Report

A point of reference in curriculum-design/development for disciplinary quality assurance in university education—mechanical engineering

August 19, 2013

Sectional Committee on the Study of a Point of Reference in Mechanical Engineering

Committee on Mechanical Engineering, Science Council of Japan

This report is the results of deliberations of the Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on Mechanical Engineering, Science Council of Japan. This is the English translation rendered by the Sectional Committee in cooperation with the National Institute for Educational Policy Research.

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Executive Summary

1 Background

In May 2008, the Science Council of Japan (SCJ) received from the Director-General, Higher Education Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT) a request addressed to the President of the SCJ entitled "Deliberations regarding the direction of disciplinary quality assurance in university education." The SCJ thereupon set up a task-specific committee in June of the same year called the "Study Committee on the Direction of Disciplinary Quality Assurance in University Education," carried out several deliberations, drafted the "Direction of Disciplinary Quality Assurance in University Education" in July 2010 in response to MEXT's request, and delivered it to MEXT in August of the same year.

In its response, the SCJ proposed developing points of reference in disciplinary curriculum-design and development as a method of disciplinary quality assurance. After delivering the response, the SCJ proceeded to develop points of reference in several areas. Since a point of reference in mechanical engineering has been completely organized, the SCJ wishes to release it so that it can be used in such organizations as universities providing curricula related to the field.

2 Overview

(1) Definition of mechanical engineering

Mechanical engineering consists of natural (epistemological) sciences and design sciences (sciences for design) related to machines with the capability of converting energy and information given from the outside into useful functions such as movement, force, and information. The epistemological science underpinning it is "mechanics," and design science is required for realizing functionality harmonized into a whole through the synthesis of individual elements. Since mechanical engineering deals with diverse functions, it is closely related to many other areas of natural sciences, and at the same time, as it provides the basic knowledge and wisdom in human life within society;, collaboration with other fields including the humanities and social sciences is therefore important.

(2) Role and characteristics specific to mechanical engineering

The role of mechanical engineering is to provide a systematic knowledge of mechanics, which is part of the fundamental laws that constitute nature, and demonstrate specific measures in machine technology that bring safe and reliable life and can live up to humankind's aspirations, taking environmental and resource limitations as well as cost effectiveness into consideration. Providing engineers with the feasibility and safety in design and manufacturing based on current knowledge is also the fundamental role of mechanical engineering.

"Mechanics," on which mechanical engineering is based as an epistemological science, covers a wide variety of scales and phenomena. Traditionally, there are fundamental disciplines of mechanics such as disciplines regarding the motion of a point mass or solid, the materials strength, fluid dynamics, and thermodynamics (thermology). As a methodology for incorporating epistemological science into a specific design, design science (which covers control of systems, optimization, and production planning) is included in mechanical engineering as an important underpinning. The following approaches exist in the learning of mechanical engineering: proceeding to an understanding of design science based on epistemological science; proceeding to an understanding of epistemological science based on design science; and, proceeding to an understanding of the entire scientific underpinnings of mechanical engineering based on practical technology.

(3) Basic grounding for all students learning mechanical engineering should aim to acquire

① Basic knowledge and understanding to be acquired in learning mechanical engineering

In addition to the underpinnings of natural sciences related to machines (fundamental knowledge of physics and mathematics), those learning mechanical engineering are required to have a fundamental knowledge and understanding of mechanics, design, and control systematized according to the aim of mechanical engineering. They are also expected to be interested in related fundamental sciences and interdisciplinary areas, and understand their core principles from a broad and comprehensive perspective. The will to study by which they can proactively learn the relevant sciences is important here. Since machines are deeply related to the fabric of contemporary society and individuals' lives, those learning sciences related to machines must be cognizant of the condition that machine technology is significantly responsible for the sustainability and development of society and individual lives within it.

② Basic capabilities to be acquired by learning mechanical engineering

As the functions of machines covered by mechanical engineering are diverse, so are what contents to learn and how to learn them. There are, however, basic commonalities in specific capabilities acquired in the learning of mechanical engineering. These commonalities can be classified as follows: a capability to logically define problems based on systematic knowledge of mechanical engineering; a capability to analytically solve problems based on systematic knowledge of mechanical engineering; a capacity to understand other areas by analogy based on systematic knowledge of mechanical engineering; a capacity to realize a specified function under constraints by applying and synthesizing individual fields of knowledge; and, a capability to give a logical and crystal-clear explanation based on systematic knowledge of mechanical engineering. In addition, once one has gone through the process of learning mechanical engineering, one will have acquired scientific thinking.

