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ABSTRACT

An examination of the development of the technical and technological disciplines in Germany over the last 500 years shows that these disciplines have recognized key developmental stages. They have evolved from the practical-oriented approaches, through knowledge-, process-, and methodology-oriented approaches, to the strategy-oriented approach. The determining factor in the human technology relationship--particularly in the field of production--has been identified as the further development/advancement of capability, not the mere satisfaction of need. From this point, new questions arise with respect to the handling of information masses as well as the capabilities for choosing the appropriate storage and retrieval mechanisms. The development process involves seven key stages: recognition of a problematic situation (thought initiator), overcoming thought barriers, envisioning possible solutions, model development (resolution of contradictions), development of approach strategies, development of time and activity plan, execution of the plan, evaluation of the results, and recognition of the new situation/problematic situation. For the technical innovation process, each of the typical barriers between the processes' stages requires the access to and proper use of a different information mass. A recommendation for education about technology is for improvement of analytical capabilities to empower people to use the problem-solving/innovation process. (YLB)

A Modular Conceptual Framework for Technology and Work

Invited Lecture

**Prepared for the
Technology and Work Theme
Technological Literacy VI
National Conference of the
National Association for Science, Technology, Society
Washington, D.C.**

by

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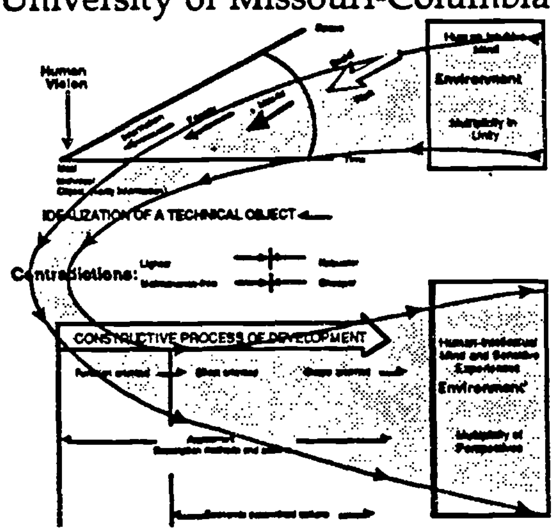

Abstract

A Modular Conceptual Framework for Technology and Work[1]

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Invited lecture presented to the National Association for Science, Technology, Society conference, Technological Literacy VI, February 1-3, 1991, Washington, D.C., U.S.A.

This paper presents a view of the outcomes of the development of the technical and technological disciplines in Germany over the last 500 years. One major finding is the recognition of key developmental stages in these disciplines. They evolved from the practical-oriented, through knowledge-, process- and methodology-oriented to the strategy-oriented approach. To conceptualize the instructional, engineering and science perspectives on technology/production processes, the paper begins with the pillars of materials, energy and information. These traditional elements are augmented by the concept of technological organization. In addition to these perspectives, we have identified four key factors common to all production processes. These are: Changing of condition or situation; the process; location and point of time characteristics, and the technical artifact or means. Using these perspectives, elements and factors, one can develop a modular concept of technology and productive work.

In my paper's second part, the determining factor in the human-technology relationship--particularly in the field of production--is identified as the further development/advancement of capability -- not the mere satisfaction of need. From this point, new questions arise with respect to the handling of information-masses as well as the capabilities for choosing the appropriate storage and retrieval mechanisms. The development process involves seven key stages: Recognition of a problematic situation (thought initiator), overcoming thought barriers, envisioning possible solutions, model development (resolution of contradictions), development of approach strategies, development of time and activity plan, execution of the plan, evaluation of the results and recognition of the new situation/problematic situation.

For the technical innovation process the typical barriers between the processes' stages are: Recognition of trends, Definition of function/contradiction, Solution of contradiction and the exploration of natural laws, Realizing of the principle,

[1]Thanks to Michael Dyrenfurth, Professor of Industrial Education, University of Missouri-Columbia, for assistance in translating, discussing and interactively detailing the ideas contained in this paper

Dimensioning of the elements/manufacturing, optimizing the solution, and Recognition of the solution's weak points. Each of these transition barriers requires the access to and proper utilization of, a different information-mass. These different information-masses are all unique in terms of hierarchy structure, nature of information they contain, and accessing method. It is important to note that the identified steps and barriers represent a composite synthesis of problem solving and innovation. Not all steps are used or barriers encountered in every situation. In the paper we provide just the examples for the information-masses of trend, generation-tables, contradictions, and assessment strategies.

