (http://maps.grida.no/go/graphic/dpsir_framework_for_state_of_environment_reporting).

Society's Need for Ethics Competency. Now more than ever before, society demands ethical engineering education. The engineers face more and bigger challenges that they respond with solutions, many times, solutions with unpredictable risks where millions of people could be damaged. At least two of the 15 Global Challenges set out by the Millennium Development Project are directly related with the ethical development: the seventh and the fifteenth. The first is related with the gap between the rich and poor and how ethical markets economies can help to reduce this gap and the fifteenth concern is how ethical considerations could be integrated in global decisions. More indirectly, others appeal to an ethical behavior and responsibility of engineers in order to design, conceive, and build products and systems that will improve the air, water or soil and people life or will reduce ethnic conflicts, discrimination, poverty and so on. UNESCO (2010) devoted significant attention to society's need for ethics competency to fight against anti-corruption. The chances of corruption increase as technological development occurs. The advancement of engineering as a science, therefore, raises significant ethical concerns.

In examining the various needs of key stakeholder groups for mechanical engineering education, it is possible to understand critical shortcomings and to thread those issues into an enriched understanding of the current state. This chapter has explored some, but not all, data sets expressing concern for present gaps in mechanical engineering education. Nonetheless, the problems highlighted are worthy starting points for driving improvement as depicted in Figure 2-4.

The points of improvement, derived from the data sets in this chapter along with the scenario work in Chapter One, provide guidance to the academy in terms of where gaps exist. This is a substantial point because there is much that is working well in mechanical engineering education and the entire system does not need to be, nor should it be, totally

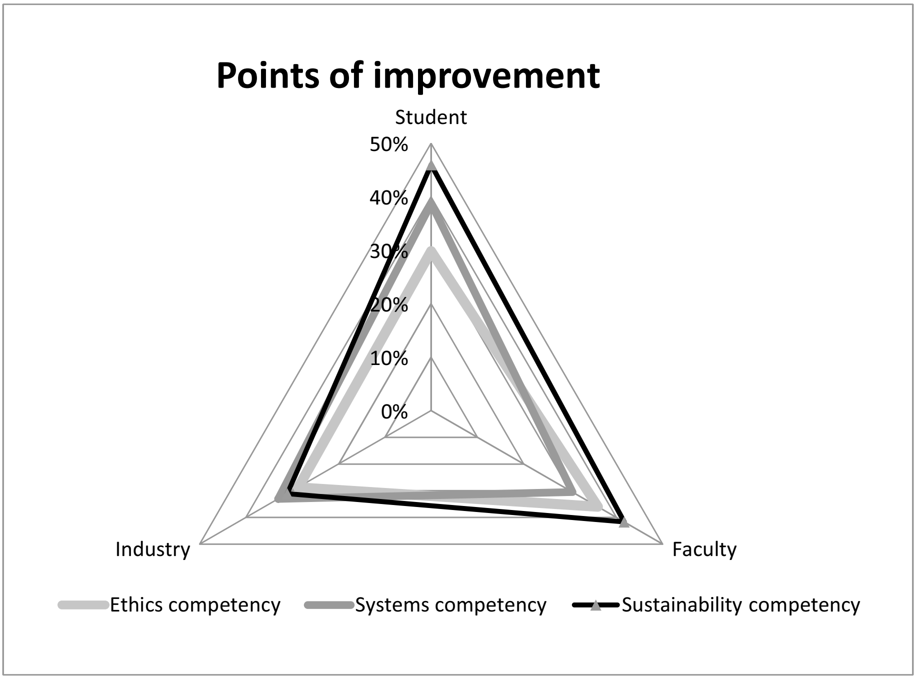

Figure 2-4 Points of improvement in planning for the future of mechanical engineering education.

dismantled. Rather, specific and focused work addressing particular deficiencies using gradualism is proposed in Chapter Three. A *Planning for the Future* protocol, designed to prompt critical inquiry for the purpose of improvement (not criticism), becomes particularly meaningful when target outcomes are identified and realized. These target outcomes, closely tied to Planning work, visioning and data analysis are presented next in Chapter Three.

3. What are the target outcomes of mechanical engineering education?

Advocacy for educational *Planning for the Future* as an exercise in mining the best corporately-held mechanical engineering intelligence through a four-step process has been presented in previous chapters. This process can be enriched through the use of scenarios and thematic gap analyses. As a part of planning for the future of mechanical engineering, this chapter provides guidance in improvement work so that knowing what to think as best educational knowledge is connected in a congruent way to knowing what to do as best educational practice. The relationship between both knowledge and practice in mechanical engineering education is posited as a mental model for planning for the future. Further, in this chapter relevant target outcomes designed to measure student development related to the three areas of competency development, systems, sustainability, and ethics, are presented as rubrics. These target outcomes are derived from the stakeholder needs of employers, students, faculty and society, for early engineering success as described in Chapter Two.

As a framework for this chapter, both mechanical engineering knowledge and practice are presented as interrelated target outcomes for students. Mechanical engineering knowledge, or knowing, comes from cognitive development around content acquisition. Content is defined as core information obtained from academic, simulated work and real work settings. Content mastery in mechanical engineering education is a long held and common target outcome. The biggest challenge in terms of planning for the future of content mastery of engineering knowledge is keeping abreast of rapidly changing and increasing numbers of theories and facts. Although the actual body of mechanical engineering knowledge evolves over time, the academy has long embraced the act of delivery of content to students as shared practice. There is acceptance in pedagogy that broadly fostering the target outcome of content acquisition as a desirable and expected goal of higher education programming.

The traditional emphasis of content mastery as a target outcome of mechanical engineering education often leaves little room for consideration of other outcomes, such as the outcome of competency mastery. Mechanical engineering education has embraced widely the target outcomes of teaching to what students know, but not what students are able to do. In fact, the case with mechanical engineering practice does not parallel that of mechanical engineering knowledge through content mastery only. The practice of engineering as evidenced in competency development, in mechanical engineering programs is a highly underdeveloped. Competencies are defined as core skills, dispositions and acumen obtained from academic, simulated work and real work settings. Competencies are acquired through the tenets of experiential learning, whereby behaviors in evidence, such as modeling, applying, and creating, are indicators of learning. Understandings of the power of methods, such as project-based learning, differentiated learning, and self-directed learning, are coming forth. The biggest challenge in terms of planning for the future of competency mastery is in adoption of and adaptation to mechanical engineering practice in the academy. There is a need for awareness as to how to teach competencies in the academy so that acceptance for broadly fostering the target outcome of competency acquisition is a desirable and expected goal of higher education programming, alongside content mastery.

This chapter urges for the combination of both of these target outcomes, early mechanical engineering content and competency mastery, as essential in mechanical engineering education. Figure 3-1 below depicts the mental model of content and competency development as a double helix DNA. The relationship between both content and competency development is spiraled and interdependent meaning that both outcomes are needed and will co-exist and support each other.

The double helix DNA of competency mastery with content mastery is derived from the specific stakeholder competency needs described in

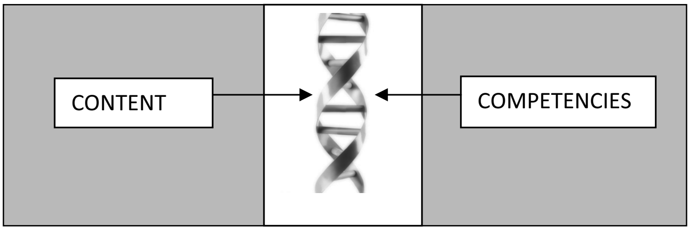

Figure 3-1 Mechanical engineering education target outcomes.

Chapter Two. Commentary on content improvement is briefly discussed next, but since this is a target outcome that is widely accepted in mechanical engineering education, an emphasis on competency mastery is fully carried out in this chapter. There is no attempt to explore the entire body of knowledge and practice of mechanical engineering education. Rather, the target outcome of competency mastery is the main focus of this chapter. Specifically the gaps in systems, sustainability and ethics competency are described in detail. To reiterate, the following discussion is not an exclusive view of what is needed in planning for the future of mechanical engineering education, but it is a starting point of a few points of improvement. Brief commentary on content mastery is presented next, followed by detailed commentary on competency mastery.

3.1 Content mastery

The need for gap analysis of mechanical engineering content is evident given the rapid nature of knowledge creation and the complexity of knowledge needed to solve current day problems. For mechanical engineering education, this implies that the simple lecturing of "hard-core" engineering and natural sciences content, and their mathematical groundings is insufficient preparation for today's students challenged to address these problems.

An understanding of the power of content mastery as one of two critical elements of target outcomes for students cannot be underestimated. Content mastery is an essential element of mechanical engineering DNA in relation to competency mastery. It also carries powerful potential within either a disciplinary or interdisciplinary approach. Since it is likely that an engineering student will typically compartmentalize knowledge after a course is completed and a grade has been recorded in the transcript, discipline specialization does provide depth of knowledge needed in the workplace. However, of the learning that occurs in subsequent courses, the acquired discipline knowledge may fall short if it is treated as a ticked box and archived in the student's mind. While some courses form an organized chain of transferred knowledge and are connected through prerequisites, there is a need to create interdisciplinary connections between the content of basic engineering sciences, such as solids/materials/design/fluids. So, both specialized and interdisciplinary content mastery is certainly under examination as a part of planning for the future of mechanical engineering education. As outlined in Chapter 1, such content mastery decisions regarding specialized vs. interdisciplinary learning should not be determined randomly, by default or based on personal preferences. Rather, this book advocates for the use of four steps in *Planning for the Future* as presented previously in Chapter 1 as, 1) *Establish a Statement of the Theme,* 2) *Describe the Core Background Elements,* 3) *Analyze the Current Condition's Shortfalls,* and 4) *Select Statement(s) of the Problem.*

The four steps in P*lanning for the Future* are a distinct protocol. So, let's examine an example of this protocol in consideration of interdisciplinary learning as a part of the DNA of mechanical engineering, content mastery. The first step is to *Establish a Statement of the Theme.* In this case, the Statement of the Theme is "Let's enrich pedagogy and paradigms of engineering design content mastery." The second step is to *Describe the Core Background Elements.* The Core Background Elements are: "Typically, engineering design students are taught to break up the product design process, such as that of a bicycle, into sub-groups like steering, frame, saddle, suspension, and wheels. This approach to design is normally referred to as a Work Breakdown Structure (WBS)." The third step in planning for the future is to *Analyze the Current Condition's Shortfalls.* The Analysis of the Current Condition's Shortfalls is: "In a WBS, however, there is a knowledge gap. This is because the systematic capture of the interconnectedness of the elements, such as the frame and suspension, and their mutual effects on each other is not realized. As a possible consequence, the potential for fatigue fractures as a result of dynamic loads on the bike frame and its weldments when riding the bike over uneven surfaces often times is also not captured. And the fourth step in planning for the future protocol is to *Select a Statement of the Problem.* In this example, it is: "In WBS, there is a lack of content mastery of mutual relations among the elements in engineering design." As a result of this planning work, solutions to this problem can be discussed, such as, "To overcome this gap, a better approach to teaching content mastery of engineering concepts is to capture the interrelationship as a Systems Breakdown Structure (SBS), where the mutual relations are recognized as critical to the design of the overall product. SBS provides enriched knowledge of mechanical engineering over WBS."

This is just one small example of what can be done to address content mastery gaps in mechanical engineering education. But it also highlights what is possible with improvement work if the planning for the future protocol is used. University courses can be made more interesting through the transformation of curricula and pedagogy using rationale and logical analysis of problems. There are many examples from the mechanical engineering academy, where planning for the protocols have lead to improvements, such as in creating more activity-based, project-based and problem-based learning, just-in-time approaches and hands-on applications. Multiple data sets provide guidance on the state of content development in mechanical engineering education. Since this book is most concerned about the lack of competency development, the rest of the chapter will focus on the target outcome of competency mastery.

3.2 Competency mastery

A gap analysis for mechanical engineering competency derived from the data sets presented Chapter Two is described next. Overall, in planning for the future of mechanical engineering education, improvements as described by graduates, employers, faculty and society were presented in Chapter Two with a thematic focus on systems, sustainability and ethics development. Understanding that systems, sustainability and ethics competencies are desirable outcomes of mechanical engineering education can be difficult. Further conceptualizing the mental model of the relationship between content and competency as the double helix DNA of mechanical engineering education presented earlier in this chapter is another challenge.

Using the planning for the future protocol, the four steps used to examine the competency mastery of the DNA of mechanical engineering education are summarized. The first step, *Establish a Statement of the Theme,* results in, "Let's incorporate competency mastery of systems, sustainability, and ethics into mechanical engineering education." The second step, *Describe the Core Background Elements,* results in "Competency mastery is not widely used as a basis for mechanical engineering pedagogy. Data sets from employers, students, faculty and society indicate that a need for competency-based mechanical engineering education." The third step, *Analyze the Current Condition's Shortfalls,* results in, "Competency development is not a mainstream method in most mechanical engineering programs. Why? There is a lack of aligning pedagogy and assessment surrounding competency-based education for mechanical engineering. Why? This is because traditional assessment systems used in elementary/primary to secondary to tertiary/higher education are largely content focused. Why? Faculty and students are unfamiliar with the teaching/learning culture of competency-based education. Why? There are many paradigm barriers in higher education learning methodology which make inclusion of competency mastery (along with content mastery) difficult to enact." And the fourth step, *Select a Statement of the Problem*, results in, "Paradigms and pedagogy regarding the need for competency mastery in mechanical engineering education need to be created and/or enriched so that the DNA double helix model of content and competency development can be enacted widely."

With this *Planning for the Future* example set forth, this chapter will focus on describing the three competency-based outcomes categorized from the data presented in Chapter 2. Each competency, systems, sustainability and ethics, is defined based on recent theories, contextualized based on recent research, and finally synthesized based on assessment rubrics. This is done to address the above Statement of the Problem, "Paradigms and pedagogy regarding the need for competency mastery in mechanical engineering education need to be created and/or enriched so that the DNA double helix model of content and competency development can be enacted widely." With that Statement of the Problem in mind, the first competency, systems competency, is presented next.

3.3 Systems competency

Systems competency encumbers the ability to "see" or comprehend various elements in a product, service or interaction, as either ordered or randomly sequenced, then interrelated, complex, and adaptive (Senge, 1990; Sterman, 2000; Checkland, 2000). Systems operate under the principle that the sum of the interdependent elements holds inherently different characteristics and outcomes than the elements in isolation do (Ackhoff, 2004). Comprehension of systems and complexity are taxonomically described as high levels of knowledge development (Bloom, 1956). This is because once a process of systems-based perspectives begins, the potential for deeper levels of critical thinking follows. Systems competency in engineering practice is a highly preferred deterrent to negative consequences (Felder, Woods, Stice, & Rugarcia, 2000). It is a proactive response to negating problems that arise as unintended results of previous decisions and actions. Inadequate communications, inferior prototype development and testing, incorrect assumptions, are generalized examples of where systems competency is needed in mechanical engineering practice to avoid failure and poor consequences.

Systems competency requires knowledge of system characteristics and principles. However, systems competency encumbers more than knowledge of what and how systems are. It also includes valuing and incorporating systems competency to create original, creative thought for application in practical situations. The disposition of systems competency is evident when enacted in values based on the tenets of extending consequences to long term implications, to caring for all system elements so that optimization of one element does not deter functionality of another element, and recognizing the adaptivity and complexity of solutions. Systems-based actions result in deliverables that are scoped using a science of improvement method, resulting in benefits for the common good.

Until systems competency is used and modeled in higher education program design and curriculum scope and sequence, it is difficult for students to comprehend how this competency might be applied in engineering practice. Engineering curriculum is typically divided into functional areas of engineering work related to stages of product design, development, production and distribution. This approach to engineering study is deductive or reductionist. When deductive learning is instilled exclusively in student learning experiences with lack of equal focus on holistic, inductive thinking, then students do not have adequate opportunities to engage in systems competency development. Breaking down engineering studies in a deductive manner is a valued perspective in engineering practice specialization, but a systematic capture of the interconnectedness of engineering practice is equally valuable. Systems competency development captures interrelationships of work, where the mutual relations are acknowledged as critical to engineering practice.

Further, the engineer must be able to contextualize practice beyond the organization and its customers to society broadly. The engineer must be able to comprehend engineering practice as a part of the global economic, political and human machine.

The Millennium Project (2009) identified 15 global challenges (Figure 3-2) which have the potential to adversely affect either the existence of life on the planet or the foundations for virtually all existence. By nature, these challenges are not geographically restricted to certain parts

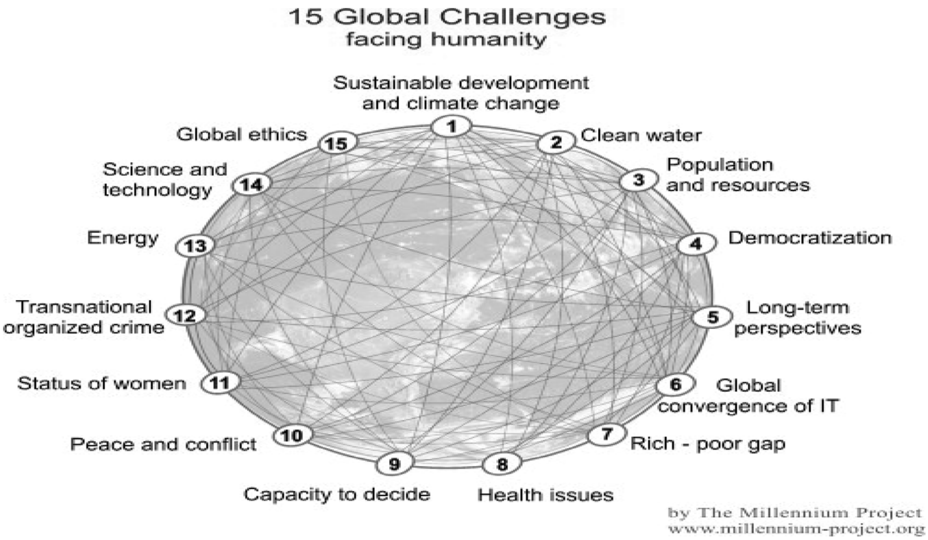

Figure 3-2 *The 15 Global Challenges facing humanity. Adapted from The millennium project (2009).* Available at <http://www.millennium-project.org/millennium/overview.html>, accessed 2011.09.25.

of the world. They are concerns shared in the worldwide system. This means that these challenges do not form a concern for one region of the planet, such as Asia, while Europe is unaffected by the same challenge. For example, the provision of and access to safe and affordable health care, drinking water, and energy are issues which all nations and peoples on the planet face. Therefore, these 15 Global Challenges represent a significant global system that mechanical engineers participate in.

It is important to note that these Global Challenges are not independent of one another but form a tightly woven net of mutual relations and dependencies. This interconnectedness can be recognized as a system of drivers with attenuating and amplifying causes and effects. These 15 Global Challenges are truly a *System of* 15 Global Challenges. The following examples highlight how this system works. Grasping the implications of these problems using the systems competency that mechanical engineers must master is presented as the following example:

(1) When a decrease of organized crime due to technological advances in mechanical engineering occurs, Global Challenge 12,

Transnational Crime, then it will increase the capacities to decide and reduce human trafficking, particularly of women, thereby improving the status of women, Global Challenge 11, Status of Women, or

(2) When sustainable development advances due to green technologies in manufacturing, Global Challenge 1, Sustainable Development and Climate Change, then energy and water consumption can be expected to decrease, Global Challenges 2 and 13, Clean Water and Energy, or

(3) When service delivery of health care is improved due to medical device affordability through mechanical engineering innovation, Global Challenge 8, Health Issues, then it is equally reasonable to expect that the population of people on the planet will increase, which in turn will increase the already high demand for natural resources (access to fertile land, minerals and ores etc.), Global Challenge 3, Population and Resources, and with a potential for increased conflict, Global Challenge 10, Peace and Conflict, which would most likely result in resource-rich geographical regions like Africa, Eastern Russia, South America and at the North Pole.

Systems competency as a target outcome of mechanical engineering provides preparation for all types of solutions for the workplace, marketplace and society. In this regard, systems competency can be both narrowly or broadly scoped. The 15 Global Challenges are widely scoped, but they related to four even larger anthropogenic activities conducted by society in its quest for well-being. These hypo-scoped activities are: raw material extraction, production, marketing and consumption. Engineers are encouraged to view these four anthropogenic elements as one of the highest perspectives of mechanical engineering systems of activities as depicted in Figure 3-3 below. And this can be accomplished by planning for the future of mechanical engineering education through the development of systems competency.