(4) Basic principles related to the learning methods and the evaluation methods for learning outcomes

The learning methods for mechanical engineering are mainly lectures, experiments, exercises, practice, and research. Since mechanical engineering covers diverse subjects, it is useful to combine subjects organically such as selecting and weighing subjects according to their purposes. The items to be evaluated include a deductive capacity, an inductive capacity, competence related to basic knowledge, the capacity to identify, analyze, and solve problems, and communication skills. It is necessary to adopt diverse and flexible evaluation methods according to the contents of and method for each type of education and the situations of individual learners.

(5) A liberal arts education in which expertise and generality are combined

Machines do not simply bring convenience into our lives, but are deeply related to society and a human sense of values. It is also important to analyze and identify the risks and benefits of technologies that are becoming larger and more complex. Having a well-rounded general education in addition to specialized expertise helps to develop accurate insights into both technological and social challenges and the capacity to solve them.

Contents

1 Introduction

In May 2008, the Science Council of Japan (SCJ) received from the Director-General, Higher Education Bureau, Ministry of Education, Culture, Sports, Science and Technology (MEXT) a request for deliberations regarding the direction of disciplinary quality assurance in university education. In June of the same year, the SCJ set up a task-specific committee and carried out several deliberations. As a result, in August 2010, the SCJ proposed to develop points of reference in disciplinary curriculum-design and development as a method of disciplinary quality assurance.

A point of reference is used for reference when identifying the specific goal of learning in the curriculum for each field. It demonstrates ideas provided with generality and comprehensiveness that contribute to the materialization of a curriculum for the relevant field—a curriculum that is voluntary and autonomous and conforms to the ideals and realities of each university (department or faculty).

This report is a point of reference in the field of mechanical engineering, and the SCJ wishes to release it this time so that it can be used in such organizations as universities providing curricula related to the field.

2 Definition of Mechanical Engineering

Mechanical engineering is an academic field that consists of natural (epistemological) sciences and design sciences (sciences for design) related to machines.

Machines can be defined as (1) "consisting of combinations of objects capable of resisting external force," (2) "by executing certain relative movement," and (3) "converting energy or information given from the outside into useful functions such as motion, force, and information." (1) and (2) indicate the relationship with natural laws that form the substance of machines, demonstrating that the science underpinning mechanical engineering as an epistemological science[2] is "mechanics." (3) indicates the functions of machines, demonstrating that design science[2] is required for realizing functionality harmonized as a whole through the synthesis of individual elements. In addition, many of the core sciences in other areas centered around engineering are included in the fundamental knowledge of machine functions. That is, machines in a broad sense indicate the diversity of mechanical engineering, and at the same time, demonstrate that the field of mechanical engineering is closely related to other areas of the natural sciences.

Technology is practice that achieves actual functions in human life within society. Engineering as a part of science (engineering science) is systematic knowledge and understanding that becomes the underpinning of that practice, which suggests that in the field of mechanical engineering, it is important to collaborate with other areas of human endeavor including the humanities and social sciences. It should be noted that in contemporary society, issues are raised about engineers' ethics and social sustainability, and that a knowledge of machine functions from a variety of perspectives is required in mechanical engineering.

Engineering science is an academic field whose purpose is to contribute to human life and social welfare, and a sense of human values is included in it. If the "functions" desired by people or societies are diverse, it follows that the classification and definition of machines are to be expanded; however, unlimited expansion of the definition of machines with diverse functions leads to unlimited expansion of the science underpinning them. Therefore, this document focuses on the science for the originally defined machines that are the core of mechanical engineering.

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[1] Similar definitions appear in *JSME Mechanical Engineers' Handbook* (The Japan Society of Mechanical Engineers), *Handy Book* (Ohmsha), and *Koujien* (Iwanamishoten).