The paper ends with selected thoughts for the education about technology. The focus is on the improvement of analytical capabilities to better structure problems to empower people to better evolve solution strategies and to develop the tools needed to proceed from step to step in the problem solving/innovation process by surmounting each barrier. The contradiction between the needed overview as well as the mastery of some detail is an ongoing problem for education that continually needs to be addressed.

A Modular Conceptual Framework for Technology and Work[1]

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Introduction

Technology has to be considered a very complex discipline based on the network of relationships among the individual, nature, society and knowledge. There is also a causal link between development of society and development of technology. The context in which technology operates involves all spheres of daily life of all people and indicates the effectiveness of societies as a whole. Therefore the relationships between people and technology are best characterized as development relat ns and in this special dimension may be considered as irreversible.

Technology is: "...the know-how and creative process that may utilize tools, resources and systems to solve problems and to enhance control over the natural and man-made environment."[2]

The purpose of this paper is to present, from our German perspective, the basic principles that frame a coherent theory relating technology and work, both in their existing condition as well as technology's developmental/innovation aspect.

We have, in Germany, and now I mean in both of the formerly separated halves, a well developed system of technological education -- in both its important dimensions: General education and vocational education.

In Germany, teachers of physics, mathematics, language and history work along side the technology teacher. The subject taught by the latter is generally named with some combination of *Technic, Work,* and *Economics*. The approach used for the 11th, 12th and 13th school years varies from Land to Land (Germany now consists of 16 Lands).

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[1]Thanks to Michael Dyrenfurth, Professor of Industrial Education, University of Missouri-Columbia, for assistance in translating, discussing and interactively detailing the ideas contained in this paper
[2]UNESCO. (1985). International Symposium on the Teaching of Technology within the Context of General Education. Paris, France: Author.

More well known however is Germany's exemplary, results-oriented system of vocational education. We term it a Dual System because both schools and companies cooperate in delivering it although the responsibilities of both are strictly defined and separated. In addition, we also have a complete system of higher and advanced technology education in our universities and technical colleges/institutes[1]. Both sets of institutions prepare both technologists and engineers. In addition to the traditional range of programs for such people (e.g., mechanical, electrical...) these institutions also are beginning to offer a set of new programs. These include: Environmental technology, Medical technology, Communications technology, Instructional technology, Bio-technology, Recycling technology, Technological cybernetics, Optical technology and Economic information technology.

From my perspective, the multiplicity of specific preparatory programs, and the private sector's demand for the immediate utility of new hires, generates a serious problem. In essence graduates are capable in a significant number of specifics, but larger, more long-range and powerful capabilities seem to be seriously slighted. In addition the ability to properly cope with information in today's information intensive environment, the ability to structure problems, and to frame strategies for the problem solving/innovation process, will become more important. Note that we use the term problem solving/innovation deliberately because the outcome of this process is for our purposes always something new or non-existent in the consciousness of the *doer*.

The three principal examples of the latter are:

1. The understanding and overview of the structure of production processes and the principles of technology.

2. The understanding of the strategies and structure of product innovation

3. New information-masses as a part of innovative thinking

Given the preceding, it is clear that the educational systems must learn to better prepare people for technological careers. An essential aspect of this improvement is that they learn to address the three preceding capabilities in an interactive fashion.

[1]Interesting is the trend that the graduates of the technical colleges/institutes, who even possess one less year of preparation, are in greater demand than those of normal universities.

1. The understanding and overview of the structure of production processes and the principles of technology.

Explanation of this point begins best with a short historical example[1].

Prehistory until about 1500	Transition/ prerequisites 1500-1800	Development 1800-1850	Consolidation 1850-1920	Transition to systems theory since 1920	
Practical oriented	Knowledge oriented	Process oriented		Methodology oriented	Strategy oriented
Technical knowledge/skills	Systematic descriptive technical knowledge	Classical technical disciplines		Engineering and technological disciplines	
Practical methodical knowledge ↓ technological knowledge ↓ Constructive technical knowledge→	Development of the natural scientific mechanics → Constructive technical knowledge (descriptive) ↓ Technological knowledge (descriptive) ↓ ↓ Specific general engineering (technology)→	Traditional disciplines of the mechanical cycle (machine building) Technological disciplines Mechanical technology ↓ ↓ Division into techniques ↓ ↓ Classical production engineering	Differentiation into → ↓ ↓ internal external ↓ ↓ structure (basic components) industrial branches Chemical, etc. technology ↓ ↓ Division into processes ↓ ↓ Classical process engineering	Formation of an independent theory of machine design from the classical engineering and technological disciplines	Formation of an independent theory of innovation processes based on the methodology of engineering and technological disciplines

Blandow/Dyrenfurth/Lutherdt, 1991

Figure 1. Unity of construction (design) and technology (engineering) in the structure of the sciences.

