Int. J. Engng Ed. Vol. 15, No. 1, pp. 32–40, 1999
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Designing as an Educational Discipline*

W. ERNST EDER
Department of Mechanical Engineering, Royal Military College of Canada, PO Box 17000 Stn Forces, Kingston ON, K7K 7B4, Canada. E-mail: eder-e@rmc.ca

With the rapid developments of technology, globalization of markets, loss of experience, and other modern trends, it is no longer sufficient to rely on either the ad hoc methods and capabilities of experienced engineering designers, or on incremental improvements of existing products. The importance of design lies in part in the properties and quality of the product ('the design') itself, in the methods and processes of its manufacture, in its interaction with users and other people, etc. The importance of design is even more significant in the processes of designing. Designing must be made more reliable and rational; it must be systematized as far as possible. Some of the published methods can be useful as tools within the design processes. Design Science in its current state of development provides a better and more complete basis for this rationalization. Design Science is now sufficiently complete to also make designing teachable. The explainable logic of certain steps, procedures, methods and forms of modeling can be used to deliver a useful basis for supporting the intuitive approaches, and gaining experience and competency in designing on projects of progressively greater difficulty. Incorporating Design Science into the curriculum makes achieving the national accreditation criteria (Canadian Engineering Accreditation Board, CEAB; Accreditation Board for Engineering and Technology, USA, ABET 2000) easier, and provides the needed evidence for demonstrating the inclusion of design capability.

INTRODUCTION

IN THE 1950s (particularly in the UK and Germany), it was recognized that engineering design was deficient, the designed products were capable of drastic improvement, but also the processes of designing needed to be radically improved and rationalized.

It was mainly in the 1960s and 1970s that several new approaches were formulated by 'good' engineering designers on the basis of their own experience. The main thrust was in continental Europe (e.g. in Germany [1–6]), where professors of engineering design were called to their positions at technical universities following at least five years of industrial experience. The resulting methodologies are not merely academic exercises, they are firmly founded in industrial practice, and have proved themselves in industry. Discussions held among the German professors and industry representatives (with the participation of Kesselring [7]) under the auspices of VDI (Verein Deutscher Ingenieure—Association of German Engineers) led to a set of agreed guidelines for designing and related tasks, e.g. VDI 2221 [8], but without developing a unifying theory.

In addition, the more artistic professions (but also engineering in the English-speaking countries) investigated design from the viewpoints of creativity, understanding from feelings, unstructured processes, participation, etc. This reflected the trends in architecture, and is still the main thrust of the Design Research Society (DRS). It is also prominent in one direction of design research in the USA, even after the NSF Initiative of 1985 [9] and the Rabins report [10].

A more extensive survey of the context of designing, the history of design research, and the development of Design Science may be found in Chapters 1, 2 and 3 of [11].

Scientific research is not the main source of products [12, 13]. Most products with a significant engineering content are the results of reverse engineering. This procedure can remain in the details and assemblies, but can also be achieved by re-conceptualizing. Only in some high-tech areas does research play a role, usually in initiating the product development—but after initiation, engineering should take over.

With the rapid developments of technology since those years, the continuing globalization of markets, the rapid loss of experiences gathered by practicing professionals who are reaching the end of their active lives, and other modern trends, it is no longer sufficient to rely on either the *ad hoc* methods and capabilities of engineering designers. It is also not adequate to rely on incremental improvements of existing products, because radical improvements and innovations need different approaches.

The importance of design lies in part (but only in part) in the properties and quality of the product ('the design') itself. Admittedly, these are the factors and properties by which the customer decides to buy the product. They decide the product's interaction with users and other people, etc. Under the concurrent engineering philosophy, the importance of design lies also in the methods and processes of manufacture of the product.

* Accepted 12 September 1998.

The importance of design is even more significant in the processes of designing. Designing must be made more reliable and rational, it must be systematized as far as possible. This does not mean that designing can become mechanized or automated (although some limited parts of designing are amenable to computer processing), human factors such as knowledge, personality, team co-operation, creativity, idiosyncrasy, etc. retain their importance.

ROLE OF THEORY, METHODS AND OBJECT

Some significant relationships were formulated in cybernetics [14, 15]. According to Klaus [14], close relationships exist between the basic theory, methods, and the objects under consideration (their nature). The theory should describe and provide a foundation for both the behavior of the object (with adequate and sufficient precision), and for the utilized methods. The method should also be sufficiently well adapted to the object. These three phenomena are of equivalent status to each other.

A mutual interplay between object (and phenomenon), theory and method, one refined and examined on the other, characterizes the normal human and social development and progress, whose scale is the state of technology.

The current relationships among objects, methods and theories are extremely significant for the situation of heuristic methods. Quoting from Klaus:

> *Both method and theory emerge from the phenomenon of the object.*

If the theory of an object-region is mature, then the methods are founded in the theory. The theory declares what is in reality the case, the method describes, on the basis of the declared facts, how the scientific and practical activities and behaviors of the humans should take place to achieve best effectiveness.