[2] See "A New System of Sciences—Combining the Humanities and Sciences for Society" (June 2003), Committee on a New System of Sciences attached to the Governing Council, the Science Council of Japan

3 Characteristics Specific to Mechanical Engineering

(1) Perspectives specific to mechanical engineering

Engineering science incorporates the perspectives of both epistemological science and design science. There are two directions in engineering:

- that of learning natural laws and putting them to use to benefit humans (from epistemological science to design science) and
- that of meeting the demand for the functions necessitating research to conform to natural laws (from design science to epistemological science).

Note that engineering science is bidirectional. Given the aforementioned three elements that define machines, mechanical engineering education requires a scientific approach related to analysis centering on mechanics, and an understanding of systematized knowledge related to synthesis centering on design science.

"Mechanics," on which mechanical engineering is epistemologically based, covers a wide variety of scales and phenomena. Traditionally, there are fundamental disciplines of mechanics such as disciplines related to the motion of a point mass or solid, the strength of a solid body, fluid dynamics, and thermodynamics (thermology). With the development of human life within society, the scale of time and space demanded by humans for machine functions has expanded vastly compared to the time and scale we were once familiar with (in the range from one millimeter to ten meters and from one second to around ten years). For example, the function of a tiny mechanical element comes to be deeply related to the individual atoms and electrons constituting that element, in which case mechanics for machines comes to include the notions of quantum mechanics. Moreover, a large-scale system in which many elements interact with one another in a nonlinear manner and demonstrate complex behaviors also comes to be covered by mechanical engineering. A typical example of that is a living body; when attention is directed to the mechanical aspect of a living body, it is also covered by mechanical engineering. From the perspective of mechanical engineering, that means that knowledge based on chemistry or biology becomes necessary. With changes in society, it can be said that the fundamental disciplines of mechanical engineering are expanding.

As a methodology for incorporating epistemological science into a specific design, design science is included in mechanical engineering as an essential underpinning. The design science held by mechanical engineering includes not only a mere functional design but also all product-related processes (such as planning and conception, development, design, production planning, sales, transportation, distribution, usage, evaluation, repair/maintenance, disposal, collection, and recycling). Furthermore, machines and machine systems produced based on the knowledge of mechanical engineering not only contribute to contemporary human life and welfare, but can also serve as a driving force that brings about innovations for the future. Mechanical engineering does not just produce "goods" as its practical activity (technology), but becomes involved with human life within society in general, including human communications and sensibilities, through its study on functions, and is deeply related to how human society ought to be.

(2) Diverse approaches

There are diverse approaches to ways of learning mechanical engineering. Firstly, one approach centers on epistemological science. Learning starts by understanding natural laws based on the mechanics related to force, deformation, motion/flow, and heat. It is an approach in which one fully grasps individual laws and then proceeds to understand design science, which achieves functionality as a system created by synthesizing those laws.

Another approach centers on design science. Learning starts by understanding system design and control with the aim of achieving functionality. It is an approach in which one views the mechanisms of various functions and processes related to their production (manufacturing) and usage as a whole, and at the same time, proceeds to understand the epistemological science related to natural laws on which those mechanisms are based.

Yet another approach centers on technology. It is an approach in which one learns a specific system (for example, transport equipment such as automobiles and aircraft) and then proceeding to understand the entire scientific underpinnings of mechanical engineering. As a practice, mechanical engineering provides human society with specific technologies. There are numerous machine systems that are likely to exert a significant influence on society, that are designed for specific purposes, and that possess a high degree of complexity. Developing expertise about those systems is also one of the missions of mechanical engineering. Through that approach, a deepening of an understanding of epistemological science and design science in the process of understanding those systems is achieved.

(3) Role of mechanical engineering

The role of mechanical engineering is to provide a systematic knowledge of mechanics—part of the fundamental laws that constitute nature—and, by using that knowledge, to demonstrate specific measures in machine technology that bring safe and reliable life, and can live up to humans' aspirations while taking environmental and resource limitations as well as cost effectiveness into consideration. Providing engineers with the feasibility and safety of design and manufacturing based on current knowledge is also the fundamental role of mechanical engineering. That is to say, the main role of mechanical engineering is to unfold the understanding required to achieve machine functions, and at the same time, reveal its limitation.

