INTRODUCTION SESSIONS

The CDIO Syllabus 3.0

For cherry-picking of futureproof learning objectives

The CDIO Syllabus (version 3.0) is the answer to the question “What are the knowledge, skills and attitudes that a graduating engineer should possess?” It is collected by focus groups consisting of industry representatives, engineering faculty and other academics, university review committees, and alumni, combined with a wish list made by industry and educators.

The different competencies are categorized in 5 ‘boxes’, see the figure below, and the lists on the following pages. The list is extensive, with three levels of sub-categories. It is meant as an inspirational cherry-picking list.

Box 4:

CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

Box 1: FUNDAMENTAL KNOWLEDGE AND REASONING	Box 2: PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES	Box 3: INTERPERSONAL SKILLS
Box 5: LEADERSHIP, ENTREPRENEURSHIP AND RESEARCH		

1 FUNDAMENTAL KNOWLEDGE AND REASONING

1.1 KNOWLEDGE OF UNDERLYING MATHEMATICS AND SCIENCES

1.1.1 Mathematics (including statistics)

1.1.2 Physics

1.1.3 Chemistry

1.1.4 Biology

1.2 CORE ENGINEERING FUNDAMENTAL KNOWLEDGE

1.3 ADVANCED ENGINEERING FUNDAMENTAL KNOWLEDGE, METHODS AND TOOLS

1.4 KNOWLEDGE OF SOCIAL SCIENCES AND HUMANITIES

2 PERSONAL AND PROFESSIONAL SKILLS AND ATTRIBUTES

2.1 ANALYTIC REASONING AND PROBLEM SOLVING

2.1.1 Problem Identification and Formulation

Data (including big data) and symptoms

Assumptions and sources of bias

Issue prioritization in context of overall goals
A plan of attack (incorporating model, analytical and numerical solutions, qualitative analysis, experimentation and consideration of uncertainty)

2.1.2 Modeling

Assumptions to simplify complex systems and environment

Conceptual and qualitative models

Quantitative models and simulations

Re-usable simulation models using reference architectures

Data mining and analytics

Limitation of models used in digital tools

Diagnostic, descriptive, predictive and prescriptive models

2.1.3 Estimation and Qualitative Analysis

Orders of magnitude, bounds and trends

Tests for consistency and errors (limits, units, etc.)

The generalization of analytical solutions

2.1.4 Analysis with Uncertainty

Incomplete and ambiguous information

Probabilistic and statistical models of events and sequences

Engineering cost-benefit and risk analysis

Decision analysis

Margins and reserves

2.1.5 Solution and Recommendation

Problem solutions

Essential results of solutions and test data

Discrepancies in results

Summary recommendations
Possible improvements in the problem-solving process

2.2 EXPERIMENTATION, INVESTIGATION AND KNOWLEDGE DISCOVERY

2.2.1 Hypothesis Formulation

- Critical questions to be examined
- Hypotheses to be tested
- Controls and control groups

2.2.2 Survey of Literature

- The literature and media research strategy
- Information search and identification using library, on-line and database tools
- Sorting and classifying the primary information
- The quality and reliability of information
- The essentials and innovations contained in the information
- Research questions that are unanswered
- Citations to references

2.2.3 Experimental Inquiry

- The experimental concept and strategy
- The precautions when humans are used in experiments
- Investigations based on social science methods
- Experiment construction
- Experiment planning including design of experiments
- Test protocols and experimental procedures
- Experimental measurements
- Experimental data mining and analysis (classification, regression, correlation etc)
- Experimental data
  - Quantity, relevance, and reliability of big data information
  - Data management
    - Building data sets required to train algorithms
    - Storage, management, and re-use of research and project data
  - Experimental data vs. available models

2.2.4 Hypothesis Test and Defense

- The statistical validity of data
- The limitations of data employed
- Analysis and conclusions, supported by data
- Possible improvements in knowledge discovery process

2.3 SYSTEM THINKING

2.3.1 Thinking Holistically

Ecological and planetary systems, and how humans, societies, and artefacts (e.g. technology), are embedded in and rely on these systems