Using systems competency, the depiction in Figure 3-3 is readily observed to be a complex and adaptive setup of interconnected drivers with attenuating and amplifying causes and effects. This extremely large system incorporates a significant number of adaptive correlations. The following examples are a few highlights of the interconnectedness:

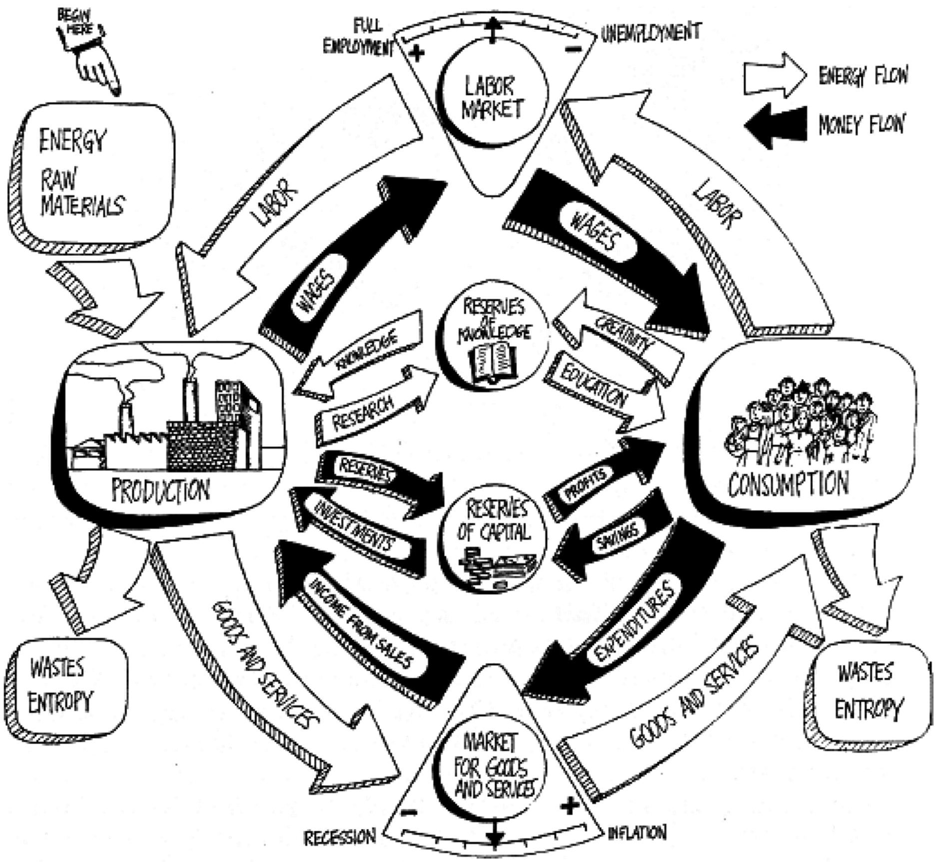

Figure 3-3 The Economic Machine (adapted from De Rosnay, 1979) depicting the systemization of four anthropogenic societal activities. F. Heylighen (2000): "Referencing pages in Principia Cybernetica Web", in: F. Heylighen, C. Joslyn and V. Turchin (editors): *Principia Cybernetica Web* (Principia Cybernetica, Brussels), URL: http://cleamc11.vub.ac.be/REFERPCP.html. (*Adapted from Joel de Rosnay, Available at http://pespmc1.vub.ac.be/MACRBOOK.html*)

(1) When consumption increases as one of the Four Anthropogenic Societal Activities due to mechanical engineering product improvements, then the marketplace expands, driving more production and higher levels of raw materials extraction, all

impacting waste entrophy, which also requires a mechanical engineering solution, or

(2) When raw materials extraction increases as one of the Four Anthropogenic Societal Activities due to mechanical engineering mining improvements, then production capacity increases, which in times of inflation increases, drive the market price up, and consumption down, also impacting waste entrophy, which in turn requires a mechanical engineering solution.

Mechanical engineers can gain understandings of the finite and infinite capabilities of both the 15 Global Challenges and the Four Anthropogenic Societal Activities through systems competency. As the data sets in Chapter Two indicated, this competency is highly valued by the four stakeholder groups, employers, students, faculty and society. This is no small issue that systems competency is called for. In fact, the importance of this competency is critical to the maintaining stability over instability in the planet. For if System Earth becomes an unstable or run-away system, this destructive path will compromise the "potential of future generations to meet their own needs [Brundtland Commission, 1987]." An unstable System Earth is characterized as self-destructive for the future of society. Systems competency development in mechanical engineering education is a significant antidote to that negative consequence. Systems competency holds grand potential as an intervention toward a stable System Earth, the 15 Global Challenges and the Four Anthropogenic Societal Activities. It also holds promise for an infinite number of other deliverable in myriads of applications.

Therefore, it is argued that systems competency should be a part of the DNA of mechanical engineering education based on the mental model presented earlier of content and competency mastery. A continuing examination of planning for the future of mechanical engineering education is presented. A second competency gap, the sustainability competency, is described next.

3.4 Sustainability competency

Sustainability is defined as the "ability to endure," literally meaning to hold up over time (Wikipedia, 2012). The term is commonly used in relation to environmental standing, but it can also be used in relation to a variety of other venues including financial and psychological positions. As described by Dierickx and Cool (1989) sustainability of financial assets is a position taken that overcomes the problems presented in opportunity costs incurred due to the allocation of resources for short term gains. In a psychological sense, sustainability is described by Bolman and Deal (2008) in relation to justice as part of organizational leadership practice. They stated, "Decisions about sustainability inevitably involve trade-offs among the interests of constituencies that differ in role, place, and time." (pp. 406–407)

Sustainability in relation to mechanical engineering education in this book refers to the capacity of the earth to endure the activities of humanity and to replenish itself in such a way that the same environmental comforts and eco-system benefits are available across generations. Sustainability infers that natural and biological systems remain diverse, healthy and productive over time. The end result of sustainability is that the earth is able and presently capably of providing vital goods and services. Underdeveloped countries need massive expansions in energy, transport, urban systems, and agricultural production. If pursued using traditional technologies and carbon intensities, these much-needed expansions will produce more greenhouse gases and, hence, more climate change. Developed countries continue to use an unfair and unsustainable share of the atmospheric commons. In both cases, sustainability is the desired outcome and its promise exists within the context of mechanical engineering.

Sustainability competency requires knowledge of sustainability characteristics and principles. However, sustainability competency encumbers more than knowledge of what sustainability is. It also includes valuing and incorporating sustainability competency to create original, creative thought for application in practical situations. The disposition of sustainability competency is evident when enacted in values based on the tenets of extending environmental/economic consequences to long term implications, to caring for all so that the greening of one element does not deter functionality of another element, and recognizing the cultural differences in valuing of sustainability solutions. It also requires that sustainability applications result in deliverables that are scoped using a science of improvement method, resulting in benefits for the common good.

Sustainability competency requires knowledge of ethics tenets. However, ethical competency encumbers more than knowledge of what ethics are, it also includes valuing and using ethical parameters in practical situations. The disposition of ethics is evident when enacted in values based on the tenets of moral and legal consequence, social justice, multicultural understandings, diversity appreciation, equity and fairness. Ethical decisions reinforce the desire to be accountable and transparent to benefit the common good. Sustainability is identified as adding to the common good.

Without the competence of sustainability fully realized in mechanical engineering practice, sustainability concerns related to climate change will continue to plague the globe, such as shifts in weather patterns due to man-made interference. The impacts of emerging new climates are already being felt, with more droughts, more floods, more strong storms, and more heat waves reported. These modifications are interrelated with sustainability because as climate change taxes individuals, firms, and governments, resources are drawn away from development. Continuing climate change at current rates, therefore, will pose increasingly severe challenges to development. It is predicted by some that by this century's end, warming of 5°C or more compared with preindustrial times may occur. If these climate changes occurred, a vastly different world from today would exist. Conditions with more extreme weather events would lead to stress for most ecosystems, extinction for many species, and the threat of inundation by whole island nations. At the current rate of sustainability development and climate change even best efforts, greatly aided by capable mechanical engineers, are unlikely to stabilize temperatures at anything less than 2°C above preindustrial temperatures. At this lower estimate of 2°C, such warming that will require substantial adaptation (World Development Report, 2010). World-based organizations, such as the United Nations Educational, Scientific and Cultural Organization (UNESCO), are tracking this global trend and anticipating future needs. UNESCO admits, "... we face two issues of truly global proportions – climate change and poverty reduction."

There has been significant action taken in regard to moving forward on global interventions related to sustainability. For instance, the United Nations community has called for action at many fronts to address the global challenges of sustainable development and climate change. These include the United Nations Environment Programme's Green Economy Initiative and Report, the United Nations Industrial Organizations' Green Industry Initiative, the United Nations Economic and Social Commission for Asia and the Pacific's Green Growth, UNESCAP's Sustainable Livelihoods Approach/Sustainable Livelihoods Approach, the International Labour

Organization's Green Jobs, the World Resources Forum, and the Decade of Education in Sustainable Development, to name a few. The United Nations has defined Education for Sustainable Development (ESD) as encouraging "changes in behavior that will create a more sustainable future in terms of environmental integrity, economic viability, and a just society for present and future generations." This defines the crux of sustainability competency for mechanical engineering education.

To better understand why the sustainability competency is needed in mechanical engineering education, the intensity of the pace of climate change, six waves of growth are presented next. As indicated in Figure 3-4, the five previous global growth periods were able to access cheap primary resources. The current sixth wave of global growth is characterized by sustainability, radical resource productivity, whole system design, biomimicry, green chemistry, industrial ecology, renewable energy and green nanotechnology. However, although this sixth era is

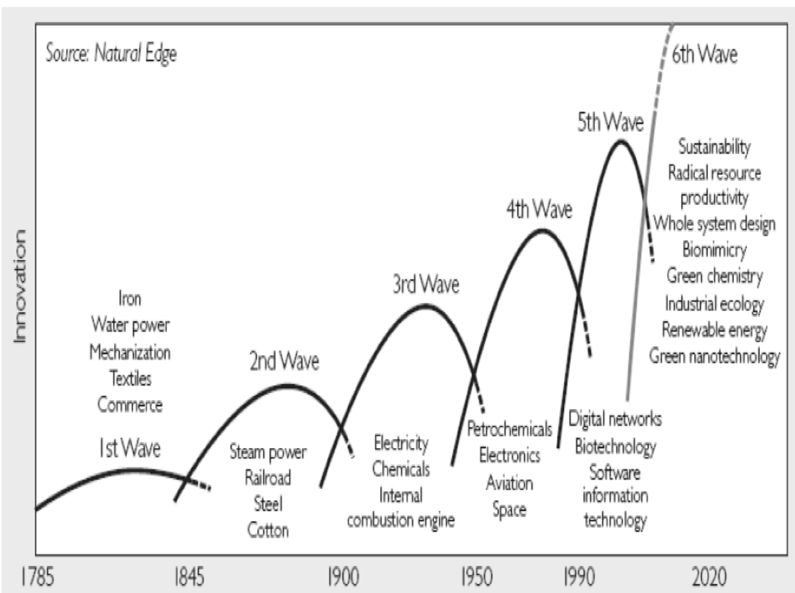

Figure 3-4 Waves of innovation of the first and the next industrial revolution (Adapted from Hargroves & Smith, 2005) Available at http://www.naturaledgeproject.net/NAON Chapter1.4.aspx.

so rich in technological acumen, it is not assured of the availability and price of these resources. So, scarcity of resources has become a core issue in the sixth wave, hence the pressing need for sustainability competency development in engineering sciences.

Sustainability competence in mechanical engineering is, therefore, in high demand. Higher education institutions have made some progress towards engineering education for sustainable development. There is however a 'time lag dilemma' facing engineering educators, where the pace of traditional curriculum renewal may not be sufficient to keep up with potential market, regulatory and institutional shifts. According to the World Federation of Engineering Organizations (WFEO), for engineering this means playing, ". . . an important role in planning and building projects that preserve natural resources, are cost-efficient and support human and natural environments." Hence, engineering education for sustainable development (EESD) is a broad area covering technical, social and economic aspects. The significance of including the sustainability competency in the DNA of mechanical engineering education is needed to successfully address such twenty-first century challenges.

There are examples of mechanical engineering's role in helping to understand and tackle global environmental problems. For example, in the case of climate change, energy efficiency and renewable energy technology are playing increasingly important roles in helping to cut greenhouse gas emissions and so to mitigate the threat, while other technologies, such as flood defenses, are allowing society to adapt to some of the changes which are already happening. Other examples, many showing that technology and innovation alone cannot save us, indicate that such solutions must be engineered using the sustainability competency.

The essential question for mechanical engineering education then, is how to equip engineers to pursue growth and prosperity without causing "dangerous" climate change (World Development Report, 2010). The global community clearly sets up a case for engineers to serve as the cornerstone for sustainability and climate change solutions. Specifically, UNESCO addresses the need for the sustainability competency and highlights hope for humanity in regard reformed engineering education and practice as, Therefore, the tasks confronting engineers of the twenty-first century are:

- engineering the world to avert an environmental crisis caused in part by earlier generations in terms of energy use, greenhouse gas emissions and their contribution to climate change, and
- engineering the large proportion of the world's increasing population out of poverty, and the associated problems encapsulated by the UN Millennium Development Goals.

In order to advance science and technology to a level where sustainability is possible, it is important that the mechanical engineering workforce of the future is prepared to lead this charge. In this sense, preparation of the engineering workforce in sustainability competency becomes one of the central strategies of accomplishing sustainability itself.

Sustainability competency development should be a part of the DNA of mechanical engineering education based on the mental model presented earlier of content and competency mastery. Next, planning for the future of mechanical engineering education engages over a third competency gap, ethics.

3.5 Ethics competency

The target outcome of ethics competency in mechanical engineering education is selected to enable early career engineers to identify and enact good means using ends that do well. History demonstrates via principle that with the ethics competency, noble outcomes are realized. Ethics, in fact, is considered the foundation of civil societies everywhere and when it replaced with corruption, everything crumbles. The absence of ethics is a violation of contracted trust and an expression of morale depravity. The disposition of ethics is evident in enacted values based on the tenets of moral and legal consequence, social justice, multicultural understandings, diversity appreciation, equity and fairness. Ethical decisions reinforce the desire to be accountable and transparent to benefit the common good.

The call for the ethics competency in mechanical engineering is present. Ethics is a value-laden competency, dependent on high levels of self-actualization and praxis. Ethics is situated in the world as a thinking and doing process involving conflicts of interests, dissonance or dysfunction.

Therefore, the ethics competency as a body of practice is exercised in emotionally, socially and psychologically tumultuous settings. It is a competency loaded with ambiguity and risk. The ethics competency encumbers decision making and actions driven by the moral imperative in spite of the vulnerability at hand. Therefore, the ethics competency is difficult and risky, reliant on delayed personal gratification and the ability to navigate through a variety of perspectives on what trust is (Hardin, 1996; Baier, 1986; Warren, 1999). Ethics competency requires knowledge of the tenets and mores of both self-regulation and collective regulation within moral imperatives.

However, ethics competency encumbers more than knowledge of what and how ethics are, it also includes valuing and using ethical parameters in practical situations. The disposition of ethics is evident when enacted in values based on the tenets of moral and legal consequence, social justice, multicultural understandings, diversity appreciation, equity and fairness. Ethical decisions reinforce the desire to be accountable and transparent to benefit the common good.

Ethical performance is an expected behavior of the engineering profession and is normally supported by a body of knowledge, such as in standards, fundamental canons and behavior descriptions by professional associations such as, the European Society for Engineering Education (SEFI), the American Society of Engineering Education (ASEE), the IEEE Education Society or National Academy of Engineering, and of accreditation boards such as the Accreditation Board for Engineering and Technology (ABET) and the National Society of Professional Ethics (NSPE). In spite of these thoughtful canons of ethics as a body of knowledge, early practicing engineers may encounter a multitude of barriers to ethical conduct in the workplace, such as, poor management philosophies, structural impediments and wasteful traditions, to name a few.

Ethics competency is advocated for in small and large projects alike as a tenet of engineering decision making. Whether a lapse in ethics causes harm to an individual on the smallest scale, such as with a professional interaction, or on the broadest scale, such as with dealing with catastrophic failure, a quagmire of ethical concerns can mount up quickly for the practicing engineer. For instance, if an oil rig is not properly designed, maintained or operated, for instance, the ethical obligations of engineering in a civilized society are clearly missed. Adequate ethical development is related to both sustainability and systems competency. The impact of ethical dispositions in engineering practice carries strategic importance for sustainability. In fact, ethics is the foundation upon which sustainability commitments are made. Therefore, the consequence of ethical maturity within professional practice for society is substantial. Ethics create boundaries for decision making at all levels and motivates perspectives for interacting with individuals and organizations. In other words, ethical engineering practice is expressed in ranges of decision making from strategic to tactical levels with implications that scope from impacting one person to the entire planet.

Ethical competency in engineering practice occurs within environments of tension or conflict, often requiring the difficult choice. Ethical decisions entail perspectives that aid the engineer in understanding what occurs as long term consequence of choices, such as considering how to preserve versus waste natural resources within the context of impact on the environment longitudinally. Since engineers make decisions within the context of the organization which includes a desire for attaining competitive advantage and the necessity of accomplishing business goals, an engineer may experience high degrees of ambiguity or conflict in abiding by ethical standards. So, the engineer committed to an ethical stance will need some habits of mind and convictions of heart that create clarity and strength to act accordingly.

The pressure of ethical decision making for the practicing engineer can be eased if there is an organizational commitment to a philosophy, culture and talent management benchmark of ethical practice. There are organizations that have embraced such a stance. For instance, as the business case for sustainability is understood and deployed through green initiatives within the organization, for example, the engineer has more clarity in regard to organizational norms and can make the ethical decision with less consternation. An organization may even include incentives for ethical solutions that reinforce green initiatives. In this case, there may be a reward for ethical decisions. In addition, if ethical development is understood as a process of growth that requires self-awareness and reflective practice, then human resource strategy can actively address the opportunities for increasing ethical maturity through evaluation processes and mentoring programs.

There is also a role for the Academy to play in the ethical development of engineers by overtly teaching the ethics competency and in modeling ethical behavior. As ethical engineering practice is understood as a foundation to effectiveness, higher education programming must respond. The Academy is in a unique position to foster the advancement of engineering as a noble occupation, one that requires more than technical expertise exercised to benefit one's own career path, but as an opportunity to advance, enhance and to benefit society with passion and commitment. The chance to contribute to a positive and lasting future is within the realm of the academy through the recognition of the ethics competency is present.

And while there are clearly delineated professional codes for engineers, without the ethics competency, these codes do collide with climate and culture in the workplace as practice. Early career engineers are often challenged as to what to do next, how to do it, and why to follow these canons. However, the benefits in utilizing the ethics competency as a part of the DNA of mechanical engineering education can better equip practitioners for such encounters.

In planning for the future of mechanical engineering education in regard to ethics competency, Bowen (2009) described that ethics in engineering is just emerging. The case for teaching the ethics competency in engineering education has been made since the 1990's. In turn, various structural and cultural barriers to teaching engineering ethics have been closely examined. While ethics tends to be treated as a body of knowledge in the academy, ethics as a competency, does receive advocacy from working groups in various engineering education societies. Even though this work is still quite nebulous, there are now some common understandings emerging in higher education as to the relevance of ethics as a competency in the field as described by Newberry et al. (2011),

> The engineering education literature has burgeoned with articles about teaching ethics. . . . But ethics education for U.S. engineering undergraduates is still a work in progress, and there is not yet anything approaching a uniform content, quality, or depth of instruction across institutions and programs (Stephan, 1999; Herkert, 2002; Haws, 2001). (p. 171)

Ethics competency creates boundaries for decision making at all levels and motivates perspectives for interacting with individuals and organizations. In other words, ethical engineering practice is expressed in ranges of knowledge of, valuing of, and deciding to exercise ethics competency. This means that ethics competency is used from strategic to tactical levels with implications that scope from impacting one person to the entire planet.

Since ethics competency in engineering practice is used within an uncertain environment of tension or conflict, often basic levels of development are not adequate for the practicing engineer. Engineers make decisions within the context of the organization which includes a desire for attaining competitive advantage and the necessity of accomplishing business goals. An engineer may experience high degrees of consternation in exercising the ethics competency. So, the engineer committed to this competency will need advanced habits of mind, heart and hand which provide clarity and strength needed.

The challenging and innovative environment where the engineers work often raises ethical concerns for the engineer practitioner. As history has demonstrated, all technology holds the potential to travel the divided path of being used for good or being used for bad. And that dilemma rests (at least partially) in the ethical foundations of engineers. Minimizing technological advances it is not the answer to avoid pernicious and problematic use of engineered solutions. Instead, it is posited that adequate knowledge, dispositions and applications of the ethics competency offers incredible potential for engineering's contributions to society.