The figure documents a long history involving key questions about the relationships between science, technology and engineering continually arise. Similarly the tension between general versus specialization in technology-oriented education is a perennial thorn.

If this perennial reoccurrence is actually the case, one must ask, what causes it to emerge with such regularity? Two answers appear with similar frequency. One involves the acceptance/respect of one discipline's

[1]Lutherdt, M. (1990). Zu den konstituierenden Elementen ausgewählten technischen Wissenschaften. Wissenschaftliche Zeitschrift der Pädagogischen Hochschule "Dr. Theodor Neubauer". 26(2). [Erfurt, Germany-East]

practitioners for those of another. Frankly, I've thought about offering an "interdisciplinary tolerance" course at my institution.

The second, and more important problem, is the lack of recognition of those in a discipline for their field's necessary interactions with and dependence on essential components of other disciplines. Therefore we must be clear about two insights:

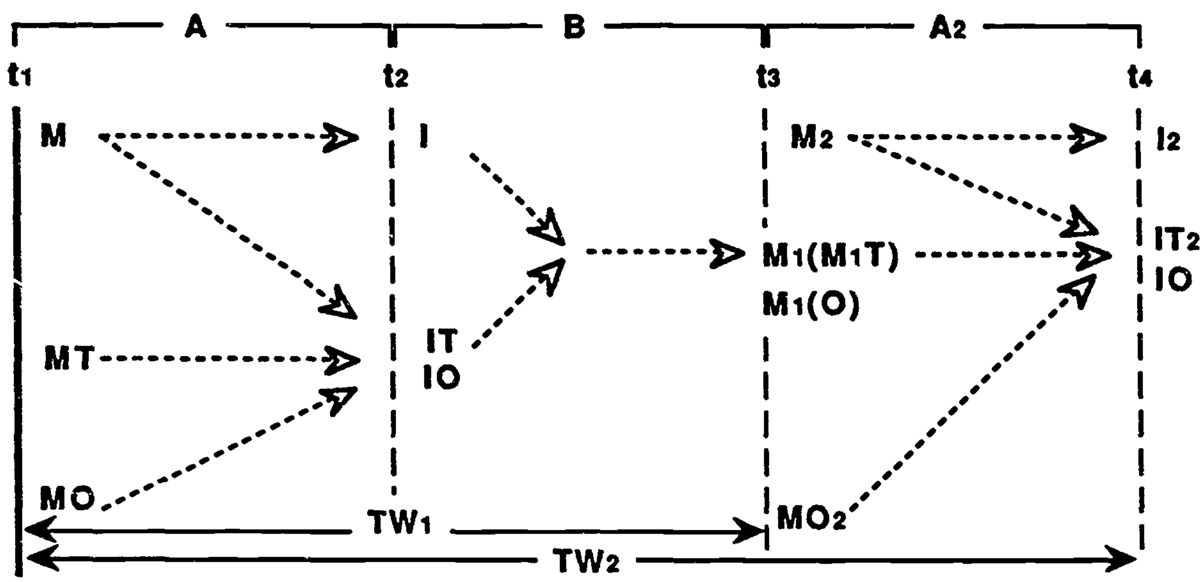
1. There exist natural overlaps among disciplines

2. The further development of society depends on the interrelationships among disciplines and the differences of their individual perspectives and approaches.

To examine the relationships of the unity of disciplines versus their uniqueness, I use the concepts shown in Figure 2. From the author's point of view, the key to developing the capability for arriving at the proper answers is to find the right starting points in one's research activities. Especially for technological subjects, the keys to all technological solutions are found in the terms z and Δz (see Figure 3).

The condition or situation, the changing of conditions or situations, the relations between input and output and feedback are the key points for understanding technical artifacts as well as technological processes.[1] Note the pertinent question here is in fact the key question. It is not so important to know what is being produced. Instead, the salient issue is what changes and processes are being used -- i.e., how are we processing!

[1]Blandow, D. (1990). A Modular Concept for Technology Education and Work. Fulbright Colloquium paper. London, UK: Southbank Polytechnic.