Where no comprehensive theory is available, methods to deal with objects can be proposed even where the structure of the objects or their behavior is not completely known (this is the cybernetic, newer interpretation). The method can conceivably have the character of an input-output relationship ('black-box' principle, first formulated by Ashby in 1956). We know that corresponding results will be generated when we act on a system in a certain fashion. The theory will then—and often after a lengthy delay—give an explanation of why this is so (to some extent an interpretation of the input-output relationship).

For many currently interesting problem groups we lack an appropriate theory which can explain the method for its treatment and solution. In such problem situations, the method (frequently an heuristic method) must first serve to open up the problem field and disclose the structure of the problem. This kind of problem situation is increasingly found in recent research efforts, and therefore the interest in heuristic methods is rising.

The methods, theory and object of engineering sciences are similar to those of the conventional (pure) sciences, but carry the additional purpose of assisting in the analysis needed as part of designing. Elegance and accurate modeling of phenomena are not the important factors in the engineering sciences; utility is the decisive factor. Thus the application of engineering sciences also contain many approximative methods, and include simplified, empirical, order-of-magnitude, and 'quick and dirty' approaches, all of which should feature in engineering education.

DESIGN METHODS AND THEORY

Engineering design is a complex subject. It is consequently worth while to investigate the complex mixture of factors that influence designing and its constituents. This may seem *reductionistic*, but without knowledge of the elements it is not possible to consider the relationships among them, and to synthesize a more *holistic* understanding and structuring.

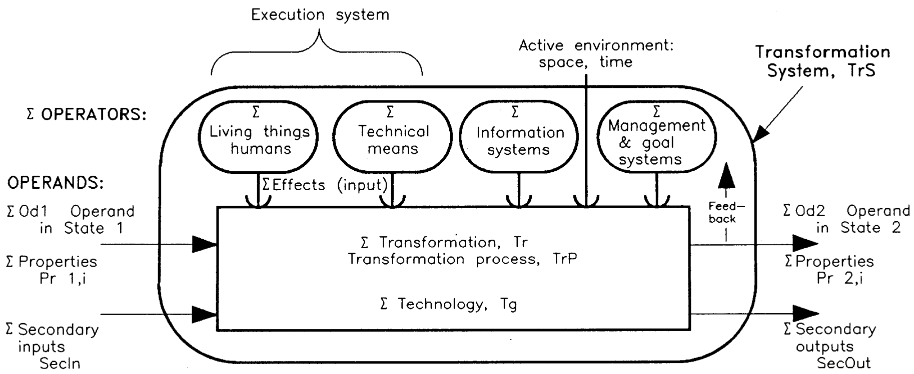
We must distinguish two aspects of design derived from a linguistic consideration. The word 'design' can be used as a noun, meaning the appearance and presence of an artifact (a product), its purpose and usages, its properties, its structures, principles, complexity, novelty, life cycle, development in time, and other characteristics. Alternatively, the word design can be used as a verb to designate the activities and *processes of designing*—of creating the design. In terms of methodology, the processes of designing lead towards a product (an artifact), a simple or more usually a complex object being designed for an intended purpose—a technical system. This is the preferred interpretation for this paper.

The methods of engineering include not only the analytical methods to investigate and predict the object's (i.e. the product's) behavior, but also (and more importantly for this paper) the *methods of designing*, which include both pragmatic methods, and methods based on (or improved as a result of) Design Science [11]. Designing involves some flair, ability, intuition, creativity, spontaneity, etc. (and consequently some mystery), but also judgment, reflection, feel, and experience, and is necessarily heuristic [16], iterative, recursive, opportunistic, flexible, and idiosyncratic. These aspects also include teamwork, reflective [17], and flexible procedures. All these are essential to designing, but as individual statements none of them captures the essence of designing. Nevertheless, some systematic and methodical procedures are available and are useful to support the activities of designers. Other attempts to provide methods exist, but they mainly consist of prescribing parts of the process (e.g. [18], which deals with the theory and mathematical methods of decision-making), usually without an adequate theory of either the design process or the generalized object being designed.

The main stages of designing have conventionally been defined from the European publications, e.g. [5, 8]. These comprise:

- clarifying the problem—developing a design specification;
- conceptualizing;
- embodying in layouts;
- elaborating and detailing.

Several subordinate activities can be recognized in these main stages. During these activities, whether they are performed according to formal methods or informally (intuitively), designers have a responsibility to consider the requirements of all other life stages of the product—manufacturing, usage, disposal, societal and environmental influences, ergonomics and esthetics, law and standards conformance, etc., but also ethics.



– Transformation (Tr) –– changes certain properties of the operand (as passive member of the process), by mutual interaction between object and means.

– Operand (Od) – WHAT is being transformed? –– object that is being changed in the transformation from an input state to an output state which should preferably be more desirable.

– State –– aggregate (vector) of values of properties (Pr) of a system at a certain time.