The pressure of ethical decision making for the practicing engineer can be eased if there is an organizational commitment to a philosophy, culture and talent management benchmark of ethical practice. There are organizations that have embraced such a stance. For instance, as the business case for sustainability is understood and deployed through green initiatives within the organization, for example, the engineer has more clarity in regard to organizational norms and can make the ethical decision with less consternation. An organization may even include incentives for ethical solutions that reinforce green initiatives. In this case, there may be a reward for ethics competency mastery. In addition, if ethics development is understood as a process of growth that requires self-awareness and reflective practice, then human resource strategy can actively address the opportunities for increasing ethical maturity through evaluation processes and mentoring programs.

The wasteful expenditures of human, financial and social capital resulting in economic loss, environmental stress and societal confusion from a lack of ethics competency can be mitigated against through the DNA mental model of content and competency-based mechanical engineering education which includes ethics competency mastery. Invigorating engineering education with this competency will add excitement to student learning, create sophisticated employees for the workplace and produce benefits shared by civil societies.

3.6 Sustainability, systems and ethics competency development in mechanical engineering

A breakthrough approach to mechanical engineering education is proposed to include competency mastery along with content mastery as the DNA of mechanical engineering education. Specifically, three competencies of systems, sustainability and ethics have been described thus far as improvements in planning for the future. When considering competency development as a complementary target outcome to content mastery of mechanical engineering education, it is possible to examine ontological schema of learning and eventually to provide a taxonomical visual of competency development in these three areas. When the academy is able to rely on the use of taxonomies in planning for the future, these three types of competency development of engineering students will be more fully facilitated in the engineering classroom.

There is much work to be done in identifying taxonomies of the three competencies, systems, sustainability and ethics. At this point however, an exploration of a holistic approach to competency mastery is presented. This is done to promote thorough development paralleling conceptualization of acclaimed learning theorists, such as Bandura (1986) and Knowles (1990). These theorists posited that learning is schema of interrelated components, a scaffold of codependent arms, a path of varied ways, and a process involving several elements. These theorists help to enlighten the personal and complex nature of learning. This understanding in turn justifies the belief that learning is a holistic engagement. When pedagogy, the art and science of teaching, includes competency mastery then it is logical to examine the schema, scaffolds, path and processes of development for the mechanical engineering student. Holistic pedagogy, therefore, informs the academy that three core activities, planning for, teaching of and assessing of, mechanical engineering students will need to be realigned.

Traditional protocols lectures based on content, teaching to the core content, and assessing by cold cognitive testing, fall short of the enlarged view of students developing holistically. However, the creation and use taxonomies of competency development can solve this problem. Taxonomies aid faculty and students in planning learning to foster paths of complex growth. Taxonomies aid faculty and students when engaging in teaching and learning in the classroom. Finally, taxonomies provide to faculty and students the foundational tool upon which assessment of holistic learning occurs via rubrics. Specifically, if ethics, systems, and sustainability competency are target outcomes of mechanical engineering education, then taxonomies and rubrics of competency development are useful planning, teaching and assessment tools. An exploration of taxonomies and learning theory are presented next. This is followed by the presentation of an exploratory competency development rubric for systems, sustainability and ethics.

To reiterate, the usefulness of taxonomies is of interest when the academy moves in the direction of including competency mastery in engineering education programming. The term "taxonomy" is derived from the Greek word "taxis," meaning arrangement of division and "nomos" meaning law. Bruno and Richmond (2003) stated,

> . . . taxonomy is the science of classification according to a predetermined system, with the resulting catalog used to provide a conceptual framework for discussion, analysis, or information retrieval. In theory, the development of a good taxonomy takes into account the importance of separating elements of a group ("taxon") into subgroups ("taxa") that are mutually exclusive, unambiguous, and taken together, include all possibilities. In practice, a good taxonomy should be simple, easy to remember and easy to use. (p. 45)

They provided further definition and stated that taxonomies are,

> . . . structures that provide a way of classifying things—living organisms, products, books—into a series of hierarchical groups to make them easier to identify, study or locate. Taxonomies

> consist of two parts—structures and applications. Structures consist of the categories (or terms) themselves and the relationships that link them together. Applications are the navigation tools available to help users find information. (ibid, p. 45)

Taxonomies have three uses, therefore, in competency-based teaching and learning. The first and second uses are planning and teaching by mapping and categorizing of generalized complex, interrelated, and co-depending schema. The third use is for assessing results through explicit descriptions of behaviors in a rubric. Taxonomies in their final form, therefore, are rubrics that codify, organize and systemize holistic learning outcomes. As such, rubrics of holistic development provide a map of a learning mastery journey and the summative destination point of the learner.

A taxonomical approach to engineering education is supported by Newberry (2004) and others who align with process-based models in adult learning (Daley, 2000; Sergiovanni, 1992; Senge, 1990). These theorists understand adult learning is an interactive relationship between knowledge and practice (Kedro, 2004; Kanungo, 2001; Prabhakar, 2005; Bennis, 1999). In other words, these theorists support taxonomical approaches to learning. Most theorists tend toward a competency taxonomy that categorizes three areas of learning as the head, knowledge development, the heart, dispositions development, and hands, applications development. Under consideration, therefore, is a three-area taxonomy and rubric of knowledge/head, dispositions/heart, and application/hands, proposed as a starting point for the academy's work in competency-based planning, teaching and assessment of systems, sustainability and ethics in mechanical engineering education.

Knowledge development, the head, for any of the three competencies includes cognitive learning such as reading, researching, talking, observing, examining research, taking notes, journaling, discussing, and using critical thinking to internalize ideas, concepts, methods and strategies. Dispositions development, the heart, for any of the three competencies includes metacognitive learning such as examining for personal meaning, considering costs/risks against benefits/value, establishing boundaries, finding inspiration, developing original thoughts based on beliefs to internalize ideas, concepts, methods, and strategies. Applications development, the hands, for any of the three competencies includes performance learning, such as doing, using, carrying out, attempting, piloting, experimenting, experiencing by trial and error, simulating and executing to internalize ideas, concepts, methods, and strategies.

The use of taxonomical schema to understand competency development is generally understood as a way to allow the learner the flexibility to draw upon different pools of knowledge, dispositions and applications in context (Goleman, 1995; Barbuto & Burbach, 2006; Johnson, Manyika & Yee, 2005) and to maximize outcomes (Hirst, Mann, Bain, Pirola-Merola & Richver, 2004). When competencies are conceptualized as a system or taxonomy of knowledge, dispositions, and application development, then planning for, teaching to and assessing the holistic growth of the emerging engineer is much easier to do. Learning preferences can be better understood and weaknesses or pitfalls in the learning process can be tracked.

For instance, powerful learning experiences in the pursuit of ethics competency development, whether garnered through formal education programs or informal learning interactions, quickly lose their potency if students experience disconnections between the higher education classroom and the practical world. For instance, uncovering a new concept, one that expands the knowledge base (head), can provide the thrill of discovery. However, euphoria can turn into disappointment and frustration if the learner cannot translate that knowledge into application (hands). Likewise, application without congruent knowledge or dispositions (heart) can prove a shallow learning experience. Application (hands), without knowing the "what" (knowledge, head) or "why" (dispositions, heart), will most likely cause a crisis of confidence at some point in engineering practice. To carry this example out further, engaging with strong dispositions (heart) is important as well, but believing in something without being able to articulate the theory or research (knowledge, head) behind the disposition rings empty. Dispositions (heart) need both knowledge (head) and application (hands), for full enrichment and meaningfulness. The process of sorting through and expanding these three areas of competency development, head, heart, and heads, are what learning theorists tell us that learning essentially is.

Molenda (2002) described developmental theories of the past, which were typically based on an "either-or" state of affairs. In other words, learning was conceptualized with the switch "on" or "off." Either there was growth occurring or there was not. These forced choice options for states of development eventually were abandoned and thinking developed around cognitive theories. It was believed that cognitive development was a stable state of developmental that occurred over periods of time. Eventually, modern theorists looked at learning and development differently. They understood that learning was not neatly sequenced, but somewhat messy. In the end, learning was understood as occurring in domain-specific modules following a personal path and timetable. If well-facilitated, self-regulated and incentivized, that path would end in a high level of mastery. This thinking is representative of constructivism. The constructivist viewpoint enforces that both the environment and the learner are interacting in a complex way that requires holistic support and examination. Learning was seen as a self-constructed internalized process (Bruner, 1996).

This progression in thinking about developmental theories changed from linear models of learning to systems processes of learning. And this is why a case for the use of taxonomies in regard to competency development can be made at this time in history. Namely, the current theories highlight that taxonomies support understandings of the process of learning as a system. Taxonomies allow the learner and/or facilitator to examine the process of learning and understand how developmental steps relate to each other. Taxonomies create a better understanding of exact learning schema or processes in use, the learner's scope and sequence of learning, and the relationship of knowledge to dispositions to application, and any combinations of those areas. Further, sound taxonomies, can be converted into rubrics and used for evaluation and assessment, also.

The properties of taxonomies exceed other approaches to planning, teaching and assessing in that the information generated from the taxonomy is a solid rendition of current understanding of learning. Taxonomies provide data that can uncover where relationships between learning points, sequences, relationships, and hierarchies of development occur. Assessment tools based on more linear models, such as check lists, do not typically reveal systemic relationships. If competency development is understood as a systemic process, then help in understanding that complex process by assessing the progress of development makes sense. The time is appropriate to elevate competency development in engineering education to the realm of taxonomies and rubrics.

There is much work to be done in the creation and use of taxonomies for facilitating and assessing engineering education competency development. For instance, as these three areas of competency learning, systems, sustainability and ethics, are tracked by a taxonomy, they can be also be examined as three phases of learning, beginning, intermediate and advanced. In this way, it is possible to create a current state of competency mastery and then to continue to map student competency growth over time. Rubrics are visual assessment tools for such uses. A rubric containing taxonomical descriptions of learning behaviors at various phases of learning can help to understand both the current state and future learning challenges. An example of such a rubric for competency development of sustainability, systems and ethics at three phases of beginning, intermediate and advanced, are presented next in Figure 3-5, representing holistic development of knowledge (head), dispositions (heart), and application (hands).

The implications for taxonomy and rubric development and use in terms of enhancing perspectives of engineering faculty for competency development are significant. A student-centered focus is required to develop useful taxonomies based on what students learn to know, value and do in competency-based learning. The potential impact of authentic and personalized assessment of competency development, and the opportunities for researching and assessing results of competency development initiatives as a part of mechanical engineering DNA are all noteworthy benefits.

To achieve new solutions for competency development in mechanical engineering education, it is necessary to develop enriched paradigms, new attitudes and different ways of teaching and learning so that competency-based learning co-exists with content-based learning and carries through to effective engineering practice.

Mechanical engineers carry a burden of enhancing the world. Professionally, engineers may choose to be conservative and slow to change. They need the support and immersion experiences of relevant and innovative engineering education that includes both content and competency mastery. The future of the world is in the hands of young engineers and there is a great opportunity to give these aspiring practitioners the ability to face the challenges of the future.

Phase of learning outcomes	Sustainability competence-students demonstrate:	Systems competence-students demonstrate:	Ethics competence-students demonstrate:
Beginning			
Based on the Taxonomy: Head-Heart-Hands That Is Self-Focused			
Elements:	*Behavior Descriptions*		
Knowledge/ Head: Exposure to	Knowledge: introductory exposure to and awareness of sustainability concepts on a personal level (such as environmental issues, eco-friendly practices, impact of sustainability on quality of life), and	Knowledge: introductory exposure to and awareness of systems concepts on a personal level (such as the presence of systems, the dynamics of systems, the impacts of systems thinking on social, environmental and economic quality of life), and	Knowledge: introductory exposure to and awareness of ethical implications of decisions in personal life (such as the need for rules, laws and standards; a definition of ethical conduct; the impact of ethics on quality of life), and
Dispositions/ Heart: Connection to	Dispositions: appreciating the value of and displaying an interest in sustainability applications, and	Dispositions: appreciating the value of and displaying an interest in systems applications, and	Dispositions: appreciating the value of and displaying an interest in ethics applications, and
Application/ Hands: Self-Confident Expression of	Applications: self-expressed confidence when using sustainability concepts.	Application: self-expressed confidence when using systemic perspectives.	Application: self-expressed confidence when using ethical principles.

(*Continued*)

Phase of learning outcomes	Sustainability competence-students demonstrate:	Systems competence-students demonstrate:	Ethics competence-students demonstrate:
<u>Intermediate</u>			
Based on the Taxonomy: Head-Heart-Hands That Is Cohort/Group-Focused			
Elements:	*Behavior Descriptions*		
Knowledge: Analysis/ Experience with Concept Use of	Knowledge: analyses and experimentation with different dimensions of sustainability (such as the knowing interactions of various elements of the natural environment, comprehending the relationship between renewable energy and politics,	Knowledge: analyses and experimentation with different dimensions of systems competence (such as knowing the interactions of various elements of a systems, comprehending the relationship between risk mitigation and systems competence, comparing the outcomes of	Knowledge: analyses and experimentation with different dimension of ethics (such as the knowing the ramifications of various rules and standards; comprehending the relationship between ethical concepts and consequences; comparing

	comparing land use development on a basis of commercial needs and environmental preservation), and	systems-based approaches with non-systems-based approaches), and	various conflicts and justifications based on ethic development), and
Dispositions: Personal Ownership of Values of	Dispositions: demonstrate personal beliefs and values about the importance of sustainability by relating to and supporting confidants in theory and practice, and	Dispositions: demonstrate personal beliefs and values about the importance of systems competence by relating to and supporting confidants in theory and practice, and	Dispositions: demonstrate personal beliefs and values about the importance of ethics by relating to and supporting confidants in theory and practice, and
Applications: Confidence Generation from Others in Use of	Applications: generates confidence from confidants in the use of personal/professional sustainability practices.	Applications: generates confidence from confidants in the use of personal/professional systems-based practices.	Applications: generates confidence from confidants in the use of personal/professional ethical practices.

(Continued)

Phase of learning outcomes	Sustainability competence-students demonstrate:	Systems competence-students demonstrate:	Ethics competence-students demonstrate:
<u>Advanced</u>			
Based on the Taxonomy: Head-Heart-Hands That Is Globally/Others-Focused			
Elements:	*Behavior Descriptions*		
Knowledge: Self-Discovery of	Knowledge: deep level comprehension of any one or all aspects or dimensions of sustainability (such as the managing the complexity of elements of the natural environment system, how renewable energy will impact society, regional solutions for fair water use), and	Knowledge: deep level comprehension of any one or all aspects or dimensions of systems competence (such as managing the interrelatedness of systems elements, how complex adaptivity impacts risk mitigation results, how to use system metrics for improvement), and	Knowledge: deep level comprehension of any one or all aspects or dimension of ethics (such as using ethical rules, codes of conduct in terms to impact human thinking and behavior, how ethical decision making impacts business value, ethical solutions for human dilemmas), and

Dispositions: Development of Original Thought About	Dispositions: is able to develop original sustainability solutions when a lack of sustainability competence is present and exhibits a strong commitment to an active role in sustainability in the world, and	Dispositions: is able to develop original systemic solutions when a lack of systems competence is present and exhibits a strong commitment to an active role in systems competence in the world, and	Dispositions: is able to develop original ethical solutions with a lack of ethical competence is present and demonstrates a strong commitment to an active role in ethics in the world, and
Applications: Mastery, Teaching, Leadership of Others About	Applications: exemplifies mastery of sustainability competence through modeling the competency, teaching others and demonstrating sustainability competence leadership in society.	Applications: exemplifies mastery of systems competence through modeling the competency, teaching others and demonstrating systems competence leadership in society.	Applications: exemplifies mastery of ethical competence through modeling the competency, teaching others and demonstrating ethical leadership in society.

Figure 3-5 Sustainability, systems and ethics competencies rubrics.

The current traditional mechanical engineering education program is incapable of serving as the catalyzing forces to improved engineering practice required in this context. Engineering students and engineers in the workforce generally have not gone through a well-formulated education process which has created the competency of systems, sustainability and ethics. For engineering education, this implies that the Statement of the Problem presented earlier in this chapter as a part of *Planning for the Future* protocol as, "Paradigms and pedagogy regarding the need for competency mastery in mechanical engineering education need to be created and/or enriched so that the DNA double helix model of content and competency development can be enacted widely." Competency-based education using taxonomies of holistic, three-part and three-phase learning are proposed here as a solution to this pressing problem. The next chapter, Chapter 4, will examine engineering education in more depth and present a specific method to the content/competency mastery target outcome challenge.

4. The future state of content & competency-based engineering education: Lean Engineering Education

In the first three chapters of this book, mechanical engineering education was explored through the lens of planning for the future. Three different future scenarios were provided to prompt thinking and actions along with a four-step protocol that can be used in planning for the future. A thematic gap analysis of the state of mechanical engineering was presented next, exploring student, employer, faculty and society needs of mechanical engineers and the academy. Advocacy for both content and competency mastery based on taxonomies was described next as a core improvement strategy for mechanical engineering education, with an emphasis on systems, sustainability and ethics competency development.

With such an emphasis on the future, the classical goals and definitions of engineering education are presented next. This is done to help the reader in framing a deeper proposal of utilizing Lean Engineering Education as a key learning management method.

4.1 The definition and goals of engineering education

While this book is focused on mechanical engineering specifically, the broad goals of engineering education are helpful in scoping out basic, shared understandings. The Technical and Social Goals of engineering education were summarized by Grayson (1978, cited in Heywood, 2005) as:

- Technical Goal:
  To prepare and perform analysis and creative design or construction, production or operation where a full knowledge of the analysis and design of the structure, machine or process is essential.
- Social Goal:
  To develop an understanding of the evolution of Society and of the impact of the technology on it, an acquaintance with an appreciation of the heritage of other cultural fields, and the development of a personal philosophy, which will ensure satisfaction in the pursuit of a productive life, and a sense of moral and ethical values consistent with the career of a professional engineer.

A recent report from UNESCO (2010) also defined engineering education as

> *. . . engineering education also seeks to develop a logical, practical, problem-solving methodology and approach that includes soft social as well and technical skills. These include motivation, the ability to perform, rapid understanding, communication and leadership under pressure, and social-technical skills in training and mentoring.* (p. 25)

Therefore, it is envisaged that engineering education must produce graduates who are able to respond to society and nature in order to satisfy their needs. This means that engineering education must adapt curriculum, teaching and assessment for a changing world without compromising the future generation's needs (WCED, 1987). However, as laid out in previous chapters, it seems that this is not being accomplished. Therefore, absent the presentation in the previous chapters and simply relying on the accepted definition of engineering education, one can surmise that improvement must be a core activity of the academy in order for engineering education to satisfy its basic definition and goals. In other words, engineering education must attend to new educational methods and strategies for engaging students in the learning process in order to guarantee higher quality at undergraduate programs. For example, Mills & Treagust (2003, p. 3) exposed the following concerns:

- Engineering curricula are debatable when focused on engineering science and technical courses without providing sufficient integration of these topics or relating them to industrial practice. Programs are content driven.
- Current programs do not provide sufficient design experiences to students.
- Graduates still lack communication skills and teamwork experience and programs need to incorporate more opportunities for students to develop these and other competencies.
- Programs need to develop more awareness amongst students of the social, environmental, economic and legal issues that are part of the reality of modern engineering practice.

- Academic staff lack practical experience, hence are not able to adequately relate theory to practice or provide design experiences. Present promotion systems reward research activities and not practical experience or teaching expertise.
- The existing teaching and learning strategies or culture in engineering programs is outdated and needs to become more student-centered.

With similar concerns, some academicians launched a particular syllabus for engineering programs, a conceive-design-implement-operate (CDIO) of products, processes and systems approach (Crawley et al., 2011). For some CDIO is considered the authentic context of engineering education. Since 2000 CDIO has been used and endorsed by an organized international educational initiative. The CDIO syllabus is based on 12 standards (CDIO, 2012):

- STANDARD 1: CDIO as Context*
- STANDARD 2: CDIO Syllabus Outcomes*
- STANDARD 3: Integrated Curriculum*
- STANDARD 4: Introduction to Engineering
- STANDARD 5: Design-Build Experiences*
- STANDARD 6: CDIO Workspaces
- STANDARD 7: Integrated Learning Experiences*
- STANDARD 8: Active Learning
- STANDARD 9: Enhancement of Faculty CDIO Skills*
- STANDARD 10: Enhancement of Faculty Teaching Skills
- STANDARD 11: CDIO Skills Assessment*
- STANDARD 12: CDIO Program Evaluation

* Essential, Distinguishing CDIO Standards

The CDIO Standards indicate gaps in engineering education. These shortfalls are also noticed by companies that employ early career engineers. In *Planning for the Future,* the CDIO initiative advances both acknowledgement of and a solution for shortfalls in programming and methodology. The response has been to analyze the shortfalls of engineering education and to develop alternative engineering training and development approaches. One program reflective of the CDIO initiative, the Toyota Education Model, is described next.