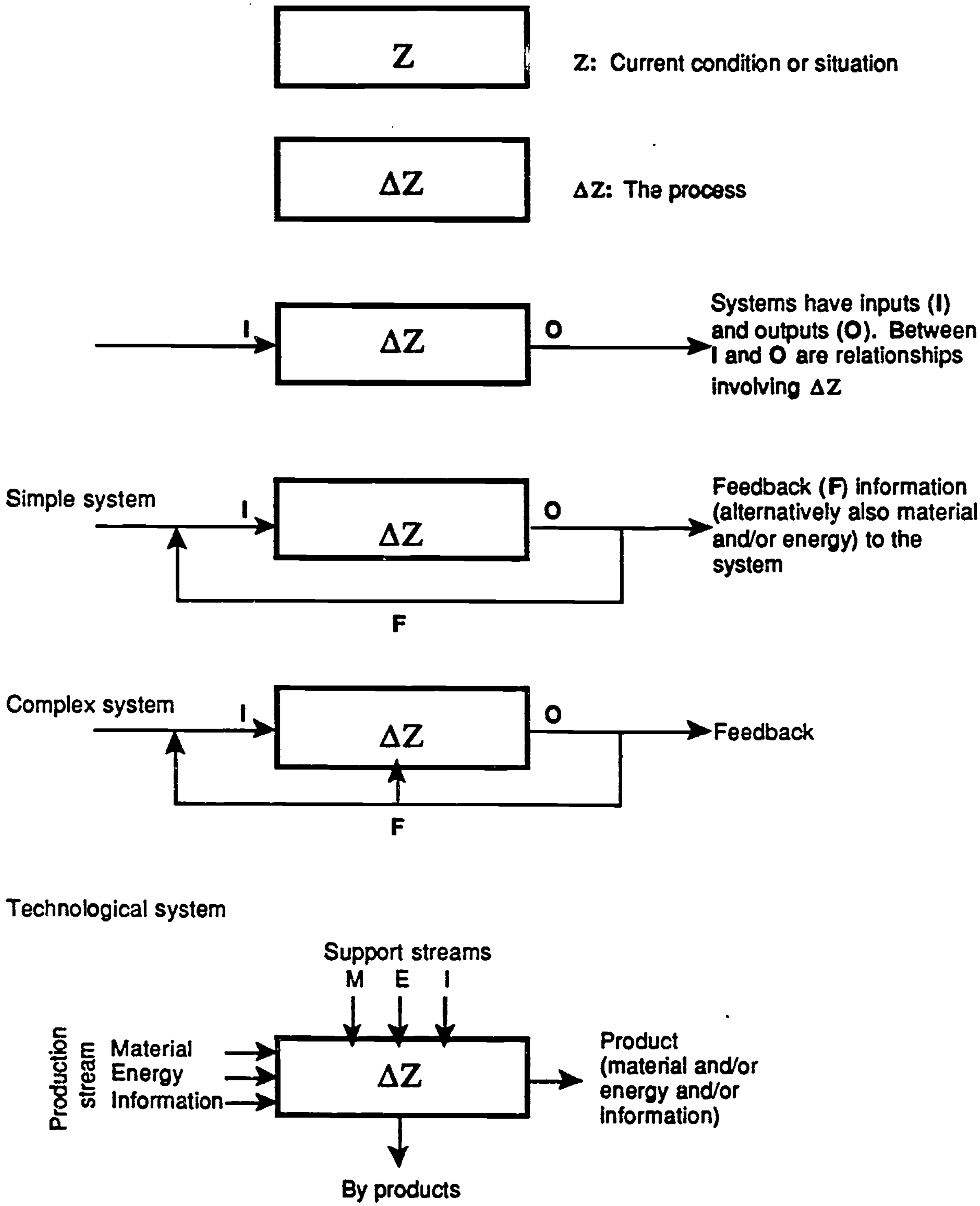


Blandow/Dyrenfurth, 1991

Legend

M	=	The material (natural) researched by scientists (e.g., physicists, chemist, biologist)
MT	=	The material, man-made object, that is developed by the technical scientist or engineer
MO	=	The organization arrangement and practical means (established by technologists)
I	=	The ideal as a result of the insights of scientists
IT	=	The ideals as a result of the insights of technical scientist or engineer
IO	=	The ideals as a result of the insights of the technologist
$M_1(M_1T)$	=	The new man-made object
M_1O	=	The new man-made organization arrangement
A	=	The domains of scientists and technical scientist or engineer where they operate independently of other disciplines
B	=	The domains where scientists and technical scientist and engineers they operate interactively with other disciplines as a team.
TW_1	=	The domain of technological assessment
TW_2	=	The domain of technological and economic assessment
$t_1 \ldots t_3$	=	Time for the first cycle
$t_2 \ldots t_3$	=	Research and development time for the second cycle