A technical (including cyberphysical) system, its function and behavior, and its elements

The social, environmental, economic, and technical context of technical systems

Human-system integration and interaction

The interactions external to the system, and the behavioral impact of the system

How systems are embedded within different domains and different scales

The system life-cycle from cradle to cradle
Transdisciplinary approaches that ensure the technical system and its social, environmental, and economic context is understood from all relevant perspectives

Acceptance of the unknown, the unexpected, the unforeseeable

Openness, tolerance of ideas and tuths different from our own

Metaphors as ways to illustrate the complexity of social problems

2.3.2 Emergence and Interactions in Systems

The abstractions necessary to define and model the entities or elements of the system

The important relationships, interactions and interfaces among elements
The functional and behavioral properties (intended and unintended) that emerge from the system, during design and operation

Evolutionary adaptation over time

Cause-effect chains, cascading effects, feedback loops, delays

Tipping points, resilience, adaptation

2.3.3 Prioritization and Focus

All factors relevant to the system in the whole

The driving factors from among the whole

Energy and resource allocations to resolve the driving issues

2.3.4 Trade-offs, Synergies, Judgment and Balance in Resolution

Tensions and factors to resolve through trade-offs

Solutions that balance various factors, resolve tensions and optimize the system as a whole

Flexible vs. optimal solutions over the system lifetime
Possible improvements in the system thinking used

2.4 ATTITUDES, THOUGHT AND LEARNING

2.4.1 Initiative and Willingness to Make Decisions in the Face of Uncertainty

Initiative taking

The needs and opportunities for initiative

Leadership in new endeavors, with a bias for appropriate action

Decisions, based on the information at hand

Development of a course of action

The potential benefits and risks of an action or decision

The recognition of one's feelings and desires related to decisions

2.4.2 Perseverance, Urgency and Will to Deliver

Sense of responsibility for outcomes

Self-confidence, courage and enthusiasm

Determination to accomplish objectives

The importance of hard work, intensity and attention to detail

Definitive action, delivery of results and reporting on actions

2.4.3 Adaptability, Resourcefulness and Flexibility

Adaptation to change

Leverage opportunities arising from the resources of the situation, group or evolving contexts

A readiness, willingness and ability to work independently

A willingness to work with others, and to consider and embrace various viewpoints
An acceptance of feedback, criticism and willingness to reflect and respond and deal with associated emotions and feelings

The balance between personal and professional life

2.4.4 Creative Thinking

Conceptualization and abstraction

Synthesis and generalization

The process of invention

Collaborative, multidisciplinary creative thinking

Computational tools for creative thinking

The role of creativity in art, science, the humanities and technology

2.4.5 Critical Thinking

Purpose and statement of the problem or issue

Assumptions

Logical arguments (and fallacies) and solutions

Reviewing and supporting evidence, facts and information

Points of view and theories

Conclusions and implications - including societal and multidisciplinary aspects

Reflection on the quality of the thinking

Question norms, practices and opinions

Reflect on one's own values, perceptions and action

2.4.6 Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration

Self-reflection - One's skills, interests, strengths and weaknesses

Reflect on willingness, effectiveness, flexibility, and motivation

Recognize one's feelings and desires and ability to deal with them

The extent of one's abilities, and one's responsibility for self-improvement to overcome important weaknesses

The importance of both depth and breadth of knowledge

Identification of how effectively and in what way one is thinking

Linking knowledge together and identifying the structure of knowledge

One's own role in the local community and (global) society

Wellbeing in a complex and changing world

2.4.7 Learning Agility, Lifelong Learning and Educating

The motivation for continued self-education

The skills of self-directed learning

Learning from experience through reflective practice

Flexibility in one's learning approaches

Enabling learning in and from others

Sharing best practices and lessons learned

Relationships with mentors and mentees

Proactively advocating and infusing technology advances

2.4.8 Time and Resource Management

Task prioritization

The importance and/or urgency of tasks

Interdependency of tasks
Efficient execution of tasks

2.5 ETHICS, EQUITY AND OTHER RESPONSIBILITIES

2.5.1 Ethics, Integrity and Social Responsibility

One's ethical standards, principles, values, and preferences

The moral courage to act on principle despite adversity

The possibility of conflict between professionally ethical imperatives

Artificial Intelligence and Ethics

Discern validity, applicability, and implications of recommendations from AI

Prepared for debates about values, ethics, morality

A commitment to service

Truthfulness, bias, data manipulation

A commitment to help others and society more broadly and to contribute to transformations for sustainability