As one recognizes the need in planning for the future in engineering education, such programs provide exemplars of what is possible. The call is established to move away from traditional models of engineering education that focus on content mastery exclusively and to include both content and competency mastery in curriculum, teaching and assessment. The Toyota Education Model is useful in demonstrating the CDIO method. Further, the Toyota Education Model, can be retrofitted for the academy. The proposed adaptation is called Lean Engineering Education, a program founded on the mastery of both content and competency and delivered through innovative methods of CDIO, particularly project-based learning and authentic assessment.

4.2 The Toyota education model

Since the origins of the Toyota Motor Company, it is possible to see marked differences, not only in the technical aspect of the production system but, more importantly, in the human aspects of culture. These distinctions rest on the philosophy that people are managed most effectively with two important concepts in mind. These concepts are having a flexible work force and using creative thinking. In other words, the connection of workers to improvement is very explicit and open. Monden (1983) described this of the Toyota Production System's (TPS) success as, ". . . capitalizing on worker suggestions."

These two philosophies increased the Japanese workers' capabilities. Sugimori et al. (1977) called this ". . . the 'respect-for-human' system where the workers are allowed to display in full their capabilities through active participation in running and improving their own workshops." This human system represented the mindset of the managers and was more important than management tools were (as explained by Toyota senior executives in Stewart & Raman, 2007). The fundamental mindset of the Toyota Education Model was related to the fact that each improvement should start from recognized gaps resulting in shared need. Further, and most important, is recognition and acceptance that workers in the company keep were the only production factor with the capacity to develop solutions to fulfill these needs (Yamamoto and Bellgran, 2010).

Additionally, in the Toyota Education Model the workers were viewed ". . . not just as pairs of hands but as knowledge workers who accumulate chie – the wisdom of experience – on the company's front lines" and further, "Toyota's culture of contradictions places humans, not machines, at the centre of the company" (Takeuchi et al., 2008).

Toyota's former President Watanabe, interviewed by Stewart and Raman (2007), reaffirmed the two main pillars of the Toyota Way: continuous improvement and respect for people which includes critical stakeholders, the employees, the supply partners and the customers. These operational and cultural tenets have been systemized within the Toyota Production System (TPS). Initially, TPS was conceived of as the "3P" model of Purpose, Process and People. However, Liker (2004) refined and extended this to the "4P" model of the Toyota Way, Philosophy, Processes, People and Partners, and Problem Solving, represented in Figure 4-1.

The 4P model posits that organizations should first be based on a Philosophy representative of long-term thinking. In TPS, this Philosophy is to satisfy the customers in five dimensions: quality, cost,

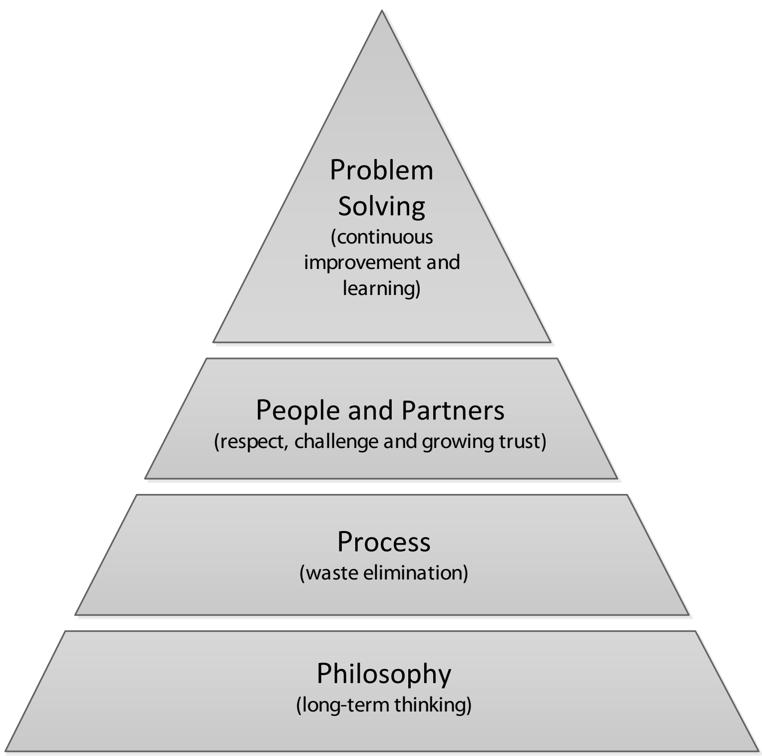

Figure 4-1 The "4 P" model of Toyota way (Liker, 2004).

delivery, safety and morale. These dimensions place the customer in a pull perspective. What this means is that the customer dictates what the organization must provide or produce. From this Philosophy, all attention is focused on ensuring that Processes actually do respond to customer pull by providing or producing what the customer wants. In order to do this, all processes adding value to the customer must continue while those not adding value to the customer must be eliminated. This sorting out of value add and non-value add is accomplished by empowered People and trusted Partners. People and Partners respond to customer pull through Problem Solving. Problem Solving is a critical and expected activity in the TPS.

The 4Ps of the TPS are developed and supported by the Toyota Education Model. This is a learning system that exists inside the factory in all activities at all levels. The Toyota Education Model daily challenges and empowers workers to continuously improve processes and operations based on customer pull through collective problem solving. Such expectations provide meaningful, fulfilling and motivating work. The TPS work environment is distinctive. It requires different attitudes and routines from traditional factory floors. Most distinctive is the requirement for People and Partners to engage core competencies described earlier, such as systems, sustainability and ethics.

Through its Philosophy, Toyota overtly acknowledges that its success relies on cultivating and mobilizing its organizational intelligence, respectfully recognized as Process improvement occurring at the hands of People and Partners engaged in Problem Solving. Therefore, the company invests heavily in people and organizational capabilities through the Toyota Education Model learning system. The Toyota Education Model provides a winning strategy for developing people in the global manufacturing environment. This learning system promotes competency mastery, particularly of system thinkers (Alves et al., 2012; Suzaki, 1993; Spear & Bowen, 1999; Spear, 2004.) As described by former president, Minoura (2003), the "T" in "TPS" corresponds to "thinking" by our employees and partners, a suggestion toward the 4P model of long term thinking as the base of work. This also indicates that competency mastery is, in fact, highly valued in the Toyota Education Model. In fact, according to Suzaki (1993), this means that shop floor management prioritizes "making people before making products." The holistic development of people is clearly in play at Toyota as People and

Partners become strong contributors who can think and follow the TPS at all levels within the organization.

TPS creates a community of scientists which, when facing a problem or a need to change a technique, are encouraged and stimulated to raise hypotheses and to conduct experiments following the scientific method (Spear and Bowen, 1999). The four rules that underline TPS are: 1) all work shall be highly specified as to content, sequence, timing, and outcome; 2) every customer supplier connection must be direct, and there must be an unambiguous yes-or-no way to send requests and receive responses; 3) the pathway for every product and service must be simple and direct; and 4) any improvement must be made in accordance with the scientific method, under the guidance of a teacher, at the lowest possible level in the organization.

The Toyota Education Model allows workers to discover the rules as a consequence of solving problems. They learn how to do their work instead of someone else telling them how to do it. Through iterative questioning and problem solving, each worker delves into his own specific work, facilitated with learning by doing. Through teaching people how to solve problems scientifically, the Toyota Group uses the "learner-leader-teacher" model, engaging people who act as consultants. This model readily reinforces the learning in addition to fostering the improvement of processes (Spear and Bowen, 1999).

Becoming a Toyota worker is simultaneous to becoming a lifelong learner, incorporating the scientific method at all levels in the company and outside the company, sharing a common goal based on continuous improvement. Toyota shares a common vision of an ideal person or group/cohort/team of people that provides deliverables that: 1) are defect free and represent the features and performance the customers expect; 2) can be delivered one request at a time (a batch size of one); 3) can be supplied on demand in the version requested; 4) can be delivered immediately; 5) can be produced without wasting any materials, labor, energy, or other resources (such as costs associated with inventory); and 6) can be produced in a work environment that is safe physically, emotionally, and professionally for every employee.

As an example of this, Spear (2004) reported on a case study of young managers who were trained in the Toyota Education Model and became problem identifiers and solvers. Some of the key approaches for success taught in the Toyota Education Model are: 1) There is no substitute for direct observation; 2) Proposed changes should always be structured as experiments; 3) Workers and managers should experiment as frequently as possible; and 4) Managers should coach, not fix.

According to Takeuchi et al. (2008), the Toyota Education Model advances some characteristics of Toyota executives as: 1) willingness to listen and learn from others; 2) enthusiasm for constantly making improvements; 3) comfort with working in teams; 4) ability to take action quickly to solve a problem; 5) interest in coaching other employees; and 6) modesty. In the Toyota work environment, it is expected that subordinates confront the boss or bring bad news to the boss. Apprentices are encouraged to expose problems instead of hiding them. These permissions gives people the freedom to voice contrary opinions, nurture new ideas, and learn from mistakes, experimenting to meet customer pull.

The Toyota Education Model provides employees with several tools to carry out expected behaviours of observation, experimentation, problem solving and coaching. Toyota teaches employees how to deal with problems rigorously and systematically through numerous tools such as the Plan-Do-Check-Act model, the eight-step Toyota Business Practices process, the A3 reporting system, the 5 Why routine and kaizen events, amongst others. There are over 40 lean tools used at Toyota. A few lean tools are described next to provide insight as to how TPS is able to operationalize the 4P model.

The most basic lean tool is the Continuous Improvement (CI) process. Bessant and Francis (1999) defined CI as an organizational process of focused and sustained incremental innovation. The CI process is dynamic, having cycles of implementation imposed by different forces and assuming different patterns (Savolainen, 1999). In order to have this dynamic capability, the company needs people (employees, administrators, management) prepared to assume a kind of attitude reflected in the 4Ps of the TPS.

In the Toyota Education Model the lean tool, CI and the Plan-Do-Check-Act (PDCA) cycle is taught to employees. PDCA is a visual management tool used to organize and implement the proposals to solve problems suggested by employee teams and quality management circles. The PDCA cycle is the practical method of using a common problem solving format to provoke small improvement steps, also known as gradualism, CI works best when the PDCA cycle is engaged through gradualism (Berger, 1997).

The PDCA cycle is systemic loop of thinking and doing (Figure 4-2), invented by Walter Andrew Shewhart (1891–1967). The PDCA cycle was initially largely disseminated in Japan by W. Edwards Deming (1900–1993). For this reason, the PDCA cycle became known as the Deming cycle.

This PDCA cycle is visually represented in a one-page A3 report. The A3 is a PDCA story board (LaHote, 2005) that leads a team through organized thinking and shared doing for solving problems, creating proposals, establishing plans, and conducting status reviews. According to Shook (2008), the A3 creates a common process for critical stakeholders to agree (or fail to agree) on a problem definition and to compare a variety of potential solutions. It is visual, representing a transparent process. The A3 can inspire and motivate people to propose solutions, because it defines clearly the problem, the root cause analysis and the proposals, followed by the implementation plan.

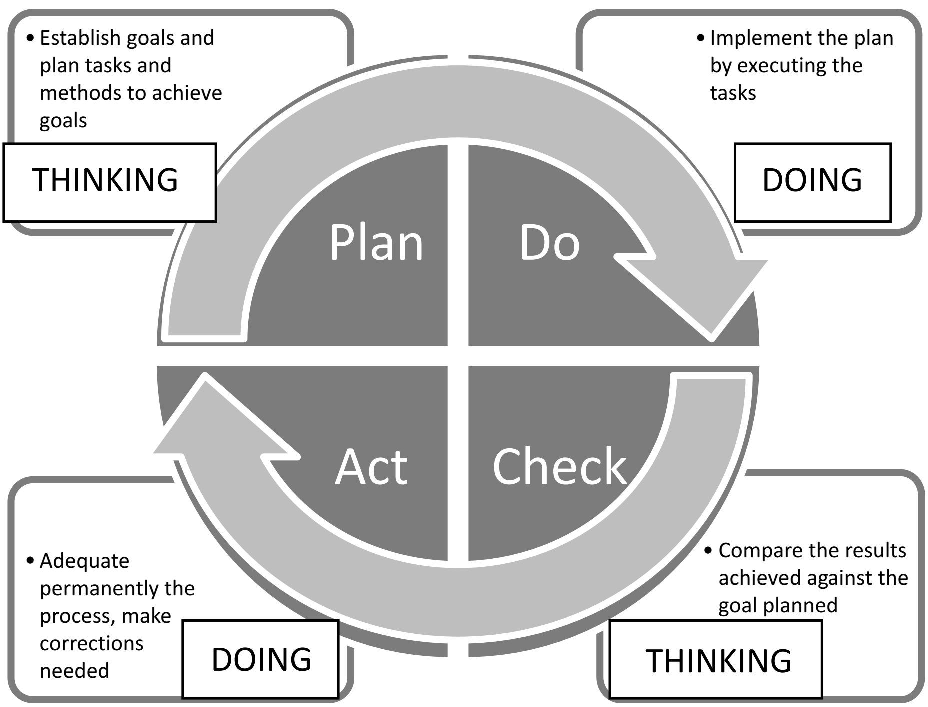

Figure 4-2 The PDCA cycle.

The A3 represents the PDCA cycle, but there are also many other tools that can stand alone or be nested within an A3. For example, there are problem-solving tools to articulate the problem clearly and to outline potential causes succinctly, such as (Suzaki, 1993):

1. Histogram
2. Cause-effect diagram (fishbone or Ishikawa diagrams)
3. Check sheet
4. Pareto diagram
5. Graph
6. Control chart
7. Scatter diagram
8. Pie chart
9. Display chart (pictograph)
10. Relations diagram
11. Affinity diagram
12. Tree diagram
13. Matrix diagram
14. Arrow diagram
15. Gantt chart
16. Radar chart
17. Process analysis sheet
18. Cycle time analysis sheet
19. Work combination chart
20. Process flow diagram
21. Man-machine chart

The simplicity and visual nature of these lean tools make them easy to incorporate into the A3 report. However, the development of lean tools provides both a broad and deep list of methods for reaching the 4Ps. For instance, additional lean tools may be used to more clearly understand the current state. Lean tools such as value stream maps, representing the flow and metrics of process steps of the current state (Rother & Shook, 2003) and spaghetti diagrams, depicting material, information or service process flows are also used to understand the current state of a system. Value stream maps and spaghetti diagrams help to identify activities that add no value to the product or service from the pull view of the customer. A skill matrix or cross-training chart is another tool that can be used to assess the people skills and try to match them to the needs of the company (Suzaki, 1993).

When it is necessary to brainstorm or to generate ideas, additional lean tools are also employed. Some of these lean tools help to raise the right questions (Suzaki, 1993), such as: the 6M1E (Man, Machine, Methods, Material, Measurement, Management Information and Environment) checklist, the asking "Why" five times (5Whys) technique, the 5W2H (What, Why, Where, When, Who, How, How much/many) checklist and Osborne´s checklist (use it another way; borrow an idea from something similar; change or replace it; expand it; reduce it; use alternatives; replace it; reverse it; and combine it).

Once the system or process is understood in its current state, and brainstorming has taken place, improving the system through additional lean tools may be used. The 5S, a sustainability tool, or the Heijunka, a leveling tool, maybe used to improve basic problem metrics, such as quality, cost, delivery, safety and morale (QCDSM) in an integrated and holistic approach. Chen et al. (2010) and Carvalho et al. (2011), Alves et al. (2011, 2014), Ribeiro et al. (2013), Costa et al. (2013, 2014), Bragança et al. (2013), Queta et al. (2014) and Resende et al. (2014) presented case studies of lean implementation at small manufacturers, benefiting from such lean tools.

There are many options for singular or combined uses of various lean tools. These tools are critical technologies for enacting the 4Ps of the TPS. As people are taught and coached in the application of these lean tools through the Toyota Education Model, these tools become familiar and widely used in common practice.

The Toyota Education Model prompts some guidance for the academy in terms of mechanical engineering education. In fact, Lean Engineering Education is presented next as a method for advancing content and competency mastery for aspiring engineers. Lean Engineering Education holds promise for addressing the need for systems, sustainability and ethics competency development.

4.3 The definition of Lean Engineering Education

The advancements of lean as a body of knowledge emerged from an incremental and analytic building process of continuous improvement as Toyota experienced over time (Womack and Jones, 1996). Attending to the previous discussion that was focused on the Toyota Education

Model and on the 4Ps, a framework for lean thinking emerges. Womack and Jones (1996) solicited five principles from their research on TPS. These include the need to 1) create value for the customer, 2) identify the value stream, 3) create flow, 4) produce only what is pulled by the customer, and 5) pursue perfection by continuous identification and elimination of waste. From this framework, the following definition of Lean Engineering Education is presented:

> *A systematic, student-centered and value-enhanced approach to educational service delivery that enables students to holistically meet, lead and shape industrial, individual and societal needs by integrating comprehension, appreciation and application of tools and concepts of engineering fundamentals and professional practice through principles based on respect for people and the environment and the rigorous use of continuous improvement.*

This definition is the basis for designing the curriculum, teaching and learning, and assessing student progress in the Lean Engineering Education classroom. This definition can also be contextualized in planning for the future of mechanical engineering education so that the engineering student, the engineering employer, society, and faculty are the four critical clients/suppliers of educational services. The engineering students pay tuition to receive a value in the form of an education. The employer hires the engineering student seeking to receive value in the form of high level employee performance. Society is the consumer of the products and services developed by engineering students working for engineering organizations. And faculty, as suppliers, provide mechanical engineering education services.

Based on the argument to deliver the double helix DNA of mechanical engineering education, both content and competency mastery, the previous chapter presented an exploratory rubric of student outcomes for systems, sustainability and ethics competency. These three competencies are the dorsal spine of the value stream that adds to the delivery of the mechanical engineering education. This process of mechanical engineering education should enrich the four-pronged client/supplier value streams of students, employers, society and faculty. Figure 4-3 below depicts a mental model as to how these outcomes can be pulled by Lean Engineering Education.

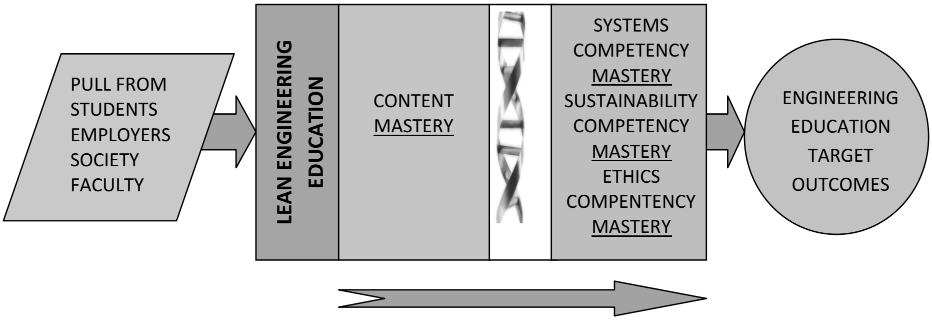

Figure 4-3 Systems, sustainability and ethics competency provided by Lean Engineering Education.

Lean Engineering Education, in simulating the 4P's of lean culture and practice, inevitably should produce a combination of content and competency development. In fact, if Lean Engineering Education requires collaborative problem identification and solution and high levels of vertical, lateral, internal and external communication, as well as highly-developed technical expertise, the engagement of the head, heart and hands of mechanical engineering students is required. When engineering degree program design relies on Lean Engineering Education, the possibilities for attaining both content and competency mastery can increase greatly. These possibilities in Lean Engineering Education are greater than they are in traditional content-based programming. Instead of introducing additional coursework to meet workplace requirements, it is possible to both integrate and spiral competency development with the content of engineering education by pedagogical alignment with the learning systems embedded in Lean.

4.4 Systems competency mastery pulled by Lean Engineering Education

Applying the problem-solving tools presented early and normally used in an industrial Lean environment, the students will develop thinking capability because they learn to think in systematized and inductive way. They also learn to search for the root cause of problems through deductive thinking instead of trying to solve symptoms; they acquire a thinker profile like workers in a Lean company (Alves et al., 2012). Workers are the only production factor with the capacity to develop solutions to fulfil these needs (Yamamoto and Bellgran, 2010). Figure 4-4 shows a framework of systems competency using Lean Engineering Education.