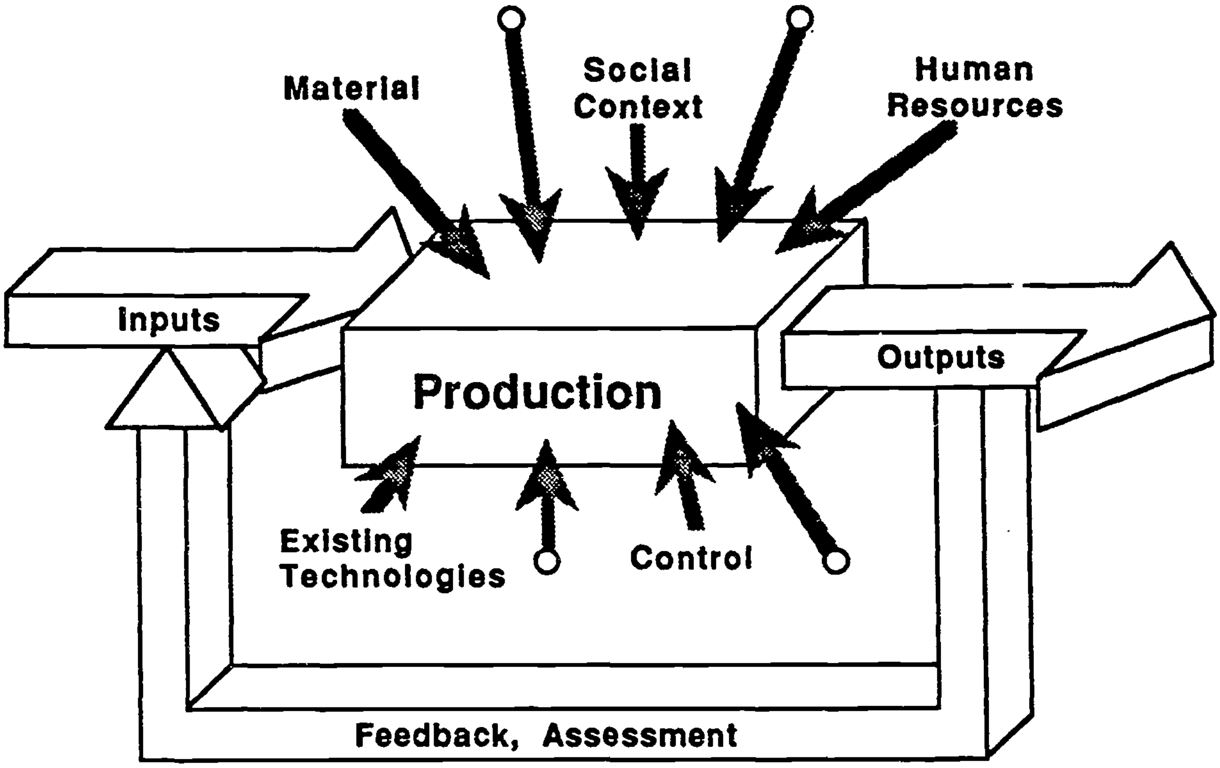
Figure 2. Model to explain the unity and uniqueness of various disciplinary perspectives views in the production cycle



Blandow/Dyrenfurth, 1991

Figure 3. Key elements of production systems

Naturally there are also general models which resulted from research to establish an overview. Figure 4 is one such model.



Blandow/Dyrenfurth, 1991

Figure 4. Model for the production process

The German approach emerges from the dynamic tension between the reductionist methodology involving specification of elements (as in Figure 3) and the holistic systems view such as the example depicted in Figure 4. Of interest now is the question of how one reconciles these two poles of approach. Our goal was to establish characteristic planes between these poles in order to identify key constants that facilitate understanding and enhance generalizability. Examination leads to the same four key frames of reference and they are used at all levels of my overall model.

1. The change of condition/situation Z1, Z2, Z3.

2. The process, ΔZ.

3. The location and/or point of time characteristics.

4. The technical artifacts or means.

In reality, these four key frames of reference interact in various planes and levels (see Figure 5).