Concepts of justice, fairness, and responsibility

Analysis, judgement, and argumentation in ethical issues

The precautionary principle

2.5.2 Professional Behavior

A professional bearing

Professional courtesy

International customs and norms of interpersonal contact

Professional conduct in social media

2.5.3 Proactive Vision and Intention in Life

A personal vision for one's future

Job crafting

Aspiration to exercise his/her potentials as a leader

One's portfolio of professional skills

Considering one's contributions to the local community and (global) society

Inspiring others

Continually evaluate and further motivate one's actions

2.5.4 Staying Current on the World of Engineering

The potential impact of new scientific discoveries on engineering
The social, environmental, economic, and technical impact of new technologies and innovations, positive as well as negative

A familiarity with current practices/technology in engineering

The links between engineering theory and practice

The links between engineering and other disciplines, including social sciences and humanities

2.5.5 Equity, Diversity and Inclusiveness

A commitment to treat others with equity and justice, including gender, race, ethnicity, religion, etc.

Global and intergenerational equity and justice

Embracing diversity and inclusiveness in groups and workforce

Empathize with others

Cultural differences in concepts of time, future, development, and progress

2.5.6 Trust and Loyalty

Loyalty to one's colleagues and team

Recognizing and emphasizing the contributions of others

Working to make others successful

3 INTERPERSONAL SKILLS: COLLABORATION, TEAMWORK AND COMMUNICATION

3.1 TEAMWORK AND COLLABORATION

3.1.1 Working in teams

Forming teams, assigning roles and responsibilities

Setting goals and objectives, planning, scheduling the work

Setting norms (ground rules, respect and diversity, confidentiality, accountability)
Coordination and management of team process: meetings - physical and distance; communication - information, listening, feedback; decision-making; documentation and reporting; representing the team

Team membership and leadership (delegating, facilitating, directing, supporting, coaching)

Handling diverse perspectives and conflicts

Creativity, empowerment and motivation (incentives, recognition)

Strategies for assessment and reflection to develop processes, team and members

3.1.2 Multi-perspective Collaboration

Facilitation of diversity and inclusiveness in group processes across cultures, social groups, communities

Using knowledge and methods from other disciplines outside engineering in addressing problems

Multidisciplinary vs. cross-disciplinarity vs. interdisciplinary vs. transdisciplinary

3.1.3 Stakeholder Engagement

Co-creation and stakeholder engagement techniques

Incorporation of diverse, underrepresented, and conflicting stakeholders' input

Understand the influence of values on stakeholder actions and activities

3.1.4 Establishing Diverse Connections and Networking

Appreciating those with different skills, cultures or experiences

Engaging and connecting with diverse individuals

Building extended social networks, in person and digital

Activating and using networks to achieve goals

3.2 COMMUNICATIONS

3.2.1 Communications Strategy

The communication situation

Communications objectives

The needs and character of the audience

The communication context

The appropriate combination of media

A communication style (proposing, reviewing, collaborating, documenting, teaching)

The content and organization

3.2.2 Communications Structure

Logical, persuasive arguments

The appropriate structure and relationship amongst ideas

Relevant, credible, accurate supporting evidence

Conciseness, crispness, precision and clarity of language

Rhetorical factors (e.g. audience bias)

Cross-disciplinary cross-cultural and international communications

3.2.3 Written Communication

Writing with coherence and flow

Writing with correct spelling, punctuation and grammar

Formatting the document

Technical writing

Various written styles (informal, formal memos, reports, resume, etc.)