– Technology (Tg) – HOW is it being transformed? –– knowledge about the transformation, formulates what effects are needed.

– Effects (Ef) – WITH WHAT is it being transformed? –– means of transformation, actions exerted onto the operand, including the necessary energy, auxiliary materials, regulation and control.

– Secondary inputs (SecIn) –– (1) all necessary (desirable) further inputs to the process, and (2) all undesired inputs (disturbances, contaminants, products of the environment that enter as operands).

– Secondary outputs (SecOut) –– mostly undesirable opeand outputs of the process to the enviroment, their nature and composition depend on the chosen technology.

– Operators (Op) – WHO and WHAT delivers the necessary effects (as active member) to the operand:
  Op (Hu) – living beings, particularly humans, but also animals, bacteria, etc.;
  Op (TS) – technical (artificial) means, technical systems;
  Op (InfS) – information systems;
  Op (M&GS) – management and goal systems (directing, setting and achieving goals);
  Op (AEnv) – active environment.

– Active environment (AEnv) – WHERE is it being transformed? –– The part of the general environment that as operator influences the transformation (desired and undesirable effects).

– Space –– the main property of the environment (surroundings) of the transformation.

– Time – WHEN is it being transformed? –– time period during which the transformation occurs.

---------- *** ----------

– Types of effects acting on the operand, secondary inputs, secondary outputs, etc.:
  –– materials; –– energy; –– information (including signals).

– Types of operand, object being transformed:
  –– biological objects (humans, plants, animals, etc.);
  –– materials; –– energy; –– information.

– Structure of the transformation process:
  –– elements = operations (O), or groups of operations;
  –– relationships = connections between the outputs of one operation (or group of operations) with the inputs of the immediately following operation (or group of operations);
  Operations can take place sequentially (in series) or simultaneously (in parallel).

Fig. 1. General model of the transformation process [21].

Design Science [11], as a system of knowledge, has investigated designing (as its object), and has formulated a complex of theory to provide the needed explanation. One part of this theory relates to the artificial (designed and engineered) object and its relation to the usage processes for which it is intended, see Fig. 1. This covers its capabilities, composition, structuring, usage, life cycle, development in time and during its design process, the theory of technical systems [19]. Another part relates to the design process as its object, the theory of design processes [20]. Structuring of any such system (of knowledge) is hierarchical: every system is a subsystem of a larger system; every system can be divided in various ways into suitable subsystems.

The transformation process, Fig. 1, can be used as a basis for designing. As soon as designers (and students) have understood the transformation process (as a black box, as an object and its theory), they can apply the appropriate method. This consists of:

- determine the essential tasks and operations of the transformation process;
- choose a favorable technology;
- establish all necessary output effects of the operators (input effects needed to transform the operands);
- distribute these optimally among the humans and the technical system in the existing situation.

This method is preferably used in the phase 'clarification of the design task', although it already belongs into the solution process (conceptualizing) phases. It should be obvious that this procedure cannot be completed in a linear-sequential fashion: iterative and recursive working is essential; feedback from later stages to earlier ones will progressively drive the solution proposals towards an optimal state. If any opportunistic and intuitive step is taken outside this procedure, at least a check should be made to ensure that the results do not violate the procedural considerations and outcomes.

Based on this formulation, a set of methods has been developed [21], and many other existing methods adapted, that can assist designing. Some methods can be distinctly improved by considering the results of Design Science [22]. Examples of use of these methods for conceptualizing of new products are available [23], and use for re-engineering of existing products has been investigated.

Some published methods can be useful as tools within the design processes. Even though some of these methods make claims to cover the whole of designing (e.g. QFD, TQM, or concurrent/simultaneous engineering), this is in most cases an over-statement.

In this state, the available theory and method can take the mystery (but not the human involvement and values) out of designing, especially for the purposes of education of future engineering designers [24, 25]. The goals of this education have been investigated, especially with respect to the phenomenon known as *'creativity'* [26, 27]. My teaching in the third-year course at the Royal Military College of Canada (RMC) is based on *redesign* with the help of Design Science, the fourth-year elective expands this to *novel designing*.

EXAMPLE—APPLICATION OF THEORY TO METHOD

One piece of advice that is usually given in design literature is that designers should analyze and define their problem before entering into a search for solutions. Some even state that designers should write a design specification. Yet these works do not normally give any guidelines or methods about how to perform these tasks.

Design Science [11] declares, in the section on the theory of technical systems [19], that the properties of all technical systems (engineering products) can be uniquely classified into twelve classes of properties, see Fig. 2. This figure contains not only the twelve classes, but also guidelines on what information about a technical system should be placed under each classification. Applied as a method to designing, and writing a design specification, these classes and guidelines should be used as prompts to think of and note down any statement of properties for the future system to be designed—classification is far less important. Any one statement about a particular property may need to be included in more than one class of properties (but this should be done only as a cross-reference, not as a duplication). Different products have different mixtures and values of these properties. Class 12 of these properties contains all the heuristics and engineering science knowledge needed for designing, and all the output from designing (drawings, parts lists, assembly and adjustment instructions, usage manuals, etc.).