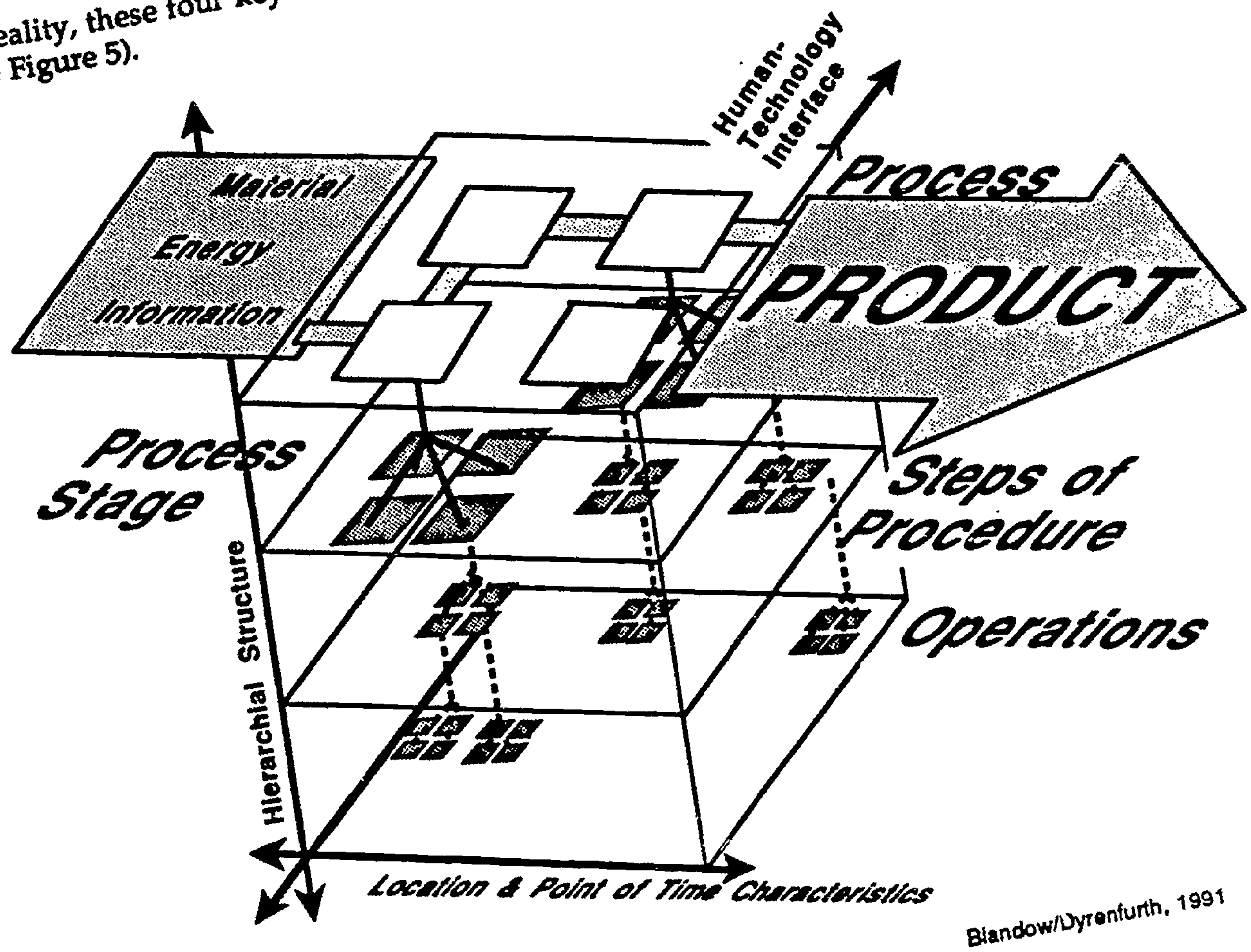


Figure 5. Hierarchical structure of production processes

This structure, shown in Figure 5, may be used to describe, explain and/or analyze production in any of the realms typically used. It is most important to note that the model is equally applicable to the traditional industrial realms of paper, metal, wood, and plastics work; as well as to the food processing industry, e.g., cheese, sugar, meat and milk processing; or the process industries such as petro-chemical, waste-water, and bio-technical. Furthermore, although not as frequently applied because of history, the model clearly also fits agriculture. From this illustration, it becomes clear that we know much about each individual level. We know much detail about material, energy and information -- but the principles that each embodies are less well known. Even less well known than these are the principles governing vertical linkage between the levels. Another great weakness is our ability to formulate variables and make decisions. The same situation is observed in the hierarchical system of technical artifacts shown in Figure 6.