Reflective writing (writing to learn)

3.2.4 Digital Communication

Preparing multimedia presentations (video, immersive technologies)

The norms associated with the use of social media, e-mail, and online meetings

3.2.5 Graphical Communications

Sketching and drawing

Construction of tables, graphs, charts, data visualization

Formal technical drawings and renderings

Use of digital tools for graphical communication

3.2.6 Oral Presentation

Preparing presentations and supporting media with appropriate language, style, timing and flow

Appropriate nonverbal communications (gestures, eye contact, poise)

Answering questions effectively

Pitching

3.2.7 Inquiry, Listening and Dialog

Listening carefully to others, with the intention to understand

Asking thoughtful questions of others

Processing diverse points of view

Constructive dialog

Recognizing ideas that may be better than your own

Body language and the silent voice

3.2.8 Negotiation, Compromise and Conflict Resolution

Identifying potential disagreements, tensions or conflicts

Negotiation to find acceptable solutions

Reaching agreement without compromising fundamental principles

Diffusing conflicts

Identify value differences and trade-offs, e.g., among different courses of actions

3.2.9 Advocacy

Clearly explaining one's point of view

Explaining how one reached an interpretation or conclusion

Assessing how well you are understood

Adjusting approach to advocacy on audience characteristics

3.3 COMMUNICATIONS IN FOREIGN LANGUAGES

3.3.1 Communications in English

3.3.2 Communications in Languages of Regional Commerce and Industry

3.3.3 Communications in Other Languages

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4 CONCEIVING, DESIGNING, IMPLEMENTING AND OPERATING SYSTEMS IN THE ENTERPRISE, SOCIETAL AND ENVIRONMENTAL CONTEXT – THE INNOVATION PROCESS

4.1 EXTERNAL, SOCIETAL AND ENVIRONMENTAL CONTEXT

4.1.1 Roles and Responsibility of Engineers

The goals and roles of the engineering profession

The responsibilities of engineers to society and a sustainable future

One's own role and impact as a responsible engineer in promoting a sustainable society

4.1.2 The Impact of Engineering on Society and the Environment

The impact of engineering on the environmental, social, knowledge and economic systems in modern culture

Using interdisciplinary knowledge and skills to understand and address complex problems

Assessment of sustainability effects/impacts

Measures and strategies for mitigating/eliminating negative impacts and promoting/enhancing positive impacts

4.1.3 Society's Regulation of Engineering

The role of society and its agents to regulate engineering

The way in which legal and political systems regulate and influence engineering

How professional societies license and set standards

How intellectual property is created, utilized and defended

Protection of personal data and information (GDPR etc)

4.1.4 The Historical and Cultural Context

The diverse nature and history of human societies as well as their literary, philosophical and artistic traditions

The history of technological innovation and how society and technology have co-evolved

Learning from historical and cultural contexts about sustainability issues and potential solutions

4.1.5 Contemporary Issues and Values [3j]

The important contemporary political, social, legal and environmental issues and values

The processes by which contemporary values are set, and one's role in these processes

The mechanisms for expansion and diffusion of knowledge

Definitions and principles of sustainability and sustainable development

4.1.6 Visions of the Future

Concepts about the future, including long-term, short-term; possible, probable, plausible and desirable

Scenario construction, forecasting, backcasting and visioning

Visions for a sustainable future for society and for one's profession

4.1.7 Developing a Global and International Perspective

The internationalization of human activity

The similarities and differences in the political, social, economic, business and technical norms of various cultures

International and intergovernmental agreements and alliances

Unofficial global communities and network

Postcolonialism

Consequences of technical systems in a global perspective

One's own role and possibilities to have a global impact

4.2 ENTERPRISE AND BUSINESS CONTEXT

4.2.1 Appreciating Different Enterprise Cultures

The differences in process, culture, and metrics of success in various enterprise cultures:

Corporate vs. academic vs. governmental vs. non-profit/NGO

Market vs. policy driven vs. value driven

Large vs. small

Centralized vs. distributed

Research and development vs. operations

Mature vs. growth phase vs. entrepreneurial

Longer vs. faster development cycles

With vs. without the participation of organized labor

Proactive vs. reactive in a transformation towards a sustainable future

4.2.2 Enterprise Stakeholders, Strategy and Goals

The stakeholders and beneficiaries of an enterprise (owners, employees, customers, etc.)