Design method [21] derived from this theory, and illustrated by examples of use [23, 28, 29], show that the task of analyzing, clarifying and defining the problem can be aided by using the classes of properties (Fig. 2) as first-cut guideline to writing the specification statements. Additional or prior information may be elicited by using quality function deployment (QFD) [30–35]. The second set of guidelines to improve this design specification is to consider the life cycle of the future product (see Fig. 3, especially each of the transformations processes involved in manufacturing, delivering, using, and disposing), and of the operators of each of these transformation processes, see Fig. 4.

The other main stages of designing are also supported by recommendations in Design Science [11]. Especially *conceptualizing* (main stage 2) has

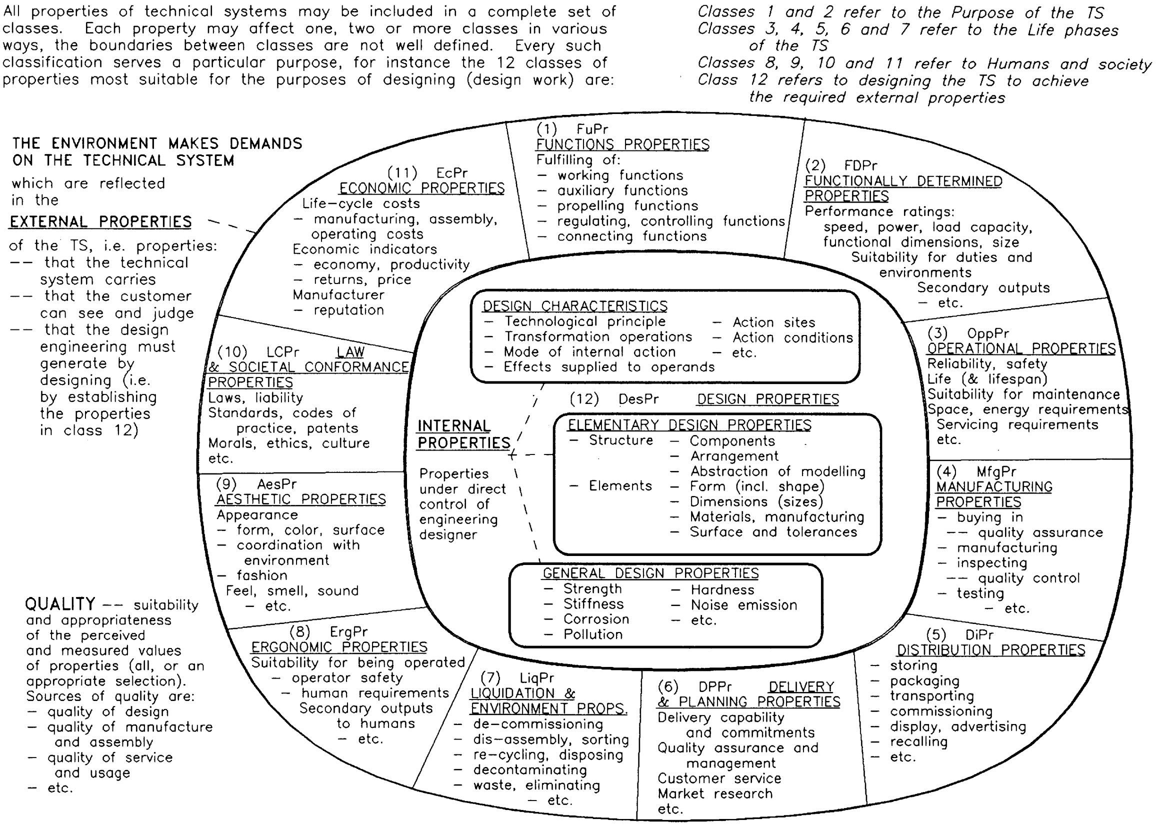


Fig. 2. Relationships among properties of technical systems (adapted from [11, 21]).

received attention, by using the models of technical systems defined in the theory [19]—transformation process structure, technology and effects, function structure, and organ structure. The other main stages are concerned with the component structure, and are treated in detail in many publications, e.g. [3–5].

SOCIO-TECHNICAL SYSTEM—CONTEXT FOR ENGINEERING

Engineering, and particularly designing, is an essential part of the socio-technical system, as defined by Ropohl [36]. It is concerned with the economics, politics and sociology of life.

But it is exactly because engineering, creating products, involves human values (including ergonomics, esthetics, law conformance, and economics, as shown in the properties listed in Fig. 2, but we should also add ethics) that a complete integration of humanities into engineering is essential, rather than just humanities as an add-on. The engineering sciences are obviously already needed for engineering design, and are thus integrated into designing. It is also essential that designing (and its methods and terminology) is integrated into the engineering sciences—design and engineering sciences should co-operate and interact, and speak with one voice.