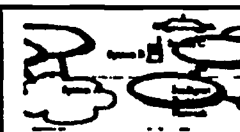
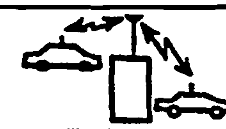
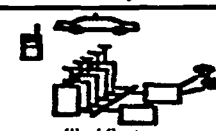
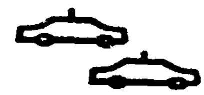
Level Six	Cybernetic Systems	 Infrastructure
Level Five	Integrated Networked	 Traffic System
Level Four	Networked Systems	 Taxi System
Level Three	Systems	 Separate Automobiles
Level Two	Standard Assemblies	 Clutch
Level One	Standard Components	 Transistors

Illustration: Tim Trogden Blandow/Dyrenfurth, 1991

Figure 6. Hierarchical system of technical artifacts

Made visible however, is the concept that hierarchy can be used to establish understandable order -- just like we learned from our study of technical artifacts (see Figure 6). The relationships between these two models, the hierarchical model of production processes and the hierarchical model of technical artifacts, are critically important but they fall outside the scope of this paper's main discussion.

The first result[1] of our work to make sense of technology was a useful structure to make sense out of the multiplicity of production by creating a matrix of the three pillars (materials, energy, information) against the nature of change (shape, structure, location, time) was shown in Figure 7.

Object of work	Nature of Change			
	Form/Shape	Altering	Location	Time
Material	Material shaping	Reconstituting	Materials handling	Aging, Wine, Patina
Energy	Energy processing	Energy conversion	Energy transfer	Half-life
Information	Information handling	Information processing	Communication	Obsolescence

Blandow/Dyrenfurth, 1991

Figure 7. Matrix between objects of work and nature of change

If one includes the principles of technological organization together with the preceding matrix, one arrives at the principles of production. This combination, depicted in Figure 8, has not yet been found elsewhere in the literature. When found or developed, however, it would become a most useful tool to help understand the correlation between the several planes (as in Figure 5) and to understand the strategy of their combination for solving specific technologic/innovation challenges.

[1]Blandow, D. & Wolffgramm, H. (1975). Zur Spezifik der fachwissenschaftlichen Grundlagen der Ausbildung von Diplomfachlehrern für Polytechnik. Wissenschaftliche Zeitschrift der Pädagogischen Hochschule "Dr. Theodor Neubauer". 11(1), pp. 5-14. [Erfurt, Germany-East]

Sample goals of process operation	Implications of the Goals on:			
	Changing conditions or situations, Z_1, Z_2, Z_n	The process, ΔZ	Location and point of time characteristics	The technical artifacts/means
Minimization of resources	Capitalization on material characteristics [Material structure]	Process integration WRT time [Work hardening]	Production timing (continuous/intermittent) [continuous casting, Just-in-time organizing]	Energy supply at point of use [Solar telephone, integral wheel-motors]
Increase of variability	Substitution, Alternative sequences [Recycled material aggregate]	Adaptation [Photochromatic glass]	Flexible reactions [Combine threshing drum pressure]	Standardized components [Microchip logic elements]
Increase of stability	Feedback systems [Sensor technology, Dash warning indicators]	Networking, optimization [Feedback driven control systems, assembly line buffers]	Quality assurance [Zero defect programs]	Parallel/redundant structure [Pilot/co-pilot]
Reduction of production cycle time	Activation characteristics [Catalysts, hardeners]	Increase of energy/work density at the work station [halogen lights, microcomputers]	Parallel processing, assembly lines [automobile manufacturing, Matrix computers]	Increase of frequency [Newspaper production]
Reduction of product planning and setup time	Standardized stock, modular construction components [Rolled steel, 4x8 panels, DIN paper]	Utilization of standardized (modular) process elements [Canned cycles in NC machines]	Modular machines, handling systems [Flexible manufacturing systems]	Automatic tool/jig fixture changers, robots [Computerized plant change over]
Increase in ecological responsibility	•••	•••	•••	•••
•••	•••	•••	•••	•••

Blandow/Dyrenfurth, 1991

Figure 8. Implications and goals of process operations

Consequences of point 1

Our scientific research yielded several insights that make things easier for teachers and researchers.

1. When one combines the constants of objects with the constants of processes of technology, one establishes one plane of my overall model (see Figure 9).