People in other contexts, future generations, and other species, as stakeholders

Obligations to stakeholders

The mission, scope and goals of the enterprise

Enterprise strategy and resource allocation

An enterprise's core competence and markets

Key alliances and supplier relations

4.2.3 Technical Entrepreneurship

Entrepreneurial opportunities that can be addressed by technology

Technologies that can create new products, systems, and services for sustainability

Commercial value of data and information

Entrepreneurial finance and organization

4.2.4 Working in Organizations

The function of management

Various roles and responsibilities in an organization

The roles of functional and program organizations

Working effectively within hierarchy and organizations

Change, dynamics and evolution in organizations

4.2.5 Working in International Organizations

Culture and tradition of enterprise as a reflection of national culture

Equivalence of qualifications and degrees

Governmental regulation of international work

4.2.6 New Technology Development and Assessment

The research and technology development process

Identifying and assessing emerging technologies, that…

might disrupt the business rules, processes, and models,

can contribute to sustainable development

can give rise to unintended and unwanted consequences

Technology development roadmaps

Intellectual property regimes and patents

Open innovation

4.2.7 Engineering Project Finance and Economics

Financial and managerial goals and metrics

Project finance – investments, return, timing

Financial planning and control

Impact of projects on enterprise finance, income and cash

4.3 CONCEIVING, SYSTEM ENGINEERING AND MANAGEMENT

4.3.1 Understanding Societal and Planetary Goals and Constraints

Needs vs. wants with respect to justice and sufficiency
Conditions for operating within planetary boundaries and social foundations for human societies

Power, politics, authority in strategy building and change

Theories and dynamics of change (e.g., behaviour change, societal transitions)
Barriers including obstacles, inertia, path dependencies

4.3.2 Understanding Needs and Setting Goals

Needs and opportunities

Customer needs, and those of the market

Capture user experience and use case scenarios

Opportunities that derive from new technology or latent needs

Environmental needs

Factors that set the context of the system goals

Enterprise goals, strategies, capabilities, and alliances

Competitors and benchmarking information

Ethical, social, environmental, legal and regulatory influences

The probability of change in the factors that influence the system, its goals, and resources available

System goals and requirements

The language/format of goals and requirements

Initial target goals (based on needs, opportunities, and other influences)

System performance metrics

Requirement completeness and consistency
Allocation of margins, responding to change and handling unknown or unanticipated requirements during the lifecycle of a design

4.3.3 Defining Function, Concept and Architecture

Necessary system functions (and behavioral specifications)

System concepts

Incorporation of the appropriate level of technology

Trade-offs among and recombination of concepts

High-level architectural form and structure
The decomposition of form into elements, assignment of function to elements, and definition of interfaces

4.3.4 System Engineering, Modeling and Interfaces

Appropriate models of technical performance and other attributes

Consideration of implementation and operations

Life cycle value and costs (design, implementation, operations, opportunity, etc.)

Trade-offs among various goals, function, concept and structure, iteration until convergence
'Trusted' system design (addressing aspects of cyber security, data privacy, consumer understanding, transparency)
System designs that are non-deterministic, that continue to learn and modify themselves during operation (e.g., critical decisions that are allocated to autonomous vehicles).

Plans for interface management

4.3.5 Development Project Management

Waterfall, agile and scrum project management models

Project control for cost, performance and schedule

Appropriate transition points and reviews

Configuration management and documentation

Performance compared to baseline

Earned value recognition

The estimation and allocation of resources

Risks and alternatives

Possible development process improvements

4.3.6 Product information and knowledge management

Capturing data and crafting a design in a digital environment.
Model-based systems engineering, using digital representations of the system, simulations, and immersive technologies

Digital SE as part of digital end-to-end business
Modeling, visualization and digital representation of system designs and end-to-end solutions

Digital twins
Knowledge sharing; data stewardship, open data sets

4.4 DESIGNING

4.4.1 The Design Process

Requirements for each element or component derived from system level goals and requirements

Alternatives in design

The initial design

Life cycle consideration and responsibility in design (economic, social, environmental)

Experimental prototypes and test articles in design development

Appropriate optimization in the presence of constraints

Iteration until convergence

The final design

Accommodation of changing requirements
Fast generation of multiple design options and evaluating them instantly in a virtual environment ('Optioneering')
What-if scenario analysis

4.4.2 The Design Process Phasing and Approaches

The activities in the phases of system design (e.g. conceptual, preliminary and detailed design)
Process models appropriate for particular development projects (agile, waterfall, spiral, concurrent, set-based design, etc.)