To date, mechanical engineering has provided the knowledge bases of functions of specific machines related to transportation, energy, and production, and systems created by combinations of specific machines. By expanding the coverage from its core area, while incorporating information, life, physical, and other sciences, it has also produced diverse machines including electronic, information, intelligent, bio-mechanical, and health and welfare machines as well as new machine systems to meet the expectations of society.

Mechanical engineering is characterized by being comprised of various areas of science. What is studied in mechanical engineering involves underpinnings, and covers diverse phenomena. In addition, mechanical engineering interacts with all the other sciences. Based on those complex characteristics, mechanical engineering will continue to assume the role as a contributor to knowledge systems for creating technologies that meet society’s needs.

(4) Collaboration with other sciences

Functions performed by artificial objects can be found in virtually every aspect of daily life. With that being the case, diverse points of contact with almost all the other sciences exist in mechanical engineering.

Given the flow of knowledge from mechanical engineering to other sciences, the following aspects of mechanical engineering can be recognized: the sharing of objectives to be studied (natural laws), collaboration for creating systems to achieve functions, and provision of the means necessary for the development of other sciences (machine functions). As a part of engineering science, in particular, mechanical engineering is strongly connected in many respects to such areas as natural science, agriculture, medical science and pharmacy. Through collaboration with other fields, mechanical engineering re-organizes the acquired knowledge for use and application. For that reason, while scientifically deepening itself, mechanical engineering can also function as a driving force for developing new areas of science or creating innovative technologies through linkage with other sciences and interdisciplinary areas.

Given the flow of knowledge from other sciences to mechanical engineering, it can be said that the current functions of machines include functions based on not only classical and statistical mechanics but also quantum mechanics, and that they have been formed by synthesizing a wide range of knowledge from other engineering areas, physics, and chemistry. In addition, their relationship with mathematical, information, and bio- and medical sciences is also deepening. Furthermore, in terms of connection with humans within society, mechanical engineering also needs study on functionality in order to adapt to or harmonize with environments, with an eye even to human emotions and sensibilities, social environments, and the global environment. It is necessary for mechanical engineering to create the knowledge leading to specific solutions and technologies by interacting with a wide range of other disciplines including the humanities and social sciences, such as economics, business studies, and psychology.

Through those collaborations, mechanical engineering will become one of the distinctive core elements of engineering science—a science supporting the satisfaction of human desires—and will form part of the assets of knowledge common to all humanity.

4 Basic grounding all students learning mechanical engineering should aim to acquire

(1) Basic knowledge and understanding to be acquired by learning mechanical engineering

① Basic knowledge and understanding to be acquired

In addition to the underpinnings of natural sciences related to machines (fundamental knowledge of physics and mathematics), those learning mechanical engineering are required to have a fundamental knowledge and understanding of the following items systematized according to the aims of mechanical engineering.

i. Basic items related to mechanics

The underpinning science related to natural laws—a source of machine functions—is "mechanics," including "thermology," and incorporates the following fundamental disciplines:

- A science on the motion of a point mass or solid
- A science on strength related to the deformation and fracture of a material
- A science on fluid for prediction and control of flow
- A science that systematizes the heat transport such as thermal conduction and radiation, chemical reactions, the thermophysical properties of fluids, and the conversion process between heat and work.

Note that notions synthesizing the above and notions combined with a knowledge of other sciences exist and that the classification of fundamental disciplines are thus not limited to the ones shown above.

ii. Basic items related to design and control

Design science is the underpinning science for synthesis that achieves machine functions and can be categorized into the following fundamental disciplines:

- A science on the correlation between humans, matter, energy, and information and for achievements of functions
- A science on prediction and control of a designed system or optimization of such a system
- A science that realizes demanded functions or values in production activities under various constraints including cost effectiveness and effects on society.

Note that although the basic items are demonstrated as above by being divided into analysis and synthesis, it is possible to create diverse structures of "mechanical engineering" according to how purposes or goals are set. In that sense, there is no unified structure of mechanical engineering, and how choices are made or weights are placed varies significantly. In addition, since machines are systems that embody diverse values related to human life, when learning mechanical engineering, it is important to pursue collaborations with a wider range of knowledge not belonging to the above fundamental areas. Therefore, students learning mechanical engineering are expected to be interested in related fundamental sciences and interdisciplinary areas, and possess an understanding of those ideas that form their core principles from a comprehensive and well-rounded perspective.