RATIONALIZING AND EDUCATING FOR DESIGN

Design Science in its current state of development [11, 19–21, 23–26] provides a better and more complete basis for the needed rationalization of engineering design work. In part it can act by providing a descriptive theory to designing, and by showing how the published methods can be co-ordinated and used. Design Science also shows various other models and methods for performing the design process on novel products, redesigned products, variants, etc.

Design Science is now sufficiently complete to also makes designing teachable. The explainable logic, based on an explicit theory, of using certain steps, procedures, methods and forms of modeling can be used to deliver a useful basis for educating the future practitioner of design. The educational process must include gaining experience in designing on projects of progressively greater difficulty. The theory, methods, examples and practice for any particular topic should be introduced in suitable stages, co-ordinated with the progressive increase in difficulty and complexity of the problems—it is definitely not advisable to present all the theory (or method, or practice) in one chunk. A useful guideline, attributed to Confucius, says:

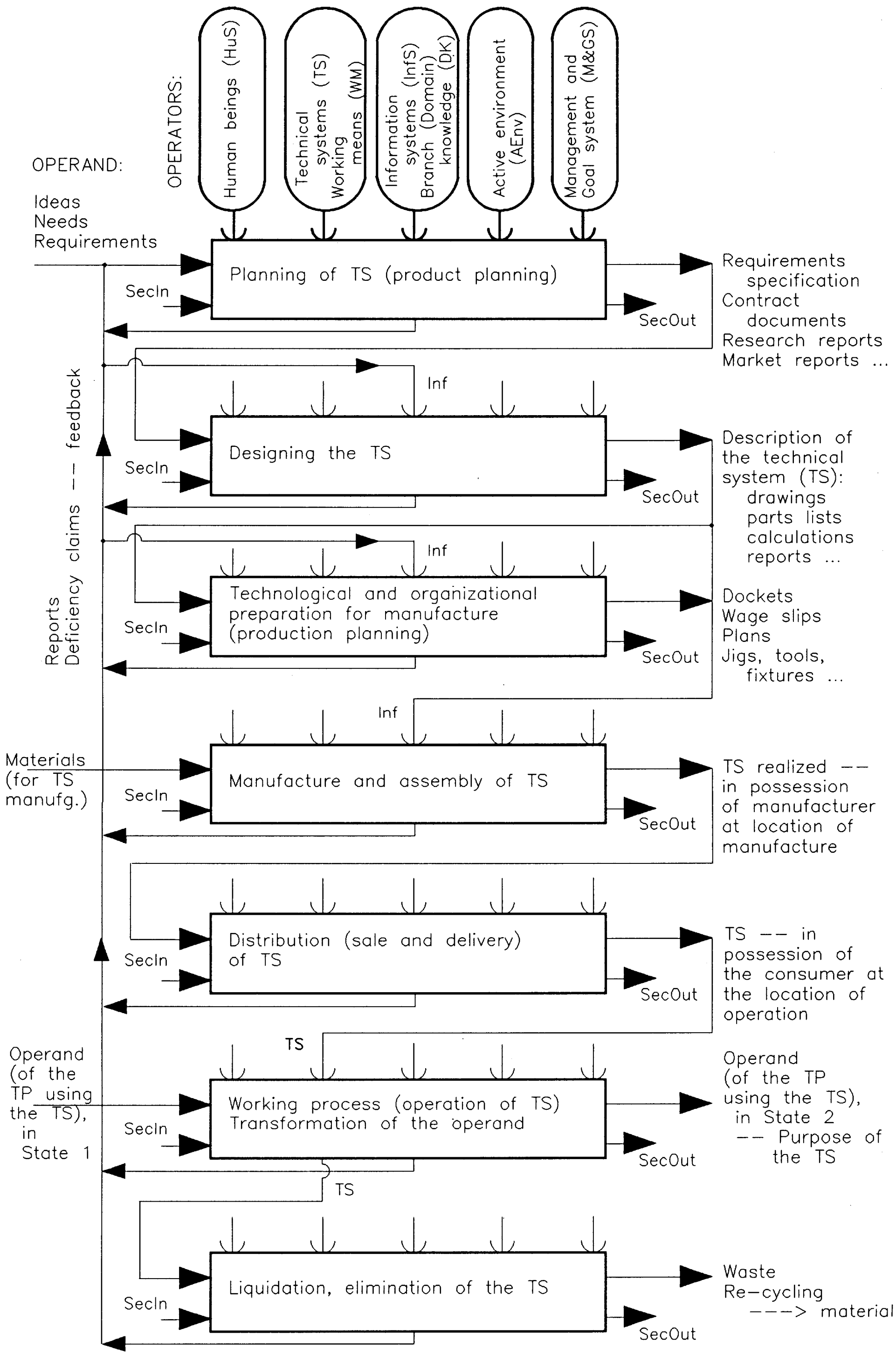


Fig. 3. General model of the life cycle of technical systems [11, 21].