The process for single, platform and derivative products

4.4.3 Utilization of Knowledge in Design

Technical and scientific knowledge
Modes of thought (problem solving, inquiry, system thinking, creative and critical thinking)
Prior work in the field, standardization and reuse of designs (including reverse engineering and refactoring, redesign)

Design knowledge capture

4.4.4 Disciplinary Design

Appropriate techniques, digital tools and processes

Design tool calibration and validation

Quantitative analysis of alternatives

Modeling, simulation, visualization and test
Analytical refinement of the design

4.4.5 Multidisciplinary Design

Interactions between disciplines

Dissimilar conventions and assumptions

Differences in the maturity of disciplinary models

Multidisciplinary design environments (physical and digital)

4.4.6 Design for Performance, Sustainability, Safety, Aesthetics, Operability and Other Objectives

Design for:

Performance, quality, robustness, life cycle costs and value

Sustainability

Life cycle perspective including envuronmental, social and economic aspects

Circular economy
Systems perspective including enviironmental, social, and edonomic aspects

Efficient and reduced use of energy, materials, and land

Reduce/eliminate environmental impact

Reusability, remanufacturing, recycling, retirement

Safety and sercurity

Aesthetics

Implementation, verification, test

Operations

Human factors, interaction and supervision
Delivery channels and service models (e.g. cloud, software-as-a-service, product-service systems, …O)

Reliability, availability, maintainability, dependability, failure mode, and effects analysis

Evolution, product improvement

4.5 IMPLEMENTING

4.5.1 Designing a Sustainable Implementation Process

The goals and metrics for implementation performance, cost and quality

The implementation system design:

Task allocation and cell/unit layout

Workflow

Considerations for human user/operators

Cyberphysical factory design

Consideration of sustainability

4.5.2 Hardware Manufacturing Process

The manufacturing of parts

The assembly of parts into larger constructs

Tolerances, variability, key characteristics and statistical process control

4.5.3 Software Implementing Process

The break down of high-level components into module designs (including algorithms and data structures)

Algorithms (data structures, control flow, data flow)

The programming language and paradigms

The low-level design (coding)

The system build

4.5.4 Hardware Software Integration

The integration of software in electronic hardware (size of processor, communications, etc.)

The integration of software with sensor, actuators and mechanical hardware

Hardware/software function and safety
Cyberphysical systems

4.5.5 Test, Verification, Validation and Certification

Test and analysis procedures (hardware vs. software, acceptance vs. qualification)

The verification of performance to system requirements

The validation of performance to customer needs
The validation of system design behavior, performance and safety of system designs with "learned" behaviors.

The certification to standards

4.5.6 Implementation Management

The organization and structure for implementation

Sourcing and partnering

Supply chains and logistics

Control of implementation cost, performance and schedule

Quality assurance

Human health and safety

Environmental security

Possible implementation process improvements

4.6 OPERATING

4.6.1 Designing and Optimizing Sustainable and Safe Operations

The goals and metrics for operational performance, cost and value

Sustainable operations

Safe and secure operations

Operations process architecture and development

Operations (and mission) analysis and modeling

4.6.2 Training and Operations

Training for professional operations:

Simulation

Instruction and programs

Procedures

Education for consumer operation

Operations processes

Operations process interactions

4.6.3 Supporting the System Life Cycle

- Maintenance and logistics
- Life cycle performance and reliability
- Life cycle value and costs (economic, social, environmental)
- Feedback to facilitate system improvement
- Continuous development

4.6.4 System Improvement and Evolution

- Pre-planned product improvement
- Improvements based on needs observed in operation
- Evolutionary system upgrades
- Contingency improvements/solutions resulting from operational necessity