② Social significance of learning mechanical engineering

The social significance of learning mechanical engineering lies in finding how a better life for those living within society can be created using machines. By acquiring a knowledge and wisdom of mechanical engineering, it becomes possible to understand the functions and mechanisms of machines that form the foundation for said significance.

As shown by the fact that the introduction and spread of machines have helped to improve standards of living and realize industrial promotion, material supply, health promotion, disaster and accident prevention, and so on, mechanical engineering has played a key role in the development of humanity. What is important for those learning mechanical engineering is thus the will to study by which they proactively learn the relevant sciences with the aim of sustaining and improving the quality of human life. We must recognize, however, that there is a danger of machines introduced in the interests of convenience causing dire results due to accidents or destruction of the environment. It is also important to understand how to prevent or avoid those results by becoming well-rounded and maintaining a certain humility. Since machines are deeply related to the fabric of contemporary society and individual lives, those handling machines must be aware of the fact that in their relationship with machines, they may be significantly responsible for the sustainability and development of society as a whole and the lives of individuals within society.

(2) Basic capabilities to be acquired by learning mechanical engineering

① Capabilities specific to mechanical engineering

i. Occupational significance

Machine technology is a means of implementation for the development of a highly convenient, safe, and reliable human society through machines. Mechanical engineering is an academic field that systematizes the background knowledge and understanding of machine technology. By learning mechanical engineering, it becomes possible to acquire the underpinnings of that technology.

It also becomes possible to acquire a perspective based on design whereby an executable solution is arrived at by making full use of knowledge even for a problem for which there is not necessarily only one solution, and a practical methodology and tenacity in which moderation is always respected while pivoting on both analysis and synthesis in a balanced manner and, if necessary, compromises are willingly made. Furthermore, it becomes possible to understand the importance of technical, ethical, and social considerations.

The machine industry is highly diversified. Therefore, a vast area of knowledge and understanding must be synthesized to create demanded functions. In other words, not only mechanical engineering but also collaboration with a wide range of other areas is essential for technology (practice). While studying the science of mechanical engineering, students can understand the importance of a wide perspective, develop an interest in other areas along with an eagerness for learning them, and acquire collaborative learning methods.

ii. Significance in civic lives

The significance of mechanical engineering in civic lives can be divided into ones for a specialist in mechanical engineering and for a citizen who has learned mechanical engineering. In the former, besides being able to contribute to society as a professional expert, significance lies in becoming able to acquire the foundation for becoming a civic leader on matters related to machine technology. In the latter, when associating oneself within society as a citizen, significance lies in providing a knowledge base with respect to machines, which have already become daily necessities, and promoting an understanding of their principles so that they can be put to appropriate use. Furthermore, mechanical engineering enables one to acquire a rational attitude of thinking about ideas and methods that further increase the convenience of everyday life and the knowledge underpinning them. Technological innovations related to machines, for that matter, create new values in society and the lives of individuals. With that being the case, those who have learned mechanical engineering can easily understand general information such as the functions, mechanisms, and principles of new machines. This also makes it possible to put machines with new functions to proper use and acquire the foundation for realizing a more comfortable, safe, and reliable society and life in general. In other words, it becomes possible to recognize new values, put them to proper use, and bring about the improvement of the quality of life within society.

Note that machines can be weapons depending on how they are used. To prevent the dangers caused by the misuse of machines or an accident, also, basic knowledge related to machines is important both as an expert in mechanical engineering and as a citizen.

Machines are deeply related to society as a whole, not only in daily life, but also in the technology of large-scale systems such as energy equipment. When thinking about how society should be and will be in the future, a fundamental knowledge of machines plays a vital role. Being able to properly understand and judge social situations regarding machine technology is a part of the underpinning knowledge (general education of engineering science) to act rationally in response to challenges, including social decisions involving difficult problems.

iii. Learning mechanical engineering and academic and social changes

Compared to the time and scale with which humans were once familiar, the scale of time and space covered by machines has expanded vastly due to the pursuit of sophisticated functions; complex and large-scale systems are currently being developed and used. Besides its importance related to the functions of individual elements, mechanical engineering plays a critically important role also from the viewpoint of grasping an overview of a given system. As the integration and sophistication of machines progress, the science of mechanical engineering itself changes in tandem with social changes.