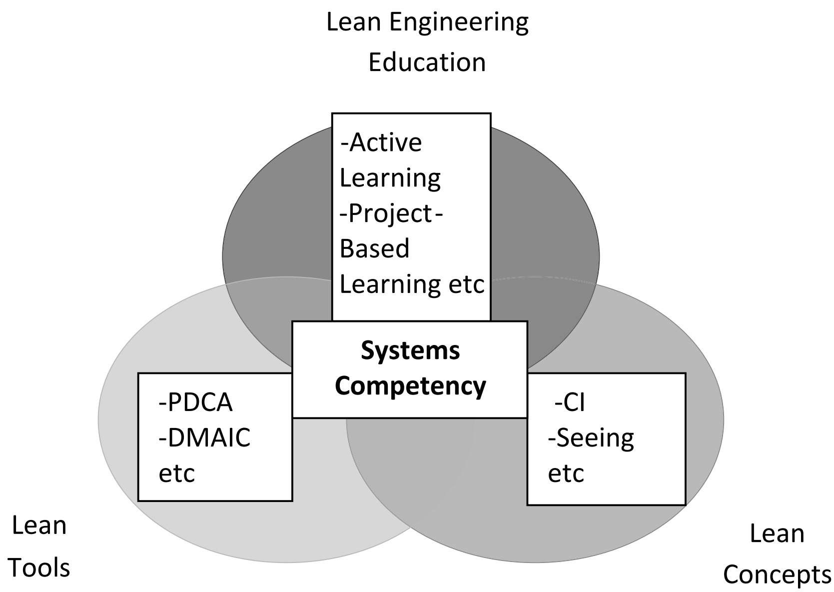

Figure 4-4 Framework of Lean Engineering Education and systems competency.

4.5 Sustainability competency pulled by Lean Engineering Education

The pursuit of perfection is a lean principle that engages the tools and thinking of continuous improvement to create value by eliminating wastes. Lean specifies nine deadly wastes as overproduction, transports, inventory, motions, waiting, over-processing, defects, knowledge and energy loss. These wastes are clearly related to sustainability competency. For example, consider environmental waste, as defined by the US-EPA (2007, p. 2) as

> . . . an unnecessary or excess use of resources or a substance released to the air, water, or land that could harm human health or the environment. Environmental wastes can occur when companies use resources to provide products or services to customers, and/or when customers use and dispose of products.

Lean attacks these problems evident in environmental waste and advocates for "doing more with less" and "creating more with less," not by

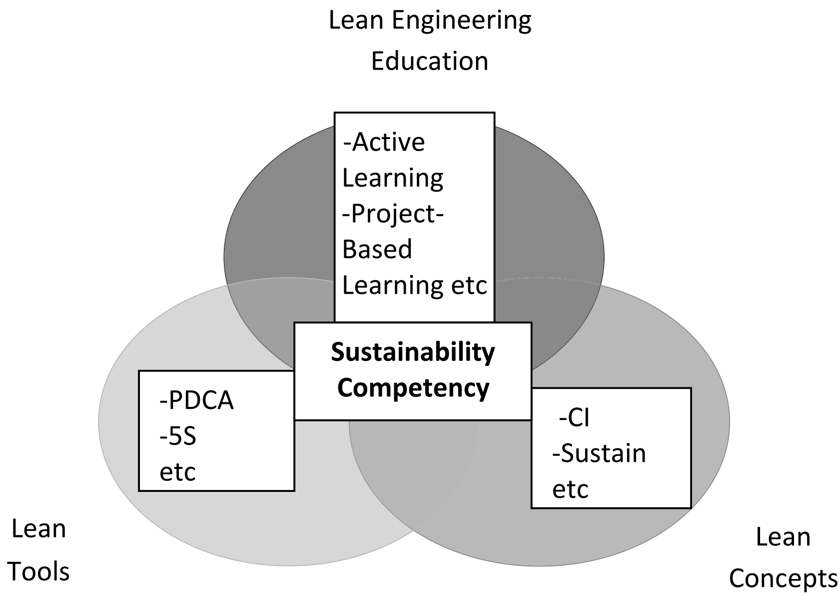

Figure 4-5 Framework of Lean Engineering Education and sustainability competency.

working harder with fewer resources but by expanding value through improvement work. In other words, as an expression of sustainability competency mastery, the Lean Engineering Education student develops a commitment to an the symbiotic relation of production and the environment (Moreira et al., 2010). Lean Engineering Education will develop a Lean seeker of wastes in all forms, a demonstration of sustainability competency development. Figure 4-5 shows a framework of sustainability competency using Lean Engineering Education.

4.6 Ethics pulled by Lean Engineering Education

Ethics development will cultivate in engineers an outcome known as corporate social responsibility. This competency is one that serves as the foundation of Lean Engineering Education, a support to the Systems and Sustainability competencies. When Lean Engineering Education teaches the ethics competency, it is possible to develop a conscientious attitude and behavior of perfection based on goodwill and moral foundations of civil society. Outcomes, such as enabling enriched thinking, mature attitudes, and sophisticated approaches to better resource efficiency and productivity or doing more with less, because it is the right thing to do, is expected and fostered. Ethics pulled by Lean Engineering Education opens up options for deeper levels of critical thinking and analyses, well-conceived mitigation of risk and consequence, engaging difficult conversations of both advocacy and inquiry, and internalizing incentives to not only do well, but to do good as work product. Lean Engineering Education seeks to develop champions of ethical competency by modeling, teaching and rewarding corporate social responsibility. Figure 4-6 shows a framework of ethics competency using Lean Engineering Education.

The impact of Lean Engineering Education could be substantial. If mechanical engineers could interact with the world to overcome failure to conceptualize systemic consequences, to withhold consumption of resources beyond the earth's means and to engage in good for the advancement of civil society, then planning for the future of mechanical engineering education is time well spent.

The future mechanical engineer will definitely be involved in companies in manufacturing or service sectors which all involve processes that are linked together in a particular fashion, sequence or design. The mechanical engineer needs to see that all these processes use man,

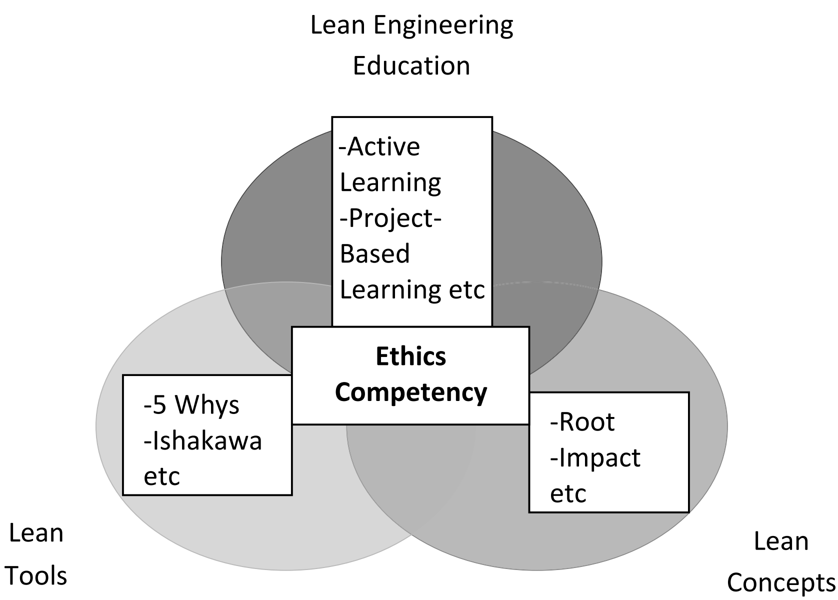

Figure 4-6 Framework of Lean Engineering Education and ethics competency.

machine, materials, methods, information, energy, utilities and consumables as inputs or factors of service or production and in turn, they all are worked on to create the final output of the system. The mechanical engineer needs to understand that these element exist in a complex configuration as all of these parts must work together to achieve a common goal to produce the output according to the level of quality and quantity required by the end client or customer. And further that all work is done in a way that produces benefits for the common good of civil society.

In designing mechanical engineering processes and products, the engineer needs to see that a starting point is understanding value from the customer's point of view and create that value into design. The engineer must realize that the customer pays only for the value adding aspects of production and the only way to maximize the economic gain from the design is to minimize all wastes and non-value adding components into the design. On a bigger system perspective she/he, he also needs to recognize that organizations exist in a supply chain and the linkages in this supply chain affect turnaround time, takt time, and ultimately, the triple bottom line of people, planet and profit.

Lean Engineering Education utilizes various sets of tools, often overlapping tools, and a series of concepts that impact dynamics within the engineering workplace. For instance, the lean tool, value stream mapping, facilitates engagement in process improvement based on metrics valued by clients/suppliers. Lean concepts, such as one-piece flow pull production, promote paradigm shifts away from mass production. Lean Engineering Education offers opportunities for students to actively engage in problem-based learning where process improvement is needed and uses the value stream map tool and pull and just-in-time production concepts (EPA, 2011). Such improvements can be conducted at the hand of the engineering student under Lean Engineering Education. This type of learning can then be revolutionary for the early career engineer who may have previously thought that excessive inventory is indicative of system success. By engaging systems, sustainability and ethics competencies, the benefits of stockless inventory, pull production, and zero waste, for examples, are strived for. Lean Engineering Education, expressed as lean engineering practice, promotes an integrated system of mutually dependent strategies hinged on continuous improvement that when combined together maximize operating performance by elimination of wasteful manufacturing or systems practices (LEI, 2007).

Further systems, sustainability and ethics competency can enrich early career practice by engaging a connection to a broader supra system. On this high level of engagement, the early career engineer may realize that supply chains across the world are intricately linked to resources from one part of the world, while production happens in another part, and distribution is entrenched across the globe, touching consumers in all nations where the create demand for all kinds of products occurs. Thus, the early career engineer needs systems, sustainability and ethics competency developed from the Lean Engineering Education experience to contend with the issues of understanding how to achieve high economic gain from all activities while minimizing negative consequences for others by balancing the needs of companies, supply chains, nations, current generations, future impact categories and life cycle stages (UNEP, 2011).

Lean Engineering Education, therefore, is advocated for as a mechanical engineering education method that encumbers relevant bodies of knowledge and practice. It provides appropriate technology, tools and concepts, to the mechanical engineering student in the design of mechanical engineering outputs. Lean Engineering Education further integrates these perspectives to commitments of continuous improvement work so that all elements of design and factors of technology such as manpower, raw materials, energy, utility and the systems that integrate them, are analyzed, improved and optimally designed and operationalized for systems, sustainability and ethics optimization.

5. Examples of content & competency-based Lean Engineering Education

In mechanical engineering education the practical application of theory proves invaluable in situations that require results. The foundation of a good education lies in the student's ability to apply learning effectively, combining both content and competency mastery target outcomes to acquire relevant deliverables in the workplace.

Currently most engineering schools tend to depend on conventional methods of teaching, approaches that rely more on the theoretical and hypothetical. What this means is that lectures are delivered to students so that are theories, concepts, frameworks, a general breadth of knowledge of solid dynamics and fluid dynamics are taught as target outcomes. Putting all these of engineering theories into practice for the early career engineering through the phenomena of "praxis" remains a significant challenge in the field. Because some engineering schools and instructors rely heavily on the target outcome of content mastery alone and use didactic instruction to reach this target outcome, the journey to workplace relevance for the early career engineer is often tenuous. A solution to this problem has been presented in Chapter Three through the double helix DNA model of intertwined content and competency mastery and in Chapter Four through approaches such as Lean Engineering Education. In this book, specific, but not comprehensive, advocacy for content and systems, sustainability and ethics competency has been set out. It is believed that through the adoption of a systematic approach in structuring the analysis and solving of a presented problem, utilization of sustainability tenets in both self-organization during the actual intervention and synthesis of the outcome of the project, and in ethical considerations of the problem and its solutions, it is possible to attain competency-based target outcomes previously neglected.

The lack of opportunity to develop systems, sustainability and ethics competency within the educational experience creates difficulties for early career engineers. These mechanical engineers may find it difficult to address challenges encountered because they do not possess the competencies required by workplace. This chapter provides alternative examples to conventional methods, designed to benefit students, employers, society and faculty. Moreover, it explores the future of mechanical engineering practice in the context of job opportunities, hiring standards, induction procedures, and work environments of early practice of the future.

The need to revamp mechanical engineering education has been set out in previous chapters. The use the four-step *Planning for the Future* protocol was suggested as a first step to creating learning conversations for improvement work. The identification of the felt needs of the four key stakeholders of mechanical engineering education, students, employers, society and faculty was done to frame and scope improvement work into themes. Next, three themes of competency-base need, system, sustainability and ethics competency were presented and examined via exploratory rubrics and possible taxonomies to guide curriculum, teaching and assessment in the future. Content and competency-based engineering education was further connected to the conceive-design-implement-operate, CDIO method, and expanded to a specific method, Lean Engineering Education. Next, specific examples of Lean Engineering Education courses or programs are presented as pioneering examples of what is being done now by the academy. These examples are shared as a beginning point for the future, as to open up the idea that possibilities for improvement are limitless against the realities of teaching Lean Engineering Education using content and competency-based methods to foster systems, sustainability and ethics competency and beyond.

Compared to traditional teaching, the Lean Engineering Education method is more demanding as it requires supervisors to deliberately choose projects that will move students to application to improve their systems, sustainability and/or ethics competency on actual projects where things are less predictable as compared to reading about them in textbooks. Albeit this challenge presents a wonderful learning opportunity, not only for the student, but also to faculty supervisors as well. Seven programmatic examples from four universities are presented next showcasing Lean Engineering Education. They highlight several strategies, including 1) offering separate lean engineering courses, 2) recognizing the alignment of Lean Engineering Education with national engineering education standards, 3) using problem-based learning, 4) scoping entire program alignment with Lean Engineering Education, 5) offering interdisciplinary Lean Engineering Options, 6) using project-based learning, and 7) employing action research methods. All of these examples are straight forward are shared to enact great potential for Lean Engineering Education and competency-based outcomes in the future. These next steps may range from entire program redesign, to program assessment, to improved teaching pedagogy within current course offerings.

For the first example, the use of two Lean Engineering courses are described. Two elective courses for graduating mechanical engineering students had been introduced and adopted in 2008 at the University of Cape Town, Cape Town, South Africa. The courses are Lean Operations (LO) and Applied Operations Engineering (AO). The LO course introduces the students to lean terminology and the origins of lean manufacturing theory. The AO course provides students the opportunity to practice the conveyed lean theory and their problem solving skills on an actual hands-on action research project. These courses utilize active learning and project-based approaches and foster systems, sustainability and ethics competency. In these courses, there is a need for a balancing the act between steering the student without telling the student what to do or how to conduct the actual analysis of the investigated problem. Faculty are challenged to facilitate learning by placing up the guardrails for the student providing, just enough protection to not cause harm, while enabling the student to independently identify and address hurdles and issues during her/his own investigation.

The second programmatic example comes from the University of Cape Town as well, where student achievement in the Lean Engineering Education courses are assessed in compliance with Exit Level Outcomes as defined by the Engineering Council of South Africa (ECSA) which highlights the following steps: developing a problem statement, solving a problem, visualizing improvements through the selection of appropriate metrics, and communicating identified project results. These Exit Level Outcomes reflect the need for content and competency mastery, an essential tenet of this book. It is positive to note that there is support for these types of outcomes from sources that interface with the academy. And at the University of Cape Town, these standards provide rationale for the Lean Engineering Education approach described above.

The third example of Lean Engineering Education from the University of Cape Town follows with the use of project-based learning within engineering courses as a key strategy and lessons learned. This occurred in February 2012. The University of Cape Town in Cape Town, South Africa. The Lean Engineering Education method was used when a group of five graduating mechanical engineering students who were assigned to carry out a feasibility study about the local production of lithium-Ion batteries and the economic impacts of doing so. The parameters for this study included measuring the locally generated value-add, increasing job opportunities for skilled labor and engineers alike, and a reducing the response time to market demands. The students were instructed to self-organize around the following deliverables, which required lean concepts and tools:

- Identification of mining, processing and delivery logistics,
- Strategic selection of a production site,
- Listing of required production site infrastructure,
- Technical installations required for lithium-ion battery production and their effects on time-to-start-of-production, associated costs, and
- An earned value stream map showing the individual processing steps from mining to the lithium-ion battery production, with time frames for the individual steps and percentage of value added (0% at mining, 100% at battery manufactured).

In order to create a project that could be concluded at the end of the semester with content and competency outcomes, the students were instructed to identify a single product to manufacture. This required a market analysis to identify opportunities and projected market growth over time while recognizing that a head-on competition with low-cost economies in their home markets was unrealistic. All students carried out this activity jointly and relied on systems, sustainability and ethics competencies to do so. For instance, they had to define the interfaces between their individual actions, recognizing that the output of one team member constituted necessary input into the work to be carried out by another team member in order for the project to be finished successfully. This utilized systems competency. The feasibility study submitted by the students showed that they had chosen to produce mobile phone batteries for the African market because of the projected growth of the African mobile phone market. It also described the selection criteria for the lithium-ion battery production site, and justified the project budget based on the three cost drivers for the manufacturing processes. This utilized sustainability competency. Observations made by the group identified that self-organization was the biggest challenge posed. The supervisor did not act as the project manager but instead steered the progress in a customer role, which engaged the ethics competency.

A fourth example of Lean Engineering Education occurs in the Philippines. Here different programmatic options are put forth as efforts towards improving the quality of engineering education through Lean Engineering Education have been undertaken since 2003. This effort has been led by De La Salle University. This University now offers classes on Lean Engineering to undergraduate and graduate students of Industrial Engineering at the College of Engineering. Some undergraduate students pursue action research in their terminal year for thesis work, while some graduate students work on their term projects and master's theses, also in their terminal term.

A fifth example of Lean Engineering Education takes place at Oakland University, Rochester, MI, USA. Lean education is supported by the Pawley Lean Institute, a research/teaching institute devoted to promoting the interdisciplinary application of lean with students. The university offers three courses, open to students in engineering, business and human resources. One cross-listed graduate course, HRD620/POM680/ISE581, Lean Principles and Applications, takes led students through lean content to form interdisciplinary project teams, replicating interdepartmental perspectives for collaborative problem solving in the workplace. Two additional undergraduate courses, HRD 304, Lean Principles and Practices in Organizations, and HRD 344, Lean Kaizen in Organizations, are undergraduate cross-listed courses striving for interdisciplinary participation dealing with workplace lean applications.

A sixth example occurs at the University of Minho, project based learning (PBL) projects promote a rich environment to explore and employ lean concepts and tools. Lean Engineering Education was put into practice by academic staff at the School of Engineering - University of Minho through hands-on projects in industrial settings. One project used a team composed of fourth year Industrial Management and Engineering students (Lima et al., 2009a, 2009b). After visiting selected companies, the team was able to diagnose, plan and propose improvement proposals to reduce wastes and create value to customers through product improvement. The positive feedback and satisfaction from companies and the motivation of the students to learn were the measures of successful systems, sustainability and ethics competency development.

A seventh example from the University of Minho involves lean projects resulting from action research methods. Action research projects were developed by senior Industrial Management and Engineering (IME) students (Alves et al., 2011). Action research methodology (Lewin, 1946, cited in Susman and Evered, 1978) has many similarities with the PDCA cycle and follows a similar path in terms of discovering solutions for problems, involving the researcher as an active participant in action, or in loci. Action research involves five iterative phases, represented in Figure 5-1.

According to Susman and Evered (1978), this research methodology has a capacity to generate knowledge for use in solving problems faced by members of organizations. The six characteristics of such methodology are strongly related to the systems, sustainability and ethics competencies as follows: 1) Being future oriented - dealing with the practical concerns of people, oriented toward creating a more desirable

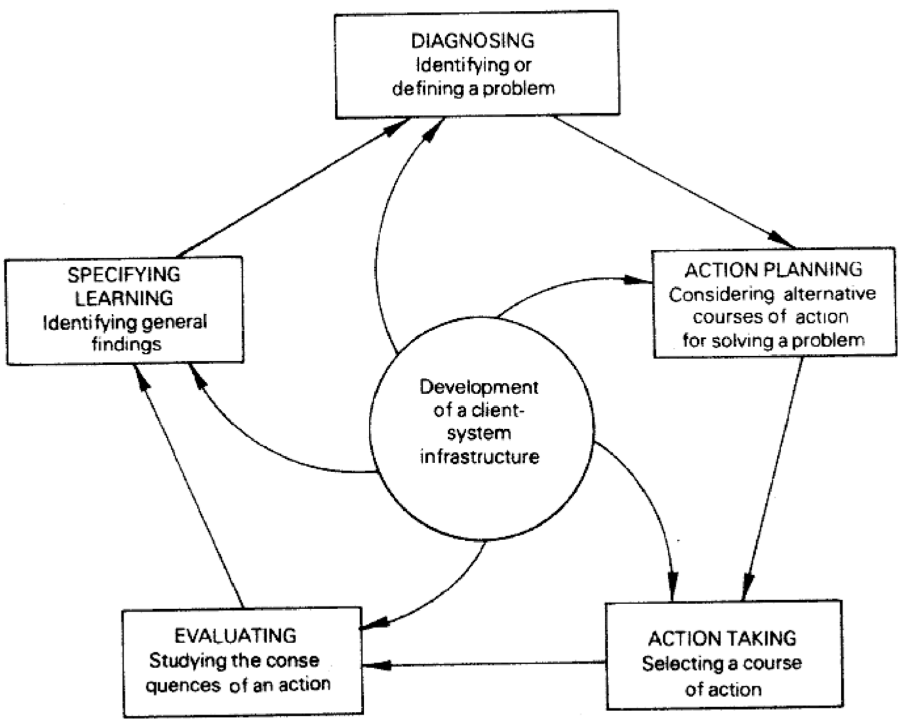

Figure 5-1 The cyclical process of action-research (adopted from Susman & Evered, 1978).

future for them-sustainability competency; 2) Being collaborative - the direction of the research process will be partly a function of the needs and competencies of the client and researcher interdependence—ethics competency; 3) Engaging in system development – generating the necessary communication and problem-solving procedures—systems competency; 4) Generating theory grounded in action – contributes to the development of theory by taking actions guided by theory and evaluating their consequences for the problems members of organizations face-this is also the systems competency; 5) Remaining agnostic - recognizing that the objectives, the problem, and the method of the research must be generated from the process itself, and that the consequences of selected actions cannot be fully known ahead of time—sustainability competency; and 6) Remaining situational - many of the relationships between people, events, and things are a function of the situation as relevant actors currently define it—systems competency. Hence the learning activity of action research interfaces naturally with the competencies under discussion within the Lean Engineering Education method.