Tell me and I will forget
Show me and I will remember
Involve me and I will understand
Take one step back and I will act.

In the usual interpretation, the first two of this set of items are often used to deny the effectiveness of lectures and demonstrations, and to advocate that only project-based education leads to learning. The last of these items is usually omitted—and, according to the same logic, would lead to rejection of project-based learning. These four statements are not alternatives, they are mutually additive. Inducing learning requires a combination of explanation (telling), demonstration (showing), coaching (involving), and stepping back (gradual release from supervision). Consequently, I would add:

Do all four and I will become competent.

Consequently, the pedagogical and didactic procedures (defining the theory of education, and the

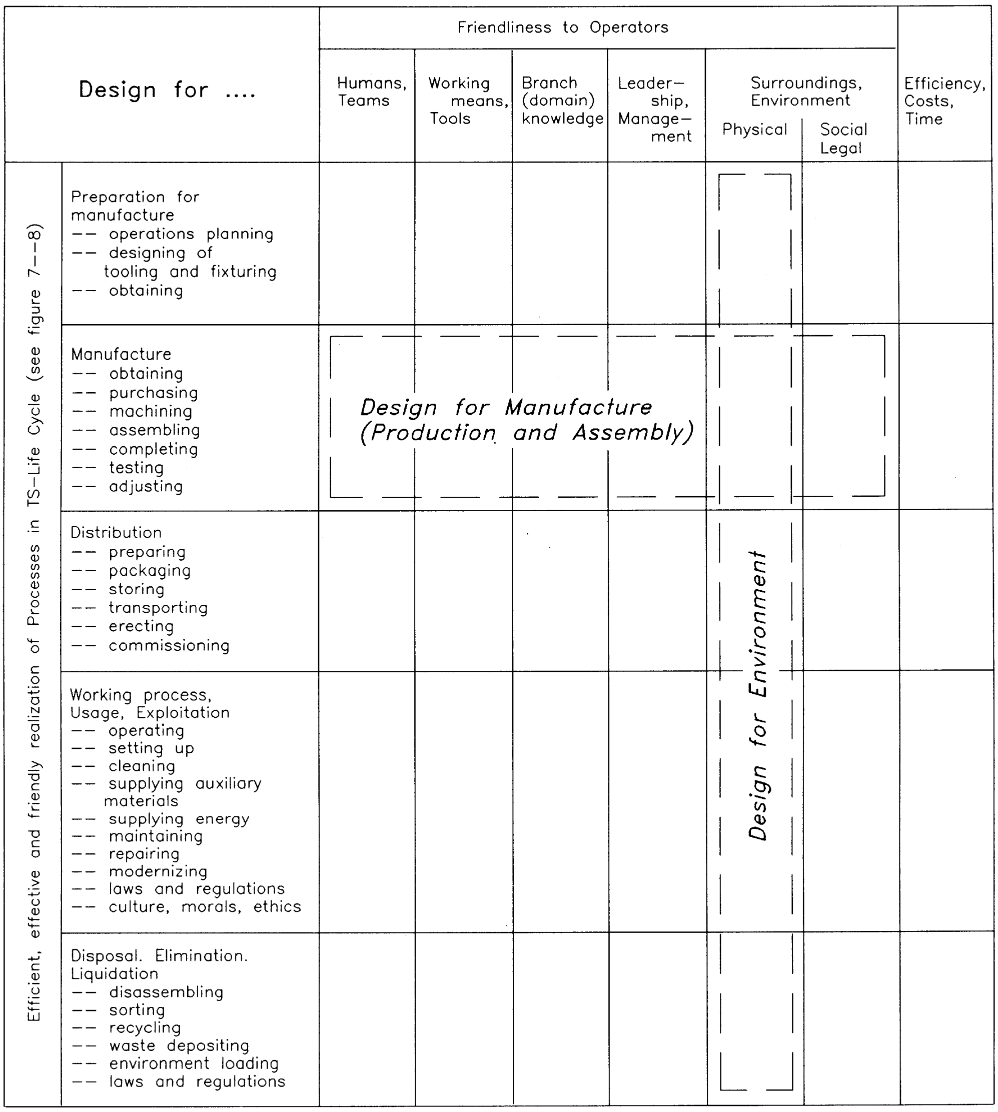


Fig. 4. General systematics of 'Design for ...' classes [11].

methods of delivering it) for engineering design (the object under consideration) must include the following.

A. Explicitly presenting the theory, preferably according to Design Science:
   (a) in suitably small but connected packages;
   (b) by lecturing and by printed (or equivalent) material.
B. Explaining the appropriate methods related to the theory, and presenting other available methods in this context.
C. Providing practice by several progressively more challenging projects under tutorial supervision:
   (a) by experienced staff members;
   (b) throughout all four years of engineering studies;
   (c) ensuring continual back-reference and augmentation to the work of previous steps;
   (d) making sure that the normal steps of designing (according to Design Science) are followed, e.g. for novel design:
      - design specification (see example above),
      - transformation process (see example above),
      - allocation of operations to humans and technical systems,
      - technologies (where technical systems are needed),
      - function structures,
      - organ structures (e.g. via a morphological matrix),
      - component structures (via preliminary layouts, dimensional layouts, detail and assembly drawings, parts lists, etc., the properties of Class 12, Fig. 2);
   (e) but providing gradual release from the strict supervision to allow the students to follow (and develop) their own preferred approaches.