There are signs of change in the relationship between practical experience and science due to the rapid development of science and technology. In the past, repetition of technological practice tended to systematize knowledge and understanding. Today, however, developing knowledge about natural laws create new technologies more often. There are two stances in mechanical engineering, one giving priority to practice and applications and the other giving priority to knowledge-base formation. This tendency points to the recent increase in the importance of developing knowledge about natural laws. It should be noted that new machine technology is emerging through the incorporation of a knowledge of information science involved in it, also an important viewpoint.

The development of science and technology demands the fusion of diverse areas and development of new areas. As seen in problems on a global scale such as environmental problems, those facing contemporary society are becoming increasingly diverse and complex. To address those problems, beyond individual research areas, various fields of knowledge must be pooled and synthesized. To that end, it is important to deepen each field of knowledge and at the same time understand the systems and structures between fields of knowledge. Mechanical engineering plays a leadership role in bringing about social development. Though its underpinning sciences are mechanics and design science, its academic contents change, always involving other sciences. Since mechanical engineering is deeply connected with human life, its academic contents need to be improved so that it may keep up with social changes.

iv. Specific capabilities expected to be acquired

The functions of machines covered by mechanical engineering are diverse, and so are what contents to learn and how to learn them. Sets of expert knowledge and understanding vary depending on the direction a teacher emphasizes and on the approach a student chooses.

Since the common aim is to identify and solve problems regarding machines that contribute to the improvement of the quality of human life and society and to their safety and reliability, however, there are basic commonalities in specific capabilities acquired in the learning of mechanical engineering. Based on what has been described so far, these capabilities can be classified as follows:

- Capable of having an opinion with ample evidence about the present and future of mechanical engineering and machine technology.
- Capable of understanding, properly evaluating, and positioning others' opinions of mechanical engineering and machine technology.
- For a newly developed machine technology, capable of giving proper
    - ✧ interpretation, expressing one's own opinion, and participating in practice.
- Capable of designing and using appropriate machinery by fully understanding the use environment and conditions.
- Capable of examining specific problems and issues related to mechanical
    - ✧ engineering and machine technology by collecting materials and data and solving them.
- Capable of explaining what machines are to those not specialized in them.

The basic capabilities to be acquired by learning mechanical engineering can be classified as follows:

1. Inductive capability: a capability to logically define a problem based on a systematic knowledge of mechanical engineering
2. Analytical capability: a capability to analytically solve a problem based on a systematic knowledge of mechanical engineering
3. Understanding: a capability to understand other areas by analogy based on a systematic knowledge of mechanical engineering

4. Design capability: a capability to realize a specified function under constraints by applying and synthesizing individual fields of knowledge

5. Explanation capability: a capability to give a logical and crystal-clear explanation based on a systematic knowledge of mechanical engineering

② **Generic skills**

Through the process of learning mechanical engineering, the capabilities that one can acquire that can be used for general purposes, i.e., scientific thinking, as follows:

- A capability to think rationally and logically
- A capability to judge an uncertain matter with awareness of a cause-and-effect relationship
- A skill in handling numbers
- Understanding with respect to natural sciences
- Understanding with respect to technology in general
- A capability to work as a member of a team
- A capability to rationally use and operate equipment related to everyday life
- A capability to find a problem related to machinery in civic life, analyze it rationally, and work out a solution

5 Basic principles related to the learning methods and the evaluation methods for learning outcomes

(1) Learning methods

The main learning methods for mechanical engineering exhibit the forms and functions shown below. Since mechanical engineering covers diverse subjects, however, it is useful to combine subjects organically such as selecting and weighing subjects according to their purposes.

① Lecture

Gives an opportunity to systematically learn diverse knowledge and understanding of mechanical engineering such as the basics of epistemological science and design science, purposes of and methods for their application, examples of their practice, and cutting edge trends, in a balanced manner. Such knowledge and understanding become the foundation for learning by other educational methods. In this case, it is important to give students the opportunity to think for themselves as well as giving them detailed explanations.