These seven scenarios of Lean Engineering Education are presented to illustrate possible solutions and accompanying challenges for mechanical engineering education. They all have high impact for transference to early engineering practice and do encumber the double helix DNA design of content and competency mastery through the Lean Engineering Education method.

To further highlight how useful competency mastery could be to mechanical engineering graduates, the three scenarios from 2030 presented in Chapter One are revisited, Mechanical Engineering Scenarios 1, 2 and 3. Each scenario was described in Chapter One to illustrate in the *Planning for the Future* protocol. Here, the scenarios are embellished with dialogue to highlight how systems, sustainability and ethics competency mastery are useful to the engineering student and early career graduate.

In Chapter One, Mechanical Engineering Scenario 1 examined what Jasmine, a mechanical engineering graduate, may encounter during the interview process with the Rebuild Division of Generalized Solutions. In this scenario, she was asked about her experiences in the use of the systems competency. This included how she conceptualized the problem, analyzed and synthesized it and subsequently considered the implications of her solution on a broader scale. Based on her experiences in the LO and AO Lean Engineering Education courses at the University of Cape Town, Jasmine answers with confidence during the interview presented below regarding her mastery of systems competency.

Interviewer: Describe how you used systems thinking in your course work.

Jasmine: During the time leading up to a major international conference to be held in Cape Town in 2011, I was placed with a local travel agency which was contracted as the conference organizer as part of my Lean Engineering Education coursework. My task was to identify the reasons for low conversions of telephonic inquiries into actual sales, and to devise interventions to increase the conversion rate. The challenge was that there is no apparent easily standardized customer behavior, and that customer demand covered a range of additional ancillary demands, such as safari tours or winery tours in addition to conference attendance.

Interviewer: How did you approach the problem?

Jasmine: I observed the agents working telephonic customer inquiries and found out quickly that there was no standardized process in place for how to engage the customer and to find out quickly what the inquirer's constraints were. If the inquiry originates from a budget traveler, then it is not very likely that he will want to look at five star hotels. However, a couple traveling on their silver wedding anniversary would be much more inclined to stay in high-end hotels with one spouse undertaking tourist activities while the other attends the conference. I was examining the system and thinking about how to optimize it. I saw standardization as a way to bring the system to higher levels of effectiveness and efficiency.

Interviewer: When you refer to standardizing, do you mean to say that you were expecting to find patterns of inquiries in the system which could maybe be lumped together? Did you expect that there would be a predictable behavior in the inquiries throughout the system?

Jasmine: Actually, yes. As I examined the system, I noticed that while there were a wide range of inquiries coming in, it was clear that some demands would be seen more often than others. Examples of comparable high demand included winery tours or excursions to game reserves. If we can identify such patterns in the system, then we can begin to categorize these patterns and plan ahead. This allows us to present thought-through options to the customer without being put on the spot. It was interesting for me to learn that other services delivery systems have used this approach to remedying system deficiencies, such as in places like hospital emergency rooms.

Interviewer: How did you convince your supervisors that you were on the right track, and that your interventions actually addressed the root cause of the problem in the system?

Jasmine: I was concerned about that aspect as well. I wanted to make sure that I was seeing the system as a whole in order to ascertain where a change in part would impact other parts. This is because systems have complex adaptivity and one change causes emergent changes sometimes unseen. Systems competency helped to realize this from the beginning. So, I decided to use some of the lean visualization tools we had been taught at the University, that is, Value Stream Mapping, 5S and a Pareto analysis. The Value Stream Map was an eye-opener because I used it to reflect what was actually happening "on the ground" throughout the system. This included seeing the interactions of events, who was involved, how many resources were tied up where, where communication lines existed, and how long events actually took. These tools helped me and other to see the system and the impacts of problems quite quickly, in that everybody now could see what actually went on at what step in the value chain, as opposed to what he thought went on within his own area of work. This is how system competency was helpful in this circumstance.

In Chapter One, Mechanical Engineering Scenario 2 examined what Harry and Sally, twin mechanical engineering graduates, may encounter regarding job opportunities in 2030. In this scenario, they each reflected about their experiences in the use of the sustainability competency as a means of creating job opportunity. This included how they conceptualized the management of resources against metrics of value, engaged improvement of processes to eliminate waste and considered the implications of solution on a long term scale. Based on their experiences in the LO and AO Lean Engineering Education courses at the University of Cape Town, Harry, working for a large corporation, and Sally, running her own consulting business, talk with each with confidence regarding their mastery of sustainability competency.

> Harry: Sally, with the increasing global demand for raw materials and for resource efficiency, it is practical that we were taught to expect that job opportunities in 2030 would focus on effective and efficient distribution of resources, and resource engineering in general. I remember learning that the term "resources" was used collectively for raw materials, utilities such as electricity and water; the natural environment; technology; machines and human resources. This expanded my understanding of sustainability. For when I encountered by first project, I had to improve a manufacturing process that ran behind production timelines. My company wanted to assign more workers to the line. I was not convinced that more workers was a good approach per se, so I used sustainability competency to figure out if there was waste occurring on the line. Through observation, examining of take time and other lean tools, I soon discovered that more workers could solve the problem. In fact, there were more resources being used than were needed because there was a redundant activity occurring in the production line. The redundancy caused the use of more electricity than was needed. So, I was able to increase efficiency while using fewer resources. It was a victory for sustainability! Sally, what are your thoughts on the sustainability competency?

> Sally: Your workplace problem reminds me of my AO student project carried out in the marine industry in Cape Town. With Cape Town being a coastal city, there is a constant demand for marine equipment manufacturing and marine services, such

> demand ranges from tug boats to research stations in Antarctica. For a local Cape Town SME, I was tasked with devising a standard operating procedure for their assembly operation, and to demonstrate the improvement of the SOP compared to the previous working approach. The company provided products that can best be described as High Variability, Low Volume (HVLV), while delivering against internationally accredited codes and standards for subsea operations. I used sustainability competency and identified opportunities for standardization. The standardization work generated good internal stakeholder interest. Utilizing value stream mapping, PDCA, 5S and installing a raw material warehouse, I was able to work with critical internal stakeholders to define standard operating procedures, create process flow diagrams, and significantly reduce the demand on human resources and utilities in the company. Further, I trained employees to correctly utilize the processes we had defined. This was such a great learning experience for the sustainability competency. I often refer to this learning as my automotive clients are very concerned about complying with new efficiency standards and sustainability outcomes. They ask me to help them with the sustainability competency.

In Chapter One, Mechanical Engineering Scenario 3 examined what Maria, a mechanical engineering graduate, may experience in the work environment in 2030. In this scenario, she was using her ethics competency. This included how she conceptualized the impact problem on stakeholders and the globe, scaled eco-efficient solutions as an ethical matter. Based on her experiences in the PBL projects and Lean action-research project, Maria reflects with confidence on her mastery of ethics competency in the workplace.

> Maria: I think that an absolute essential in my preparation for the engineering workplace boils down to my capability to solve problems working with others in teams because they trust me. As engineering projects are growing in size, the number of involved stakeholders that needs to comply with multinational regulations and certifications, it is not practical and no longer conceivable to have one engineer work on a technical or logistical

> issue in isolation without interaction with, input from, or output to others working on the same project. Therefore, the need for me to use ethics competency always in all ways, is essential to this dynamic. This applies for my role as both a leader and a subordinate on any project. This has helped me to distinguish myself in the workplace—relying on ethics competency is essential to me.

The importance of content and competency mastery in mechanical engineering education is a theme carried out in this book. A series of additional examples of Lean Engineering Education projects are provided next to further illustrate the practicality of *Planning for the Future of Mechanical Engineering Education* and to showcase the advantages of Lean Engineering Education and competency-based target outcomes. These projects represent global efforts to utilize Lean Engineering Education in the academy, regardless of culture and nation.

Project 1 was the work of a student at the University of Cape Town, South Africa. The quality of healthcare service delivery in public hospitals in South Africa is a source of constant disappointment and complaints among its population. The needs of the population are not met from the point of admission. While triage codes specify certain response times for physicians to attend to patients, they often fail to meet the required response time. In worst cases, a patient arrives at a public hospital early morning and leaves in the afternoon of the same day because there are no physicians available. This poor healthcare service delivery prompted an investigation to establish the causes of inefficiency. An analysis of the operations in the trauma ward at GF Jooste Hospital in the "Cape Flats" in Cape Town suburbs was carried out. The GF Jooste Hospital was chosen in 2010 as a home for this project because it presented the most challenging environment in the Greater Cape Town region, serving approximately 1.5 million people with less than 300 beds for stationary patients. The student was tasked to classify the appropriate lean tools to identify and visualize the shortcomings of service delivery. Utilizing value stream mapping, standardized operating procedures and 5S as lean tools, the student found out that the hospital was not efficiently organized in basic tools for the trauma ward to serve patients swiftly, and that the supply chain for triage supplies presented a large number of opportunities for streamlining. In engaging with the hospital staff, the student was regarded as a consultant and facilitator. However, the hospital had no internal champion to oversee an improvement process and because of the student's status as an external consultant to the trauma ward, such cases were referred to the respective line manager. The student devised process flow diagrams and a status monitoring board to optimize the supply chain and to improve response times in the trauma ward.

A second example of Lean Engineering Education, Project 2, also took place at the University of Cape Town. The international airport at Cape Town has undergone a significant structural expansion and facelift in 2008 and 2009, to accommodate the escalating number of passengers throughout the 2010 football world cup. As part of this expansion project, the airport sets out to investigate and reduce its energy consumption. The demand patterns of Cape Town International Airport exhibit distinct operating cycles with high passenger throughput between 5:00 h and 10:00 h, and between 17 h and 21:30 h. The largest energy consumer for the airport is the air conditioning system in the departure and arrival halls, and the student was tasked to identify and visualize the energy demand over the course of the day and to propose an operating pattern of the air conditioning system that matches the cyclical passenger throughput. The student chose value stream mapping, visual management and Pareto charts to address the posed problem and to visualize findings. An unforeseen outcome of this project was the realization that consumers could not be correctly identified in the electrical circuits, rendering a correct allocation of energy consumption per electrical consumer is impossible. As a learning experience, this outcome presented a welcomed deviation from the chartered course as the assigned problem was not the actual problem that required solving.

The third example of Lean Engineering Education, Project 3, also occurred at the University of Cape Town. A project for two students was defined for a local subsidiary of an international automotive supplier. The posed technical challenge consisted of identifying the root cause for welding defects of three-dimensional filter casings, and to devise an improved welding process. Two students addressing this problem had to identify potential causes for the welding defects, and then devise a coordinated way to eliminate the welding defects and to devise process improvement. The process improvement in turn had to be coordinated with all stakeholders and integrated into the entire production line. The students developed process flow diagrams and standard operating procedures, and carried out employee training on the standard operating procedures.

The fourth example of Lean Engineering Education, Project 4, took place at the University of Cape Town as well. For a local farming equipment manufacturer, two students were assigned to develop standard operating procedures. Both students were able to work independently of each other in the company's warehouse and on the production floor. Utilizing value stream mapping, PDCA and 5S, both students were able to develop internal standard operating procedures.

Another example of Lean Engineering Education, Project 5, also occurred at the University of Cape Town. In collaboration with the local municipal administration, two students were tasked to identify opportunities to streamline purchase orders and supply chains, and to assess the load distribution between various distributed offices in the municipality. Utilizing value stream mapping, 5Whys and 5S, the students jointly investigated the seasonal demand variation and the ordering workload distribution between the regional offices. Flow diagrams were developed and opportunities to reduce order lead times and to improve the supply chain were identified. Unfortunately, the amount of data collected from previous years was not sufficient to allow solid conclusions on workload distribution and staffing requirements in the supply chain.

Another example of Lean Engineering Education from the University of Cape Town is shared next, Project 6. The MTN Science Center in Cape Town had identified that their water display was not holding the attention of any visitors. The water display was configured to be interactive and showed the effects of weirs, vortices, and then conversion of geodesic energy into kinetic energy. It also allowed boat races. The general expectation was that a water exhibit should be popular with children. Unfortunately, the actual demand for the exhibit was extremely low. The consensus among the science center management was that, in its current shape and form, the water display was an inefficient use of floor space. The science center management felt that the importance of water as a natural resource for mankind would justify an improvement of the water display, and that the display should be improved to the point where it can generate and sustain more interest. Two students were assigned to this project and they were to formulate a problem statement, to substantiate the problem statement, and to propose an improved water display. The students defined customer groups ranging from children to adults. They assessed the customer interaction with the exhibits and visualized the lack of interaction with the display followed by breaking the display into its individual segments. They identified the reasons why the display was not receiving and sustaining as much attention as was expected. The students suggested that the revisions of the display should be based on sound fluid dynamic principles and benchmarked by the displays with other science centers globally. They carried out their analysis using value stream mapping and PDCA and then presented their results using visual management. Their results were captured in flow diagrams reflecting improved display designs. The science center in Cape Town is currently relocating and is expected to include the recommended new designs at their new location.

Project 7, is yet another example of Lean Engineering Education at the De La Salle University in the Philippines. The project involved the transformation of a paint production area. Smartsco Inc. is one of the leading and most respected industrial and architectural paint manufacturers in the Philippines today. It presently employs over 200 workers, they produce industrial and architectural paint and for each type they have three different sub-types, resulting in six different product families. Thus, students were tasked to conduct a study to transform Smartsco to a Lean Manufacturing company geared towards development and sustainability. The students used value stream mapping to identify priorities. They assessed the current and projected the future state of the company through a comparative analysis with emphasis on 4Ms (Man, Machine, Materials, Method and Information). Moreover, they proposed a flow chart with company's production data with various charts and diagrams to present a cleaner manner of conducting business in addition to standardized operations to avoid duplication. Likewise, they identified Lean transformation methodologies, which included reforms in logistics, production control and standardized work procedures. The application of Lean principles in the system meant creating more value to the customer with fewer resources. Eliminating non-value adding activities as well as wastes along entire value streams to Smartsco, Inc. creates processes that need less human effort, less space, less capital and less time to produce products that has far less costs which much fewer defects, compared to traditional business systems. As such, Smartsco, Inc. would be able to respond to changing customer desires.

Although customer would order in high variety, high quality and low cost with fast throughput lines can still be observed. In addition, information management becomes much simpler and accurate. The students learned that lean manufacturing implementation put the company towards development and sustainability leading them to expand and gain more customers in the long run. While it is very beneficial to implement lean process improvement, the cooperation of employees is just as important. Employees should be committed on considering lean principles and practices on their work. As such, procedures and trainings should therefore be designed and organized well in order to reap the benefits without disrupting flow of the system.

Project 8, also originating from the De La Salle University involved an initiative entitled, the LEANer Amalgamated Specialties Corporation (AMSPEC). The Amalgamated Specialties Corporation, also known as AMSPEC originated in August 21, 1963, when Rennolds Group Management Companies decided to establish an office and school product manufacturing firm in the Philippines. AMSPEC currently has about 240 employees and has expanded its operations in the country in the field of manufacturing and distribution. Most of its products have become household names in the industry, namely, TPencil formerly Mongol, Crayola, Magic touch and Lotus. They have been leading and they intend to uphold their reputation on producing top quality school and office supplies. The students were tasked to identify areas for improvement and classified overproduction and accidents in the work area as major problems holding the company's opportunity to achieve its full potential. The students designed an approach to transform AMSPEC system towards a more efficient and competitive organization through the adoption of lean manufacturing system/technology. Lean tools, such as value stream mapping, kaizen, mistake proofing mechanism, 5S, demand analysis and level management cell manufacturing was employed to reduce accidents, work and processes, improve lead time and value added time. The proposed changes have created a drastic change in the company's performance. Work in process has been reduced to just 8% from the present system, finished goods holding costs down to just 36%, and lead time resulting to only 25% from the original. In addition, total cycle time has decreased with the addition of automatic pencil slat drying machine. Other wastes, such as motion and transportation were also minimized due to the re-designing, cell manufacturing, and 5S.

This has resulted in less non value-added activities, which is necessary in lean to increase flow. A lean culture is also promoted where everyone ought to be committed in adopting the principles, otherwise the benefits would not be fully realized if the company's employees do not cooperate. Recommendations from the students also stated that additional metrics and transformation strategies be explored to further see the benefits of lean outside of just reducing WIP and lead time. Health and safety metrics can be added since lean tools can also be used to improve health and safety measures. Furthermore, with the growing trend of going green, lean can be applied to reduce environmental impacts and emissions.

And Project 9, is yet another example of Lean Engineering Education at De La Salle University. This ninth project involved lean manufacturing in offset printing. The graduate students of De La Salle University (DLSU) had identified several challenges faced by the EC-tec commercial, an offset printing press in the country. They aimed to transform an offset printing system towards a more efficient and competitive organization through the adoption of lean manufacturing system/technology. The students observed that wastes in terms of production, transportation, non-value added processing and inventory characterize the present printing system. Although there is a minimal overproduction wastes since they only produce according to the demand, allowances for rejects are still anticipated by the company. Overproduction in the form of overruns and defective products has been observed. One of the recommendations is to produce quality products to reduce overproduction and avoid buffer for rejects. They also developed an optimal layout of the area to improve the transportation or movement of products and consequently reduce the lead time for production. The students also suggested to adopt the following processes: employee empowerment, total productive management or routine maintenance of equipment; Kaizen or forming a team geared towards continuous improvement; visual controls or the installation of production board schedule to monitor the progress of the operations and process standardization. The suggested processes are intended to increase efficiency and shorten the lead time, therefore, preventing penalties due to late delivery of products.

Project 10, an example of Lean Engineering Education at De La Salle University, involved the application of lean concepts and tools to improve the production process of a soap manufacturing company.

The graduate students of De La Salle University had identified that Glowkal Manufacturing, one of the country's leading soap manufacturers, incurred a lot of wastes in their manufacturing system. The company used the "push system" strategy, resulting in the production of more soap than what was needed. This happened because of various factors such as unnecessary transportation movement and bulk orders from their supplier abroad. Glowkal produced about 9,000 to 10,000 products a day as compared to actual demand of 3,000 to 5,000 on an average. With this kind of set up, the company was tying up too much money and space with excess inventory. The graduate students of De La Salle University were tasked to formulate a problem statement and to propose ways to improve the manufacturing system of Glowkal. The students suggested that Glowkal shift from the push to the pull strategy which would dictate just-in-time production based on customer demand. Pull is a lean technique. In a lean pull system, the mixing process is done when the need arises, therefore cutting the current production into half resulting in 3,100 soap bars per day. The students also recommended shortening the transportation movement. Further, they figured out that processes be put together to prevent damage and to speed up the production. Through the implementation of lean tools, it was found that the system was able to reduce its cycle time and non-value adding activities significantly. Thus, the company was able to save additional time and money and prevent wastage.

Project 11 takes places at the University of Minho in the Masters Degree in Industrial Engineering and Management Program, Portugal, and serves as an example of Lean Engineering Education. This project presents a work undertaken in a metal structures production system with a company producing several assorted products for civil construction. The project's aim was to improve the production process, solving several problems encountered in the production system, such as: deliveries delays, long lead times, too many materials being handled, high stock levels, errors and defects in metal structures assembly and production, and unnecessary motions. The identified problems were analyzed as forms of waste and improvement actions were scheduled and subsequently implemented. These improvement actions were based on the lean production organizational model and some lean tools. The 5S methodology, a standardization and sustainability tool, was implemented in the workplace as well as mistake proofing, standardized procedures, production activity control system and layout reconfiguration. These actions led to a reduction of the lead time, work in progress, transports, delivery delays, defects and errors in assembly and production.