The personal aspects can and should also be included as educational objectives, and in the learning experience. These aspects are probably best delivered by projects of increasing difficulty, co-ordinated with the theory and methods instruction, and distributed throughout the (two, three or four) years of study. They include teamwork, and intuitive, idiosyncratic, opportunistic, heuristic, iterative, recursive, creative, reflective, and flexible procedures (see above). These are essential to designing, but do not capture the essence of designing. Yet only a planned and conscious (but iterative) designing procedure can ensure that an optimal solution of the presented problem can be approached in an effective process.

This comprehensive consideration of design process, product, theory, method and the human should take place during the whole of engineering education, not just in specific design courses. Such factors can lead to competency, as defined in [37], with some recognizable sub-groupings in the following aspects:

- heuristic (use of 'rules of thumb', guideline values, intuitive guesses, etc.);
- branch-related;
- methods-related (synthesis methods, analysis methods, design methods, management methods, etc.);
- systems-related (input, output, transformation, operators, behavior, properties, etc.);
- social (general: societal awareness, cultural sensitivity; particular: teamwork, inter-personal skills, communication skills, leadership, flexibility).

Incorporating Design Science into the curriculum makes achieving the accreditation criteria (CEAB, ABET 2000, etc.) easier, and provides the needed evidence for demonstrating the inclusion of design capability.

REFERENCES

1. F. Hansen, *Konstruktionssystematik* (2nd ed.) V.E.B. Verl. Technik, Berlin (1966); and *Konstruktionswissenschaft—Grundlagen und Methoden* (Design Science—Foundation and Methods), München: Carl Hanser Verlag (1974).
2. W. G. Rodenacker, *Methodisches Konstruieren* (Methodical Designing), Berlin: Springer-Verlag (1970).
3. K. Roth, *Konstruieren mit Konstruktionskatalogen* (Designing with Design Catalogs), Berlin/Heidelberg: Springer-Verlag (1972).
4. R. Koller, *Konstruktionsmethode für Maschinen-, Geräte- und Apparatebau*, Springer-Verlag, Berlin (1976); and *Konstruktionslehre für den Maschinenbau* (Study of Design for Mechanical Engineering) (2nd ed.), Berlin: Springer-Verlag (1985).
5. G. Pahl and W. Beitz, *Konstruktionslehre*, 3rd ed. (1993) Berlin/Heidelberg: Springer-Verlag (1977); and *Engineering Design* (2nd ed., edited and translated by K. M. Wallace, L. Blessing and F. Bauert), London: Springer-Verlag (1995).
6. K. Ehrlenspiel, *Kostengünstiges Konstruieren* (Designing for Favourable Costs), Berlin/Heidelberg: Springer-Verlag (1986).
7. F. Kesselring, *Technische Kompositionslehre* (Study of Technical Composition), Berlin: Springer-Verlag (1954).
8. *VDI Richtlinie 2221: Methodik zum Entwickeln und Konstruieren technischer Systeme und Produkte*, VDI, Düsseldorf (1985); and *VDI Guideline 2221: Systematic Approach to the Design of Technical Systems and Products*, (K. M. Wallace, ed.) Düsseldorf: VDI (1987).
9. *Program Announcement Design Theory and Methodology*, Nr. OMB 3145-0058 12/31/85, Washington, DC: National Science Foundation (NSF) (1985).
10. M. J. Rabins, *Goals and Priorities for Research in Engineering Design*, New York: ASME (1986).
11. V. Hubka and W. E. Eder, *Design Science: Introduction to the Needs, Scope and Organization of Engineering Design Knowledge*, London: Springer-Verlag (1996).
12. S. J. Kline, Styles of innovation and their cultural basis, *CHEMTECH*, (Aug 1991) pp. 472–480; (Sep 1991) pp. 525–535; (Oct 1991) pp. 654–659.
13. D. Mahdjoubi, *The Mapping of Innovation,—prepared for Joint Adjustment Committee of Etobicoke*, 122 Ashbourne Drive, Etobicoke ON, M9B 4H8 by Darius Mahdjoubi, 2085 Islington Ave., Suite 1508, Toronto ON, M9P 3R1 (1997).
14. G. Klaus, *Kybernetik in Philosophischer Sicht* (Cybernetics in Philosophical View) 4th ed., Berlin: Dietz Verlag (1965).
15. W. R. Ashby, An Introduction to Cybernetics, London: Methuen Univ. Paperbacks (1968).
16. B. V. Koen, *Definition of the Engineering Method*, Washington DC: ASEE (1985).
17. D. A. Schön, *The Reflective Practitioner: How Professionals Think in Action*, Basic Books (1983).
18. N. P. Suh, *Principles of Design*, Oxford: University Press (1989).
19. V. Hubka and W. E. Eder, *Theory of Technical Systems*, Berlin/Heidelberg and New York: Springer-Verlag (1988).
20. V. Hubka, *Theorie der Konstruktionsprozesse* (Theory of Design Processes), Berlin: Springer-Verlag (1976).
21. V. Hubka and W. E. Eder, *Engineering Design*, Zürich: Heurista (1992).
22. S. Hosnedl, I. Borusikova and W. Wilhelm, TQM methods from the point of view of design science, in *WDK 25: Proc. ICED 1997*, Vol. 1, Tampere, Zürich: Heurista, (1997) pp. 391–394.
23. V. Hubka, M. M. Andreasen and W. E. Eder, *Practical Studies in Systematic Design*, London: Butterworths (1988).
24. V. Hubka, *Konstruktionsunterricht an Technischen Hochschulen* (Design Teaching at Technical Universities), Konstanz: Leuchtturm (1978).
25. W. E. Eder, V. Hubka, A. Melezinek and S. Hosnedl, *WDK 21—ED – Engineering Design Education – Ausbildung der Konstrukteure—Reading*, Zürich: Heurista (1992).