4.6.5 Disposal, End-of-Life, and Circularity

- The end of useful life
- Disposal options
- Residual value at life-end
- Waste hierarchy (reduce, reuse, repair, recycle, recover, disposal)
- Environmental and social considerations and constraints for disposal
- Circularity

4.6.6 Operations Management

- The organization and structure for operations
- Partnerships and alliances
- Control of operations cost, performance and scheduling
- Quality and safety assurance
- Possible operations process improvements
- Life cycle management
- Human health and safety
- Environmental security

5 LEADERSHIP, ENTREPRENEURSHIP AND RESEARCH

These expansions of the core CDIO Syllabus are provided as a resource for programs that seek to respond to stakeholder expressed needs in the areas of Engineering Leadership and Entrepreneurship. Some topics, such as Engineering Research may also be expected in master's degree CDIO programs.

5.1 LEADING ENGINEERING ENDEAVORS

Engineering Leadership builds on factors already included above, including:

- **Personal skills and attributes** including topics in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Interpersonal skills** including topics in Teamwork and Collaboration (3.1), Communications (3.2) and potentially Communications in Foreign Languages (3.3)
- **Conceiving, designing, implementing and operating systems skills**, including topics in External , Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3).

5.1.1 Identifying the Issue, Problem or Paradox Paradox (which builds on Understanding Needs and Setting Goals 4.3.2)

Synthesizing the understanding of needs or opportunities (that relate to technical systems)

Clarifying the central issues

Framing the problem to be solved

Identifying the underlying paradox to be examined

5.1.2 Thinking Creatively and Communicating Possibilities Possibilities (which builds on and expands Creative Thinking 2.4.4)

How to create new ideas and approaches
New visions of technical systems that meet the needs of customers and society

Communicating visions for products and enterprises

Compelling visions for the future

5.1.3 Defining the Solution (which builds on and expands Understanding Needs and Setting Goals 4.3.2)

The vision for the engineering solution

Achievable goals for qual i ty performance, budget and schedule

Consideration of customer and beneficiary

Consideration of technology options
Consideration of regulatory, political and competitive forces

5.1.4 Creating New Solution Concepts (which builds on and expands 4.3.2 and 4.3.3)

Setting requirements and specifications

The high-level concept for the solution

Architecture and interfaces

Alignment with other projects of the enterprise

Alignment with enterprise strategy, resources and infrastructure

5.1.5 Building and Leading an Organization and Extended Organization Organization (which builds on 4.2.4 and 4.2.5)

Recruiting key team members with complementary skills

Start-up of team processes, and technical interchange

Defining roles, responsibilities and incentives

Leading group decision-making

Assessing group progress and performance

Building the competence of others and succession

Partnering with external competence
Continuous self-evaluation in relation to collaboration, teamwork and leadership

Ability to show leadership that recognizes feelings and varying desires

5.1.6 Planning and Managing a Project to Completion

Plans of action and alternatives to deliver completed projects on time

Deviation from plan, and re-planning

Managing human, time, financial and technical resources to meet plan

Program risk, configuration and documentation

Program economics and the impact of decisions on them

Interfaces to program and project portfolio management in large-scale environments
Continually evaluate and further motivate one's actions in managing a project and its members and stakeholders

5.1.7 Exercising Project/Solution Judgment and Critical Reasoning Reasoning (which builds on 2.3.4, 2.4.4, 2.4.5, 2.5.3)

Making complex technical decisions with uncertain and incomplete information

Questioning and critical ly evaluating the decisions of others

Corroborating inputs from several sources

Evaluating evidence and identifying the val idi ty of key assumptions

Understanding alternatives that are proposed by others

Judging the expected evolution of al l solutions in the future

5.1.8 Innovation – the Conception, Design and Introduction of New Goods and Services

From research to readiness for industrial application and commercialization

Designing and introducing new goods and services to the marketplace

Designing solutions to meet customer and societal needs
Designing solutions with the appropriate balance of new and existing technology