Project 12, also emanating from the University of Minho's graduate program as Lean Engineering Education took place at a plastic injection company. This project uncovered the results of a lean production project implementation developed mainly in babies chair injection section and assembly lines. The main aim of the project was the application of lean principles and tools involving the collaborators of the company and the researcher, also a collaborator. The first tool applied was Value Stream Mapping (VSM) to diagnose the production system and to identify the wastes and the main improvements points. Other lean proposals were presented and implemented using lean tools such as Kanban, Plan-Do-Check-Act (PDCA) cycle, Single Minute Exchange of Dies (SMED) and Kaizen. Some tangible and financial results obtained were an increase of productivity of the assembly lines of 12%, an operating income of 6%, a reduction of cycle time of six dies down 10% and a reduction of 15% in tool changeover time. In addition, total incomes were estimated in 360000€, a bottom line improvement. Intangible results were the operators' engagement and involvement with the continuous improvement and with lean implementation.

The University of Minho used Lean Engineering Education with Project 13. This project had as main objective the reconfiguration of a luxury bed company's production system, using the principles of lean thinking and applying techniques of management methodology and organization of lean manufacturing production. The philosophy of lean thinking was aimed at removing all activities that do not add value to the product and to further to contribute to the reduction of time and production costs, leading to prompt responses to customer requirements and deadlines. After a careful review of the literature, based on a theme theoretical introduced, lean thinking was presented as a solution to the company. The analysis of the current situation of the assembly sector of beds led to the definition of some problems such as the disorganization in supplying materials, the workstations, the information of the products and the production process as well as the significant number of Work in Process (WIP) and high lead time. These issues were determined through the graphing process analysis and sequence charts, which helped to determine the activities that added value to the product. For example, graphics of movement that permitted the visualization of material flow, through Value Stream Mapping, which determined the activities that added no value to the Work in Process (WIP) and the lead time, were used. In addition, quality problems were also considered, for which cause-effect diagrams were drafted. These identified problems related to waste management. An analysis of worker job satisfaction was also done. After the presentation of lean analysis and synthesis was completed, proposals for intervention were drawn up. Several responses were provided to the existing problems, including standardization of production processes, organization of materials and supply stores, standardization of the workstations, which included the suggestion of lean tools 5S, to sustain improvements, and the Toyota Production Method.

Another example of Lean Engineering Education, Project 14, took place at an electronics component company through the University of Minho's Masters in Industrial Engineering and Industrial Management. This project was developed in an electronic components company in the car radio assembly lines. Its objective was to implement a pull leveling strategy between the car radio final assembly lines and the Original Equipment Manufacturing (OEM) clients. In order to respond quickly to the clients, the firm maintained a stock level of approximately ten days of finished product for each client. This implied high costs for the firm. The implementation of the lean pull leveling strategy reduced these costs and increased the flexibility with the production to demand process, in both quantity and in diversity, as required by the clients. Additionally, this implementation permitted the detection of deviation, identification of problems, creation of standards and continuous improvement, stabilization of the upstream processes and the reduction of components stock. The performance indicators used by the firm to measure the performance of this implementation were the fulfillment of the production leveling plan supplied by the Production Planning Department, the minimizing of the stock level, the Every Part Every Interval (EPEI) number and on time deliveries as negotiated with the client.

Project 15, also offered by the University of Minho, was developed in the operating spaces of the Centro Hospitalar of Porto - Hospital de Santo António, called Project Lean Operating Room (Project Lean OR). Lean Engineering Education was the focus of the project as it used lean tools and concepts such as 5S, visual management, eliminating waste, and Kanban. By applying these lean tools, there was improvement in inventory management of stores, where the exposed material in storage spaces fell around 20 to 50%, the organization of the surgical areas was improved, and surgical material and equipment out of use was eliminated. Further, there was improvement equipment management. Indicators of productivity were posted in the operating room to assist the visual inspection process which resulted in decreased operating times and created a lean thinking attitude with employees. With this lean approach, the hospital managed the process improvements and engaged better resource management, creating a culture oriented to optimization, waste reduction, and quality of the working environment. In short, this meant that a culture shift occurred oriented to customer satisfaction and improving customer service when accessing the National Health System. To do this, the involvement and training of employees of the operating room proved essential for obtaining positive results and for continuity and improvement of the Project LeanOR.

Project 16, took place at Oakland University, Rochester, Michigan, USA, in the undergraduate Industrial, Mechanical Engineering degree program. A course called Flexible Lean Manufacturing, offered as a senior course, engages students not only in project-based learning, but also in real world application. Students spend more than half of their time learning lean concepts and tools and slightly less than half of their time learning systems. The Flexible Lean Manufacturing class places senior students into lean teams of three or four. The School of Engineering maintains a permanent relationship with the local hospital and this hospital provides problems of practice for the lean team to solve. Further, the solution is then fostered to completion by a student or students who subsequently serve in a paid internship at the hospital. One project focused on the Emergency Room at the hospital in examining the processes used in following a doctor's order for a scan as it went it out and came back to the doctor. By using lean process improvement, a four-hour turnaround was reduced. The seniors made the recommendation for the process improvement in the course and the intern ensured that the recommendations were fully carried out and implemented to standardization.

Project 17, also came from Oakland University's as an example of Lean Engineering Education on the master's level. The electrical utility company, an organization considered a leader in the state in lean practices, invited two teams of graduate students to examine the process of construction/repair work, which typically occurs in the street. The graduate students identified 128 different jobs that were required for these types of repairs. The utility company sought process improvement to the extent that work could be standardized to gain efficiencies. The graduate students analyzed equipment needs, resources available, response time and other critical factors. This project was similar in design to Project 16 in that a team of students solved the problem and an intern subsequently followed up on the implementation of the solution.

Project 18, from Oakland University's graduate program, engaged masters and doctoral students through a lean course, Lean Principles and Applications, where industrial consulting through implementation took place within the semester. This project involved product layout improvement in the assembly line of an automotive supplier of fuel tanks and washer fluids. The assembly area was crowded and messy and students used lean principles and tools to improve it. Current and future state value stream maps, pre- and post-spaghetti diagrams, In Frame/ Out of Frame examination, analysis of five wastes, 5S + 1 (Safety), and cell manufacturing were used to analyze problems and develop solutions. Work areas, walkways, containers usage and storage, waste storage and removal as well as warehouse practices were reviewed and improved. The cost savings of these changes was small, but they provided a significant change in employee morale due to increased productivity, quality, decongestion and safety. The students' analysis of the improvements revealed important cost avoidance in the future.

And Project 19, an industrial project, also occurred with masters' degree and doctoral students in the Lean Principles and Applications course at Oakland University and serves another example of Lean Engineering Education. The process of crash testing was examined in the context of production. The students figured out what was needed, without engaging in doing more than was needed (overproduction) for crash testing. The crash test was downtime from production, but was also essential to product quality standards. A multi-pronged examination was conducted using lean thinking and to create four different options that were considered from many angles. Tools used in the examination included SMED (single minute exchange of dies), heijunka (rearranging the work), automation, SWI standardized work instructions), and analyses such as hierarchy decision cost-benefit and payback period. Tools used in providing solutions included an implementation plan. The crash test downtime was reduced from 6.25 hours to 4.0 hours from solutions that stemmed from the lean practice of observations. These solutions ranged from hiring more people to removing the crash test process off site away from the assembly process to modified fixtures for testing to physically converting space to the crash test lab within the facility. Payback analysis was conducted and data driven decision making, a key lean practice was used to make the final decision. It is interesting to note that the option that required the most capital expenditure had the shortest payback period. In this course, students had exposure to the use of lean as a strategy and philosophy, rather than as just a tool or an idea. The attributes of unstable systems were engaged well with lean continuous improvement.

In presenting these nineteen examples of Lean Engineering Education, it is evident that classroom work utilizes problem/project based learning, action research and the wide variety of lean concepts and tools to engage the student. There are many, many opportunities for both content and competency mastery by engineering students to occur with Lean Engineering Education. In addition, there are minimal differences between classroom and workplace applications of Lean Engineering Education and lean performance management. A Lean Engineering Education student experiences a blended approach of moving from the classroom to the real world. This dynamic enhances the case of *Planning for the Future* because the need to include competency mastery does occur with the Lean Engineering Education method. The following examples are shared to highlight such educational delivery to engineering students, intended to influence the work of early career engineers and beyond.

These nineteen examples from the University of Cape Town, De La Salle University, University of Minho and Oakland University may seem more like actual engineering work than classroom work. But, that is what active project-based learning in a Lean Engineering Education program looks like—real work. The opportunities in these examples to develop and master the competencies of systems, sustainability and ethics are plentiful, as each example is rife with competency-based learning in an authentic context. To prove this point that the work of engineering students in Lean Engineering Education programs parallels the engineering workplace, two examples of lean production management from the workplace are presented next. This is done so that the reader can examine how similar the nineteen examples, Projects 1–19, of student work presented above are to the engineering workplace. The two examples below, Workplace Projects 1–2, are lean workplace projects that took place in the Philippines. It is hoped that Projects 1–19 described above and that Workplace Projects 1–2 described below are perceived as parallel in terms of work expectations, quality of the work experience deliverable, and content and competency mastery required.

The first example of lean workplace management, Workplace Project 1, involved a clean-lean production system for fish canning. While the Philippine fish canning industry contributes substantially to the growth of the economy, it is also responsible for negative environmental impacts due to wastes from the whole production process. A study by Chiu, Manalang, Dona and Brilliante (2011) of the De La Salle University College of Engineering, stated that these environmental wastes are currently 77.96% higher in wastewater generation and 10.45% higher in effluent loads than the fish canning industries of countries that have implemented cleaner technologies.

In a similar study, the application of Cleaner Production (CP) and lean production systems were applied to assuage the fish canning environmental impacts in order to bring the industry to the same decent levels as worldwide eco-friendly industries having new cleaner technologies. The continuous application of an integrated preventive environmental strategy to processes, products and services to increase efficiency and reduce risks to humans and the environment resulted (COWI, 2000). In this case, an evaluation of the company's procedures was conducted first. Second, a cleaner production assessment was employed, where two types of material balance, whole system and per unit of operation material balance, were made in order to identify the weights and quantities of raw materials, auxiliaries, products, by products, energy waste and emissions consumed or produced by the whole system and in each unit or process operation. The resulting material balance was based on 20-working days of the month. Third, a lean assessment was applied to the system study of the fish canning to remove the non-value adding materials without compensating the demands of the customers. Last, to avoid any redundancy and resolve duplication, CP options were analyzed and all the lean transformation strategies were implemented with reference to the proposed lean-clean solution framework for the company. Notwithstanding the consideration of environmental concerns, it is evident in this study that systems, sustainability and ethics competencies were present and essential to success. The employment of lean tools and concepts, such as value stream mapping to see waste, assisted in the incorporation of lean production in the fish canning with clean technologies. This served as a catalyst in achieving a waste minimization of zero waste.

The second example, Workplace Project 2, also takes place in the Philippines and involved a cavite integrated water resource management plan. The province of Cavite in the Philippines has recognized the need to update, integrate, and employ a comprehensive water management plan in view of the rapid growth in population, increased economic activity, decreasing groundwater levels resulting in groundwater mining, saltwater intrusion in coastal areas, pollution in rivers, and competition over water rights. Hence, the Cavite Integrated Water Resource Master Plan was prepared as a response to this rising need. The Cavite Provincial Development and Physical Framework Plan (PDPFP) 2008–2013 identified the annual depletion of ground water and the pollution of major rivers as among the issues concerning water supply sources. Other studies, which focused on ground water source development for selected areas in Cavite, are also streamlined and examined to consider the incorporation of recommendations. Value stream mapping and interdependent planning were given due respect to enable a positive working relationship with critical stakeholders. Given this lean planning approach, it is evident that systems, sustainability and ethics competencies were needed to address the water concerns of the people of Cavite.

The use of lean concepts and tools, and the need for advanced systems, sustainability and ethics competency are present in these two Workplace Projects. These are provided to simply make the point that the Lean Engineering Education classroom is very much like the engineering workplace and that such methods are within the capacity of the academy. There is a need for the academy to work closely with the workplace to provide adequate learning experiences for mechanical engineering students. When lean is used properly in the workplace, there are both key tools and key tenets that drive decision making and actions. This day-to-day commitment to lean as a body of knowledge and as a body of practice can be taught to students. Lean Engineering Education coupled with the double helix DNA of content mastery and systems, sustainability and ethics competency mastery does provide an informative perspective on what can be planned for and accomplished in the delivery of mechanical engineering education. What should be on the table for discussion in *Planning for the Future of Mechanical Engineering Education* is now in the hands of the academy.

References

Ackoff, R. (2004). Transforming the systems movement. Opening speech at *3rd International Conference on Systems Thinking in Management, May 2004.* Philadelphia, PA. http://www.acasa.upenn.edu/RLAConfPaper.pdf

Alves, A. C. and van-Hattum, N. (2011). Hands-on simulation in the classroom to teach new concepts and to prepare future industrial engineers as operator's instructors. *Proceedings of International Symposium in Project Approaches in Engineering Education* (PAEE2011), 1–2 October, Lisbon.

Alves, A. C., Carvalho, D., Sousa, R., Moreira, F. and Lima, R. (2011). Benefits of Lean Management: Results from some industrial cases in Portugal. *Proceedings of 6th Congress Portuguese-Mozambican of Engineering* (CLME2011), 29 August–2 September, Maputo, Mozambique.

Alves, A. C., Dinis-Carvalho, J. and Sousa, R. (2012). Lean production as promoter of thinkers to achieve companies' agility. *The Learning Organization, 19*(3), 219–237, ISSN: 09696474, http://dx.doi.org/10.1108/09696471211219930

Alves, A. C., Sousa, R. M., Dinis-Carvalho, J., Lima, R. M., Moreira, F., Leão, C. P., Maia, L. C., Mesquita, D. and Fernandes, S. (2014). Final year Lean projects: Advantages for companies, students and academia. *Proceedings of the Sixth International Symposium on Project Approaches* (PAEE2014), Medellin, Colombia, 28–29 July, ID56.1–56.10. http://hdl.handle.net/1822/30172

Argote, L., Beckman, S. L. and Epple, D. (1990). The persistence and transfer of learning in industrial settings. *Management Science, 36*, 140–154.

Armett-Kibell, C. (2007). Future promise of women in science. *The New England Journal of Public Policy, 22*(1), 135–150.

ASCE-American Society of Civil Engineers (2009). Achieving the Vision for Civil Engineering in 2025: A Roadmap for the Profession. ASCE Task Committee.

ASME Board on Education (2012). Vision 2030: Creating the Future of Mechanical Engineering Education, ASME Board on Education, V2030 Project Group, go.asme.org/v2030

ASME Board on Education (2013). ASME Vision 2030 Project: Drivers for Change Data Actions & Advocacy, Vision 2030: Mechanical Engineering Education.

ASME-American Society of Mechanical Engineers (2010). Vision 2030, Excerpts presented during panel 8-5-1, *Workforce Development-Global Experience in Operations Engineering Education at International Mechanical Engineering Congress & Exhibition* (IMECE2010), Vancouver, BC, Canada.

ASME-American Society of Mechanical Engineers (2011). Vision 2030 Creating the Future of Mechanical Engineering Education. Phase 1 – Final Report. Center for Education.

Avolio, B. J. (1999). *Full leadership development: Building the vital forces in organizations*. Thousand Oaks, CA: Sage Publications.

Azapagic, A., Perdan, S. and Shallcross, D. (2005). How much do engineering students know about sustainable development? The findings of an international survey and possible implications for the engineering curriculum. *European Journal of Engineering Education, 30*(1), 1–19, March 2005.

Baier, A. (1986). Trust and antitrust. *Ethics, 96*, 231–260.

Bandura, A. (1986). *Social foundations of thought and action: A social cognitive theory*.

Barbuto, J. E. and Burbach, M. E. (2006). The emotional intelligence of transformational leaders: A field study of elected officials [Electronic version]. *The Journal of Social Psychology, 146*(1), 51–64.

Bennis, W. (1999). The leadership advantage. *Leader to Leader*, 12. Retrieved 1 March 2006, from http://www.pfdf.org/knowledgecenter/journal.aspx?ArticleID=53

Berger, A. (1997). Continuous improvement and kaizen: Standardization and organizational designs. *Integrated Manufacturing Systems, 8/2*, 110–117.

Bessant, J. and Francis, D. (1999). Developing strategic continuous improvement capability. *International Journal of Operations & Production Management, 19*(11), 1106–1119.

Blockstein, D. E. and Greene, J. (eds.) (2003). Recommendations for Education for a Sustainable and Secure Future, National Council for Science and the Environment (NCSE).

Bloom, B. S. (1956). *Taxonomy of educational objectives, Handbook I: Cognitive domain*. New York: David McKay Co Inc.

Bolman, L. G. and Deal, T. E. (2003). *Reframing organizations: Artistry, choice and leadership*. San Francisco, CA: John Wiley & Sons, Inc.

Bowen, W. R. (2009). *Engineering ethics: An aspirational approach*. London: Springer London Ltd.

Boyce, M. (2011). Creating the engineer of 2020: Customizing the Mechanical Engineering Degree for the next generation of engineers. *2011 International Leadership Summit on Mechanical/Multi-disciplinary Engineering Education*, Hong Kong, 26–29 September.

Bragança, S., Alves, A. C., Costa, E. and Sousa, R. (2013). The use of Lean tools to improve the performance of an Elevators company. *Proceedings of Integrity, Reliability and Failure* (IRF2013), INEGI Editions, Funchal/Portugal, 23–27 June 2013, http://hdl.handle.net/1822/25316

Bruner, J. (1996). *The culture of education*. Cambridge, MA: Harvard University Press. p. 49.

Bruno, D. and Richmond, H. (2003). The truth about taxonomies. *Information Management Journal, 37*, 48–50, 52–53.

Burris, D. (2005). *Marine Technology and SNAME News, 42*(3), A19. ISSN 0025-3316.

Canadian Council of Professional Engineers (2001). Guideline on the Professional Engineering Practice in Canada.

Carvalho, R., Alves, A. C. and Lopes, I. (2011). Principles and practices of Lean Production applied in a metal structures production system. Lecture Notes in Engineering and Computer Science: *Proceedings of The World Congress on Engineering 2011,* WCE 2011, 6–8 July, 2011, London, U.K., pp. 744–749.

CDIO (2012). Worldwide CDIO Initiative Standards. Available at: http://www.cdio.org/implementing-cdio-your-institution/standards, accessed August, 08.

Checkland, P. (2000). Soft systems methodology: A thirty year retrospective. *Systems Research and Behavioral Science, 17,* S11–S58. doi: 10.1002/1099-1743(200011) - http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.133.7381&rep=rep1&type=pdf

Chen, J. C., Li, Y. and Shady, B. D. (2010). From value stream mapping toward a lean/sigma continuous improvement process: An industrial case study. *International Journal of Production Research, 48*(4), 1069–1086.

Costa, E., Bragança, S., Alves, A. C. and Sousa, R. (2014). Action-research methodology to improve performance using lean production tools. *Technics, Technologies, Education, Management (TTEM), 9*(2), 253–264.

Costa, E., Sousa, R., Bragança, S. and Alves, A. C. (2013). An industrial application of the SMED methodology and other Lean production tools. *Proceedings of Integrity, Reliability and Failure* (IRF2013), INEGI Editions, Funchal/Portugal, 23–27 June 2013. http://hdl.handle.net/1822/25314

Crawley, E. F., Malmqvist, J., Lucas, W. A. and Brodeur, D. R. (2011). The CDIO Syllabus v2.0 - An Updated Statement of Goals for Engineering Education. *Proceedings of the 7th International CDIO Conference,* Technical University of Denmark, Copenhagen, 20–23 June.

Daley, B. J. (2000). Learning in professional practice. [Electronic version]. *New Directions for Adult and Continuing Education, 86,* 33–42.

DeFillippi, R. J. (2001). Introduction: Project-based learning, reflective practices and learning. *Management Learning, 32*(1), 5–10.

DeGrasso, D. and Martinelli, D. (2007). Holistic engineering. *The Chronicle of Higher Education, The Chronicle Review,* 53(28), B8-9, March 16.

De Rosnay, J. (1979). The Macroscope. Available at http://pespmc1.vub.ac.be/MACRBOOK.html. Retrieved from F. Heylighen (2000): Referencing pages in principia cybernetica web. In F. Heylighen, C. Joslyn and V. Turchin (Eds.), *Principia Cybernetica Web* (Principia Cybernetica, Brussels), URL: http://cleamc11.vub.ac.be/REFERPCP.html

Desha, C., Hargroves, K., Smith, M., Stasinopoulos, P., Stephens, R. and Hargroves, S. (2007). State of Education for Energy Efficiency in Australian Engineering Education - Summary of Questionnaire Results, The Natural Edge Project (TNEP), Australia.

Dewey, J. (1897). My pedagogic creed: Article one. What education is. *School Journal, 54,* 77–80.

Duderstadt, J. J. (2008). Engineering for a Changing World: A roadmap to the Future of Engineering Practice, Research, and Education. The Millennium Project, The University of Michigan.