26. W. E. Eder (ed), *WDK 24—EDC—Engineering Design and Creativity—Proceedings of Workshop EDC*, Zürich: Heurista (1996).
27. W. E. Eder, 'Developments in education for engineering design—some results of 15 Years of WDK activity in the context of design research,' *Jnl. Eng. Design*, **5**, No. 2 (1994) pp. 135–144.
28. V. Hubka and W. E. Eder, Theoretical approach in design methodology, *Symposium*, *Designers—the Key to Successful Product Development*, Technical University Darmstadt, 3–5 December 1997 (Proceedings in preparation, Springer-Verlag).
29. W. E. Eder, Konstruieren aus der Sicht eines Konstruktionswissenschaftlers, (Designing from the viewpoint of a design scientist), for *Konstruieren im Spannungsfeld von Kunst und Wissenschaft* (Designing in the Tension Field between Art and Science), Gerhard Banse and Käthe Friedrich (eds.), Technische Universität Cottbus (in press).
30. J. L. Bossert, *Quality Function Deployment*, New York: Marcel Dekker (1990).
31. W. E. Eder, Methode QFD—Bindeglied zwischen Produktplanung und Konstruktion (Method QFD—connective link between product planning and design), *Konstruktion,* **47**, 1/2, Springer-Verlag, (Feb 1995) pp. 1–9.
32. J. R. Hauser and D. Clausing, The house of quality, *Harvard Business Review* (May–June 1988) pp. 63–73.
33. Hofmeister, K., 'Quality function deployment: market success through customer-driven products', in *Food Products Development from Concept to the Marketplace,* E. Graf and I. S. Saguay (eds.), New York: Van Nostrand Reinhold (1990).
34. A. Locascio and D. Thurston, Quantifying the house of quality for optimal product design, *Design Theory and Methodology - DTM '94*, **DE-68**, New York: ASME Press (1994) pp. 43–54.
35. R. H. Lochner and J. E. Matar, *Designing for Quality: an introduction to the best of Taguchi and Western methods of statistical experimental design*, White Plains, NY: Quality Resources (1990).
36. G. Ropohl, *Eine Systemtheorie der Technik* (A Systems Theory of Technology), München: Carl Hanser Verlag (1979).
37. G. Pahl, Ergebnisse der Diskussion (Results of the discussions), in G. Pahl (ed), *Psychologische und pädagogische Fragen beim methodischen Konstruieren—Ladenburger Diskurs* (Psychological and Pedagogic Questions of Methodical Designing), Köln: Verlag TÜV Rheinland, (1994) pp. 1–37.

Ernst Eder was employed in the 1950s in industry, mainly in Austria, in detail design engineering ranging from vehicles for alpine forestry to electrical power transformers and processing plant for steel strip. His first academic appointment was at University College, Swansea in 1961 where he started his involvement in teaching engineering design. He was granted an M.Sc. in Engineering from the University of Wales in 1968. He was Associate Professor in Mechanical Engineering at the University of Calgary (1968–77) then moved to Loughborough University of Technology, UK, to help in developing a Design and Manufacturing option within the Department of Engineering Production. Since July 1981 he has been in the Department of Mechanical Engineering at the Royal Military College of Canada, Ontario, where he is still heavily involved in design teaching. He was made Professor in 1987. Ernst Eder has published more than 130 papers on design methodology and teaching, has co-authored seven books on the subject, and edited the Proceedings for the International Conference on Engineering Design, ICED'87, Boston, and an International Workshop on Design held in the Czech Republic. Since 1980, he has worked closely with Dr V. Hubka, Zürich, and the WDK (Workshop Design Konstruktion) society.