Robust, flexible and adaptable products

Consideration of current and future competition

Validating the effectiveness of the solution

5.1.9 Invention – the Development of New Devices, Materials or Processes that Enable New Goods and Services

Science and technology basis and options

Imagining possibilities
Inventing a practical device or process that enables a new product or solution

Adherence to intellectual property regimes

5.1.10 Implementation and Operation – the Creation and Operation of the Goods and Services that will Deliver Value

Leading implementing and operating

Importance of quality

Safe operations

Operations to deliver value to the customer and society

5.2 ENGINEERING ENTREPRENEURSHIP

- Engineering Entrepreneurship includes by reference all of the aspects of Societal and Enterprise Context (4.1 and 4.2), all of the skills of Conceiving, Designing, Implementing and Operating (4.3 – 4.6) and all of the elements of Engineering Leadership (5.1).

5.2.1 Company Founding, Formulation, Leadership and Organization

Creating the corporate entity and financial infrastructure

Team of supporting partners (bank, lawyer, accounting, etc.)

Consideration of local labor law and practices

The founding leadership team

The initial organization

The board of the company
Advisors to the company

5.2.2 Business Plan Development

- A need in the world that you will fill
- A technology that can become a product
- A team that can develop the product
- Plan for development
- Uses of capital
- Liquidity strategy

5.2.3 Company Capitalization and Finances

- Capital needed, and timing of need (to reach next major milestone)
- Investors as sources of capital
- Alternative sources of capital (government, etc.)
- Structure of investment (terms, price, etc.)
- Financial analysis for investors
- Management of finances
- Expenditures against intermediate milestones of progress

5.2.4 Innovative Product Marketing

- Size of potential market
- Competitive analyses
- Penetration of market
- Product positioning
- Relationships with customers
- Product pricing
- Sales initiation
- Distribution to customers

5.2.5 Conceiving Products and Services around New Technologies

- New technologies available
- Assessing the readiness of technology
- Assessing the ability of your enterprise to innovate based on the technology
- Assessing the product impact of the technology
  - Incremental, architectural, radical/disruptive
- Accessing the technologies though partnerships, licenses, etc.
- A team to productize the technology

5.2.6 The Innovation System, Networks, Infrastructure and Services

Relationships for enterprise success

Mentoring of the enterprise leadership

Supporting financial services

Investor networks

Suppliers

5.2.7 Building the Team and Initiating Engineering Processes (conceiving, designing, implementing and operating)

Hiring the right skill mix

Technical process startup

Building an engineering culture

Establishing enterprise processes

5.2.8 Managing Intellectual Property

IP landscape for your product or technology

IP strategy – offensive and defensive

Filing patents and provisional patents

IP legal support

Entrepreneurial opportunities that can be addressed by technology

Technologies that can create new products and systems

Entrepreneurial finance and organization

5.3 RESEARCH

Research builds on factors already included above, including topics in:

- **Personal and professional skills and attributes, including topics** in Attitudes, Thought and Learning (2.4), and in Ethics, Equity and Other Responsibilities (2.5)
- **Interpersonal skills**, including topics in Teamwork and Collaboration (3.1), Communication (3.2) and potentially Communications in Foreign Languages (3.3)
- **Conceiving, designing, implementing and operating systems skills**, including topics in Societal and Environmental Context (4.1), Enterprise and Business Context (4.2) Conceiving, Systems Engineering and Management (4.3) and System Thinking (2.3)

5.3.1 Identification of needs, structuring and planning of research projects

Identifying relevant research problems

Reviewing and synthesizing relevant previous work
Specifying the aims with respect to sustainability and various stakeholders' needs

Selecting research approach and methodology

Designing and structuring the project

5.3.2 Execution of research

- Performing empirical and theoretical work
- Documenting research process and findings
- Analyzing results
- Drawing appropriate conclusions, acknowledging limitations

5.3.3 Presentation and evaluation of research

- Reporting the work in a coherent manuscript
- Explaining what makes the work trustworthy and accurate
- Relating the work with previous work
- Acknowledging the work of others
- Discussing implications of the work

5.3.4 Research ethics

- Safeguarding the quality of the research
- Honesty in reporting the research
- Accountability for research from idea to publication
- Respect for colleagues, research participants, society and environment