② Experiment

Deepens the understanding of epistemological science by reproducing things that follow natural laws. Promotes an understanding of design science by reproducing the effects of synthesis expected under assumed conditions. Furthermore, helps in the acquisition of evidence related to a basic theory or application method by actually testing whether a certain theory or hypothesis is valid.

③ Exercise

To understand a field of generalized knowledge deeply, of great value is testing what cause-and-effect relationship obtains under various assumed conditions. Experience of testing from the viewpoint of not only epistemological science but also design science is also important. Through exercises related to specific matters, students can recognize their own levels of understanding. It is also important to recognize the diversity and complexity of actuality by comparing theory and reality.

④ Practice

Experience through actual manufacturing can deepen an understanding of basic knowledge and at the same time, helps students experience the knowledge and methodology of design science that incorporates basic knowledge into technology as practice. Through that experience, students also become able to actually perceive the significance of mechanical technology's contribution to society, recognize the value of acting as a member of a team, and understand the importance of communication. In addition, the practice here involves practice outside of school whose educational purpose and method are made clear and a type of education that helps students learn trends of technology overseas (including the importance of culture and cross-cultural communication related to that technology).

⑤ Research

Carries out investigation, experiment, design, and analysis for a task given or assigned on one's own. Helps to comprehensively develop capabilities to identify, analyze, and solve problems through search for and acquisition of necessary knowledge during the aforementioned process. In addition, helps to promote competence through the careful reading of scientific documents and the creation of reports.

(2) Evaluation methods

Evaluation methods for learning outcomes differ depending on educational purposes and methods. There is no standardized measure for evaluation. Those learning mechanical engineering are evaluated based on combinations of diverse types of evaluation. Major types are shown below. Note, however, that there can be other types of evaluation. It is necessary to use diverse and flexible evaluation methods according to individual curricula, individual educational methods, and the situations of individual students.

· Evaluate (mainly through lectures and exercises) the level of understanding regarding basic knowledge (deductive capability).
· Evaluate (mainly through lectures, exercises, and experiments) the level of acquisition regarding a capability to apply basic knowledge (inductive capability).
· Evaluate (mainly through experiments and task-oriented research) competence related to basic knowledge.
· Comprehensively evaluate (mainly through task-oriented research) capabilities to identify, analyze, and solve problems.
· Evaluate (mainly through practice and task-oriented research) communication skills.

6 A liberal arts education in which expertise and generality are combined

Mechanical engineering is integrally related to humans and society, which derives from the essential significance of engineering. Knowledge related to machines gives not only the background knowledge related to recognition and application of natural laws, but also insights into the relationship among objects, energy, and information with humans and society. From the viewpoint of generality, an understanding of the humanities and social sciences in the context of the relationship of machines with humans and society is especially important. That understanding also leads to an understanding of the public aspects of machine technology in a society in which machine technology is shared.

Machine technology requires linkages among diverse fields of knowledge. Those learning mechanical engineering are thus required to have the will and understanding with which they learn not only other engineering fields but also the basics of other fields such as natural science, agriculture, medical science and pharmacy, as well as the general trends of their development. When studying mechanical engineering, students are required to have a capacity to explain technical details to non-specialists in general terms, and at the same time, to acquire a basic knowledge for understanding explanations given by experts in mechanical engineering and other fields. In other words, beyond the narrow confines of fields of specialization, organic collaboration with those in other fields is essential; it is important to have a relative view of one's expertise and recognize its limitations on one hand, and to acquire communication skills, share knowledge bases with people in other fields, and establish channels of communication, on the other. This ability is one of the areas of general education of technology absolutely essential for citizens in contemporary society living amongst machines.

Machine technology has underpinnings common in human society. Therefore, developing a global view as a citizen with expertise is important. What is called for is the understanding that the essence of globalization lies in developing common values within human society based on the organic linkage of many distinct regional cultural groups. Also called for is a general education that becomes the basis for dynamic activities that go beyond national borders and particular scientific domains. We must bear in mind that a superficial type of learning intended to improve linguistic abilities alone without also addressing cross-cultural awareness does not constitute genuine globalization.

Technologies that have grown large and complex have correspondingly made the risks and benefits associated with them in society and humans' lives large and complex. When thinking about the direction over the future of the society or the world in which one lives, one cannot make rational judgments without a knowledge of machine technology. To achieve social consensus, it is demanded that citizens properly analyze and identify the risks and benefits technology brings and the causes or reasons for them, and participate in decision-making on social matters through communication with others. Those learning mechanical engineering must possess the above awareness as a requisite general education principle.