Dutton, J. M. and Freedman, R. D. (1985). External environment and internal strategies: Calculating, and experimenting, and initiating organizations. In R. Lamb and P. Shrivastave (Eds.), *Advances in Strategic Management.* Greenwich, CT: JAI. pp. 39–67.

Eagly, A. H. and Carli, L. L. (2003). The female leadership advantage: An evaluation of the evidence. *The Leadership Quarterly, 14*(6), 807–834.

Englewood Cliffs, NJ: Prentice Hall.

Eurydice (2010). Focus on higher education in Europe 2010: The impact of the Bologna Process. *Education, Audiovisual Culture Executive Agency* (EACEA P9 Eurydice).

Felder, R. M., Woods, D. R., Stice, J. E. and Rugarcia, A. (2000). The future of engineering education: Teaching methods that work. *Chemical Engineering Education, 34,* 26–39. Retrieved from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.34.1082&rep=rep1&type=pdf

Felder, R. M., Woods, D. R., Stice, J. E. and Rugarcia, A. (2000). The future of engineering education: Teaching methods that work. *Chemical Engineering Education, 34,* 26–39. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.34.1082&rep=rep1&type=pdf

Flumerfelt, S., Alves, A. C., Kahlen, F.-J. and Manalang, A.-B. S. (2012). Why require ethics in engineering? *Proceedings of the ASME 2012 International Mechanical Engineering Congress & Exposition* (IMECE2012), 9–15 November, 2012. Houston, Texas, USA (accepted).

Gharajedaghi, J. (1999). *Systems thinking: Managing chaos and complexity: A platform for Designing Business Architecture.* Boston: Butterworth-Heinemann, Print. (BOOK) http://libcat.oakland.edu/vwebv/holdingsInfo?searchId=1432&recCount=25&recPointer=0&bibId=631502

Goleman, D. (1998). *Working with emotional intelligence*. New York, NY: Bantam Books.

Gorman, M. (2001/2002). Turning students into ethical professionals. *IEEE Technology and Society Magazine, 20*(4), 21–27.

Graham, R. (2012). *Achieving excellence in engineering education: The ingredients of successful change*. Royal Academy of Engineering, Massachusetts Institute of Technology.

Grayson, L. (1978). On a methodology for curriculum design. *Engineering Education, 69*(3), 285–295.

Hardin, R. (1996). Trustworthiness. *Ethics, 107*(1), 26–42.

Hargroves, K. and Smith, M. H. (2005). *The Natural Advantage of Nations (Vol. I): Business Opportunities, Innovation and Governance in the 21st Century*. The Natural Edge Project (TNEP). London: Earthscan. Available at http://www.naturaledgeproject.net/NAONChapter1.4.aspx

Harris, C. E. Jr., Davis, M., Pritchard, M. S. and Rabins, M. J. (1996). Engineering ethics: What? why? how? and when? *Journal of Engineering Education, 85*(2), 93–96.

Harrisberger, L. (1976). *Experiential learning in Engineering Education*. Washington, DC: American Society for Engineering Education.

Haws, E. D. (2001). Ethics instruction in engineering education: A (mini) meta-analysis. *Journal of Engineering Education, 90*(2), 223–231.

Heitmann, G. (2005). Challenges of engineering education and curriculum development in the context of the Bologna process. *European Journal of Engineering Education, 30*(4), 447–458, Dec 2005.

Herkert, J. R. (2000). Engineering ethics education in the USA: Content, pedagogy and curriculum. *European Journal of Engineering Education, 25*(4), 303–313.

Heywood, J. (2005). *Engineering education: Research and development in curriculum and instruction*. Institute of Electrical and Electronics Engineers.

Hirst, G., Mann, L., Bain, P., Pirola-Merlo, A. and Richver, A. (2004). Learning to lead: The development and testing of a model of leadership learning. *The Leadership Quarterly, 15*(3), 311–327.

Imai, M. (1997). *Gemba Kaizen: A common sense, low-cost approach to management*. New York, NY: The Kaizen Institute, McGraw-Hill Inc.

Johnson, B. C., Manyika, J. M. and Yee, L. A. (2005). The next revolution in interactions. *The McKinsey Quarterly: The Online Journal of McKinsey & Co.*, 4. Retrieved November 4, 2006 from http://www.mckinseyquarterly.com/article_page.aspx?ar=1690&L2=18&L3=30&srid=6&gp=1

Jonassen, D. and Land, S. (2000). *Theoretical foundations of learning environments*. Mahwah, NJ: Lawrence Erlbaum.

Kail, R. V. (2004). Cognitive development includes global and domain-specific processes. *Merrill-Palmer Quarterly, 50,* 445–455.

Kanungo, R. N. (2001). Ethical values of transactional and transformational leaders [Electronic version]. *Canadian Journal of Administrative Sciences, 18*(4), 257–265.

Kedro, J. (2004). When the puzzle is complete. *Principal Leadership, 4*(8), 28–32.

King, R. (2008). Addressing the Supply and Quality of Engineering Graduates for the New Century, the Australian Learning and Teaching Council (formerly the Carrick Institute for Learning and Teaching in Higher Education), Sydney, pp. 24–29.

Kirkpatrick, A. T. and Danielson, S. (2011). Industry-related recommendations of the ASME Vision 2030 Task Force 'Creating the Future of ME Education'. *2011 International Leadership Summit on Mechanical/Multi-disciplinary Engineering Education*. Hong Kong, 26–29 September.

Knowles, M. (1990). *The adult learner. A neglected species, 4th Edition*. Houston: Gulf Publishing.

LaHote, D. (2005). A3 Story board. PDCA Story boards (A3s).

Lewin, K. (1946). Action research and minority problems. *Journal of Social Issues, 2,* 34–46.

Liker, J. (2004). *The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer*. McGraw-Hill.

McCauley, C. and Wakefield, M. (2006). Talent management in the 21st century: Help your company find, develop, and keep its strongest workers. *The Journal for Quality and Participation, 29*(4), 4–7, 39. Retrieved 3 March 2011, from ABI/INFORM Global. (Document ID: 1214836601).

McCormick, N. (2011). Mechanical Engineering Education for the 21st century: An Industry Perspective. *2011 International Leadership Summit on Mechanical/Multi-disciplinary Engineering Education*. Hong Kong, 26–29 September.

McKenna, M. (2007). Women in power. *The New England Journal of Public Policy, 22*(1), 7–16.

McManus, H. L., Rebentisch, E., Murman, E. M. and Stanke, A. (2007). Teaching Lean Thinking principles through hands-on simulations. *Proceedings of the 3rd International CDIO Conference*. MIT, Cambridge, Massachusetts, 11–14 June.

Mills, J. and Treagust, D. (2003). Engineering Education – is problem-based or project-based learning the answer? *Australasian Journal of Engineering*

Education. Available online at http://www.aaee.com.au/journal/2003/mills_treagust03.pdf

Minoura, T. (2003). The "Thinking" Production System: TPS as a winning strategy for developing people in the global manufacturing environment. [Acessed 2003-04-21]. On-line at http://www.toyotageorgetown.com/tps.asp

Molenda, M. (2002). *A new framework for teaching in the cognitive domain*. Syracuse, NY: ERIC Clearinghouse on Information and Technology. (ERIC Document No. ED470983).

Monden, Y. (1998). *Toyota Production System - an integrated approach to just-in-time*. 3rd Edition, Engineering and Management Press, Institute of Industrial Engineers.

Moreira, F., Alves, A. C. and Sousa, R. M. (2010). Towards Eco-efficient Lean Production Systems. IFIP Advances in Information and Communication Technology, Volume 322, Balanced Automation Systems for Future Manufacturing Networks, pp. 100–108, Available from: http://www.springerlink.com/content/v6181026252x1025

National Research Council (1998). *Visionary manufacturing challenges for 2020*. Committee on Visionary Manufacturing Challenges, Board on Manufacturing and Engineering Design, Commission on Engineering and Technical Systems. National Academy Press, p. 22. Retrieved from: http://search.nap.edu/readingroom/books/visionary/index.html

Newberry, B. (2004). The dilemma of ethics in engineering education. *Science and Engineering Ethics, 10*, 343–351.

Newberry, B., Austin, K., Lawson, W., Gorsuch, G. and Darwin, T. (2011). Acclimating international graduate students to professional engineering ethics. *Science & Engineering Ethics, 17*, 171–194.

Nguyen, D. and Pudlowski, Z. (2007). *Issues and challenges in engineering education and future outlook of the engineering profession in Australia*. Monash University Research Publications.

Nguyen, D. and Pudlowski, Z. (2004). *The need for the modernisation of environmental engineering education: A response to current problems and challenges*. Monash University Research Publications, Collection.

Nilsson, St. (2010). On the meaning of higher education in professional practice: The case of physicians and engineers. *Journal of Education and Work, 23*(3), 255–274.

Penney, S. H., Brown, J. and Oliviera, L. M. (2007). Numbers are not enough: Women in higher education in the 21st century. *The New England Journal of Public Policy, 22*(1), 167–182.

Piaget, J. (1972). *Psychology and epistemology: Towards a theory of knowledge*. Harmondsworth: Penguin. [Psychologie et epistémologie] (1970).

Policy Studies Institute, PA Consulting Group, and the University of Bath Centre for Research in Education and the Environment (2008). HEFCE Strategic Review of Sustainable Development in Higher Education in England, Report to the HEFCE, January 2008, London.

Poon, P. (2011). Major strategies in shaping Mechanical Engineering Education. *2011 International Leadership Summit on Mechanical/Multi-disciplinary Engineering Education*. Hong Kong, 26–29 September.

Prabhakar, G. P. (2005). An empirical study reflecting the importance of transformational leadership on project success across twenty-eight nations [Electronic version]. *Project Management Journal, 36*(4), 53–60.

Queta, V., Alves, A. C. and Costa, N. (2014). Project of ergonomic shelves for supermarkets in a Lean work environment. *Proceedings of the International Symposium on Occupational Safety and Hygiene – SHO 2014, Guimarães*, SPOSHO 2014, ISBN 978-989-98203-2-6.

Resende, V., Alves, A. C., Baptista, A. and Silva, A. (2014). Financial and human benefits of Lean Production in the plastic injection industry: An action research study. *International Journal of Industrial Engineering and Management, 5*(2), 61–75. http://www.iim.ftn.uns.ac.rs/casopis/volume5/ijiem_vol5_no2_2.pdf

Ribeiro, L., Alves, A. C., Moreira, F. and Ferreira, M. (2013). Applying standard work in a paint shop of wood furniture plant: A case study. *Proceedings of 22nd International Conference on Production Research* (ICPR 22), 28th July–1st August, Iguassu Falls, Brazil.

Richmond, A. (Lead Author), Zencey, E. (Contributing Author), Cleveland, C. (Topic Editor). Environmental kuznets curve. In: *Encyclopedia of Earth*. Eds. C. J. Cleveland (Washington, DC: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth 4 December 2007; Last revised Date 4 December 2007; Retrieved 8 October 2011 <http://www.eoearth.org/article/Environmental_kuznets_curve>

Ridgeway, C. L. (1999). The gender system and interaction. *Annual Review of Sociology, 25*, 191–216.

Rokkjæ, O., Nørgaard, B., Jensson, P., Schinner, H.-D., Appold, W., Byrne, T., Nolan, D., Polman, T., Schut, A., Bayard, O. and Areskoug, M. (2011). Industrial Engineering Standards in Europe - industry needs versus education. In *WEE2011*, Eds. J. Bernardino and J. C. Quadrado. Lisbon, Portugal, 27–30 September.

Rosenberg, S. Z. (2008). Uncommon women: Moving past tokenism and box checking opens doors to more diversity [online]. *Directorship: Boardroom Intelligence*. Retrieved 20 January 2009 from http://www.directorship.com/uncommon-women/

Rosener, J. B. (1990). Ways women lead [online]. *Harvard Business Review, 68*(6), Retrieved May 2008 from Business Source Premier http://web.ebscohost.com.huaryu.kl.oakland.edu/ehost/detail?vid=5&hid=7&sid=2562cc14-9a55-4c82-8660-8644991bb151%40sessionmgr9&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=buh&AN=9012241294

Rother, M. and Shook, J. (2003). *Learning to see value-stream mapping to create value and eliminate muda*. Brookline: The Lean Enterprise Institute.

Savolainen, T. I. (1999). Cycles of continuous improvement - realizing competitive advantages through quality. *International Journal of Operations & Production Management, 19*(11), 1203–1222.

Scott, K. A. and Brown, D. J. (2006). Female first, leader second? Gender bias in the encoding of leadership behavior. *Leadership Behavior and Human Decision Processes, 101*(2), 230–242.

Senge, P. M. (1990). *The fifth discipline: The art and practice of the learning organization*. New York: Doubleday.

Senge, P. M. (2006). *The fifth discipline: The art and practice of the learning organization*. London; Sydney: Random House.

Sergiovanni, T. J. (1992). *Moral leadership: Getting to the heart of school improvement*. San Francisco: Jossey-Bass.

Sheppard, S. D., Macatangy, K., Colby, A. and Sullivan, W. M. (2008). *Educating engineers: Designing for the future of the field*. The Carnegie Foundation of the Advancement of Teaching.

Shook, J. (2008). *Managing to learn – using the A3 management process to solve problems, gain agreement, mentor and lead*. Lean Enterprise Institute.

Spear, S. J. and Bowen, H. K. (1999). Decoding the DNA of the Toyota Production System. *Harvard Business Review, 77*, 97–106.

Spear, S. J. (2004). Learning to lead at Toyota. *Harvard Business Review*, 78–86, May.

Spears, S. (2011, January 9). Creative experimentation: Developing a skill critical for managing complex operating systems [Webinar]. *MIT SDM Systems Thinking Webinar Series*.

Stephan, K. D. (1999). A survey of ethics-related instruction in U. S. engineering programs. *Journal of Engineering Education, 88*(4), 459–464.

Sterman, J. (2000). *Business dynamic systems thinking and modeling for a complex world*. New York, NY: McGraw-Hill.
Sterman, J. D. (2001). System dynamics modeling: Tools for learning in a complex world. *California Management Review, 43*(4), 8–25. Retrieved 11 April 2011, from ABI/INFORM Global. (Document ID: 82668655). http://proquest.umi.com/pqdlink?vinst=PROD&fmt=6&startpage=-1&ver=1&vname=PQD&RQT=309&did=82668655&exp=04-09-2016&scaling=FULL&vtype=PQD&rqt=309&TS=1302576861&clientId=43939
Stewart, T. A. and Raman, A. P. (2007). Lessons from Toyota's long drive. *Harvard Business Review*, 74–83.
Stodgill, R. M. (1947). *Leadership, membership and organization*. New York: Prentice Hall.
Sugimori, Y., Kusunoki, K., Cho, F. and Uchikawa, S. (1977). Toyota production system and Kanban system materialization of just-in-time and respect-for-human system. *International Journal of Production Research, 15*(6), 553–564.
Susman, G. I. and Evered, R. D. (1978). An assessment of the scientific merits of action research. *Administrative Science Quarterly, 23*, 582–603.
Suzaki, K. (1993). *The new shop floor management: empowering people for continuous improvement*. New York: Free Press.
Takeuchi, H., Osono, E. and Shimizu, N. (2008). The contradictions that drives Toyota's success. *Harvard Business Review*, 98–104, June.
Taylor, F. W. (1911). *Principles of scientific management*. New York, NY: Harper & Brothers.
The Alliance for Global Sustainability (2006). The Observatory: Status of Engineering Education for Sustainable Development in European Higher Education, EESD-Observatory, Technical University of Catalonia, Spain, p. 4, Available at: http://www.upc.edu./eesd-observatory/ (Accessed: 28 May 2010).
The Millennium Project (2009). Available at http://www.millennium-project.org/millennium/overview.html, (Accessed: 25 September 2011).
The National Academy of Engineering (2005). *Educating the engineer of 2020: Adapting engineering education to the new century*. The National Academies Press.
Thompson, M. D. (2000). Gender, leadership orientation and effectiveness: Testing the theoretical models of Bolman & Deal and Quinn. *Sex Roles, 42*(11/12), 969–992.
U.S.-EPA (2007). *The Lean and Environment Toolkit*. United States Environmental Protection Agency, available from: http://www.epa.gov/lean/

environment/toolkits/environment/resources/LeanEnviroToolkit.pdf, [accessed 21 February, 2012].

UN General Assembly (2002). Proclamation of the Decade of Education of Sustainable Development (2005–2014) – 57th Session. Available at: http://www.desd.org/ (Accessed: 28 May 2010).

UNEP (2010). Assessing the Environmental Impacts of Consumption and Production – Priority Products and Materials. International Panel for Sustainable Resource Management, UNEP Publication, Paris.

UNEP (2011). Decoupling natural resource use and environmental impacts from economic growth, A Report of the Working Group on Decoupling to the International Resource Panel. Fischer-Kowalski, M., Swilling, M., von Weizsäcker, E. U., Ren, Y., Moriguchi, Y., Crane, W., Krausmann, F., Eisenmenger, N., Giljum, S., Hennicke, P., Romero Lankao, P., Siriban Manalang, A.

UNEP, WFEO, WBCSD, ENPC (1997). Engineering Education and Training for Sustainable Development, Report of the joint UNEP, WFEO, WBCSD, ENPC Conference, Paris, France, 24–26 September 1997, Chapter 10: Appendices - IV WFEO, Survey, p. 42.

UNESCO (2010). Engineering: Issues, Challenges and Opportunities for Development. UNESCO Report.

Vicere, A. A. (2002). Where have all the leaders gone? *Employment Relations Today,* (29), 1–8. doi: 10.1002/ert.10046.

Warren, M. E. (1999). *Democracy and trust.* Cambridge: Cambridge University Press.

Washington, DC.

WCED (1987). Our Common Future [online]. Report of the World Commission on Environment and Development, United Nations. Available from: http://worldinbalance.net/intagreements/1987-brundtland.php [accessed 16 February 2012].

Weimer, M. (2002). *Learner-centered teaching. Five key changes to practice*. San Francisco, CA: Jossey-Bass.

Wilson, M. C. (2007). *Closing the leadership gap: Add women, change everything.* New York: Penguin Books. p. xii.

Womack, J., Jones D. and Roos D. (1990). *The machine that changed the world*. Rawson Associates.

Womack, J. and Jones, D. (1996). *Lean thinking*. New York, USA: Siman & Schuster.

Woods, D. R., Felder, R. M., Rugarcia, A. and Stice, J. E. (2000). The future of engineering education 3. Developing critical skills. *Chem. Eng., 34,* 108–117. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.43.5906&rep=rep1&type=pdf

World Federation of Engineering Organizations' Committee on Technology (2002). Engineers and Sustainable Development, WFEO, Germany.

Yamamoto, Y. and Bellgran, M. (2010). Fundamental mindset that drives improvements towards lean production. *Assembly Automation, 30*(2), 124–130.

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Franz-Josef Kahlen, PhD, is an Associate Professor in the Department of Mechanical Engineering at the University of Cape Town, South Africa. Prof. Kahlen's research interests are in visualization of system complexity, performance, and risks. It is highly useful to note that there is significant knowledge about systems and complex systems performance in other disciplines and professions, such as biology and medicine, economics, or air traffic control. Cross-fertilization and adaptation of such knowledge between medicine, economics, engineering, and other professions looks to be very promising approach to understanding systems and their static and dynamic responses.

Before joining the University of Cape Town, Prof. Kahlen worked as a consultant in technology and project management, applying lean engineering principles in a large number of projects with customers in optics, telecom, data storage, and biomedical engineering.

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Lean Engineering Education

Driving Content and Competency Mastery

Shannon Flumerfelt • Franz-Josef Kahlen • Anabela Alves • Anna Bella Siriban-Manalang

Recent studies by professional organizations devoted to engineering education, such as Vision 2030 (ASME) and Vision 2025 (ASCE), highlight the need for the restructuring of engineering education. Deficiencies of many engineering graduates include poor systems thinking and systems analysis skills, lack of sensitivity for sustainability issues, poorly developed problem solving skills and lack of training to work in (multi-disciplinary) teams, as well as a lack of leadership, entrepreneurship, innovation, and project management skills. The book's contents include an analysis of current shortfalls in engineering education and education related to professional practice in engineering. Further, the authors describe desirable improvements as well as advocacy for the use of lean tenets and tools to create a new future for engineering education.

This book presents, for the first time, an outside-in lean engineering perspective of how this commonly accepted and widely practiced and adapted engineering perspective can shape the direction in which the engineers of the future are trained and educated. By its very nature, lean engineering demands systems thinking and systems analysis as well as problem solving skills. In this sense, "Lean Engineering" immediately talks to sustainability of operations. Hence, this book adds to the body of knowledge regarding engineering education. It blends the perspectives and expertise of mechanical, industrial and production engineers and academics and the perspective from social sciences on the challenges encountered in engineering education. Because of the unique mix of authors, the book presents a well-rounded perspective of how lean thinking can address shortcomings in engineering education.

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