As mentioned above, machines do not just bring conveniences into our lives, but are deeply related even to society and a human sense of values. Having a broad general education and expertise fosters accurate insights into technological and social challenges and the capacity to meet them.

<Reference material 1> Deliberation progress of the Sectional Committee on the Study of a Point of Reference in Mechanical Engineering

Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on the Promotion of Disciplinary Quality Assurance in University Education

2012

March 16	SCJ Board of Secretaries, 148th meeting The Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on the Promotion of Disciplinary Quality Assurance in University Education established and committee members determined.
April 17	Sectional Committee, 1st meeting Board members elected. Definition of mechanical engineering. How to proceed.
June 26	Sectional Committee, 2nd meeting Information about JABEE accreditation programs provided. Direction of a point of reference.
August 27	Sectional Committee, 3rd meeting Information about the Central Education Council's report provided. Characteristics specific to mechanical engineering.
October 15	Sectional Committee, 4th meeting Occupational significance and significance in civic lives.
December 3	Sectional Committee, 5th meeting Basic capabilities to be acquired by learning mechanical engineering.

Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on Mechanical Engineering

2012

November 30	SCJ Board of Secretaries, 166th meeting Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on Mechanical Engineering, established and committee members determined (effective on December 21).

2013

January 21	Sectional Committee, 1st meeting Learning methods and evaluation methods of mechanical engineering Expertise and generality
March 22	SCJ Board of Secretaries, 170th meeting The extension of the committee's operating period decided.
June 15	Sectional Committee, 2nd meeting Public symposium "A Point of Reference in Mechanical Engineering in Undergraduate Education"
July 26	Committee on Disciplinary Quality Assurance in University Education, 4th meeting Report by the Sectional Committee on the Study of a Point of Reference in Mechanical Engineering, Committee on Mechanical Engineering "A point of reference in curriculum-design/development for disciplinary quality assurance in university education—mechanical engineering" approved.

<Reference material 2>　Public symposium

Science Council of Japan Public Symposium
"A Point of Reference in Mechanical Engineering in Undergraduate Education"

Date and time: Saturday, June 15, 2013 13:00-16:00
Venue: Collaboration Room, 9th West Building, Ōkayama Campus, Tokyo Institute of Technology

About the Symposium

The Science Council of Japan (SCJ) is presently creating a point of reference in each field of expertise for the purpose of quality assurance in university education. Now that a draft point of reference in mechanical engineering has been completed, this public symposium is held with the aim of hearing diverse opinions from those involved in mechanical engineering education in universities, those in industries, and those interested in faculty education to deepen discussions, and reflect results on said point of reference.

Schedule:

Opening address　13:00-13:05

Kitamura, Takayuki, Chairperson, Sectional Committee on the Study of a Point of Reference in Mechanical Engineering; SCJ member; Professor, Kyoto University

1. "Disciplinary Quality Assurance in University Education and a Point of Reference" 13:05-13:45
   Kitahara, Kazuo, Chairperson, SCJ Committee on the Promotion of Disciplinary Quality Assurance in University Education; SCJ special associate member, Professor, Graduate School at the Tokyo University of Science; Professor emeritus, Tokyo Institute of Technology and International Christian University
2. "A Point of Reference in Mechanical Engineering" 13:45-14:30
   Kitamura, Takayuki, Chairperson, Sectional Committee on the Study of a Point of Reference in Mechanical Engineering; SCJ member; Professor, Kyoto University
3. "Engineer Education Program Accreditation" 14:30-15:10
   Kishimoto, Kikuo, SCJ member; Professor,Tokyo Institute of Technology
4. "Expectation of Human Resources Development in University" 15:20-16:00
   Arinobu, Mutsuhiro, SCJ member; Comptroller, The University of Tokyo
5. Plenary Discussion 16:00-16:45

Closing address　16:45-17:00

Tsuchiya, Kazuo, Vice-chairperson, Sectional Committee on the Study of a Point of Reference in Mechanical Engineering; SCJ special associate member; Professor emeritus, Kyoto University