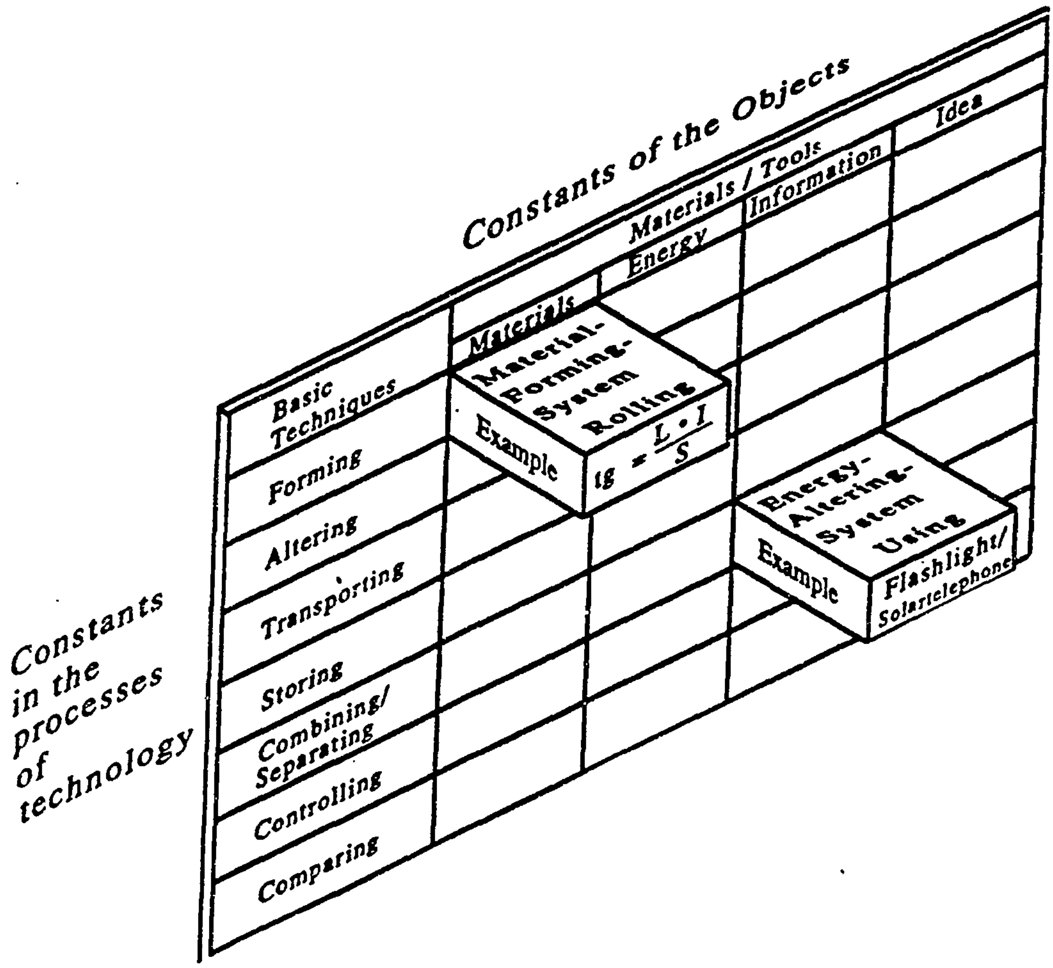


Figure 9. Model plane 1: Constants of objects vs constants of technological processes

2. The second plane is formed by combining the constants of the processes, with the constants of the objects. Then, by adding the constants of technology interaction sites one generates a three dimensional model that represents a matrix of technological activity. Selected provocative examples might include (also see Figure 10):

   - Energy transport in space
   - Material transport in hospitals
   - Information storage in water
   - Energy storage in water
   - Material altering in space
   - Information forming in factories

   Note that these are not merely academic musings or wishful thinking. Immediately behind them emerge questions regarding the emerging possibilities of technological capability. For example, and one step more concrete than the preceding, are:

   - Lasers as surgical tools
   - Electrophoresis gene identifying
   - Lasers as dynamic measuring devices
   - Biotechnology use in laboratories

   Furthermore, the emergence of such technological possibilities brings with it a responsibility to incorporate an inclination towards such forward looking tendencies into our various technician, technologist and technology educator curricula.

3. The large field of production principles (see Figure 8) is also used as an activity guide during our degree programs when we prepare students and researchers for practical work as engineers and teachers of technology.

4. Technology is interdisciplinary and all its applications represent compromises.

5. With the increase of relations between materials and energy (e.g., refer to column ΔZ in Figure 8) we can distinguish between laws of development and laws of structure (see Figure 11).

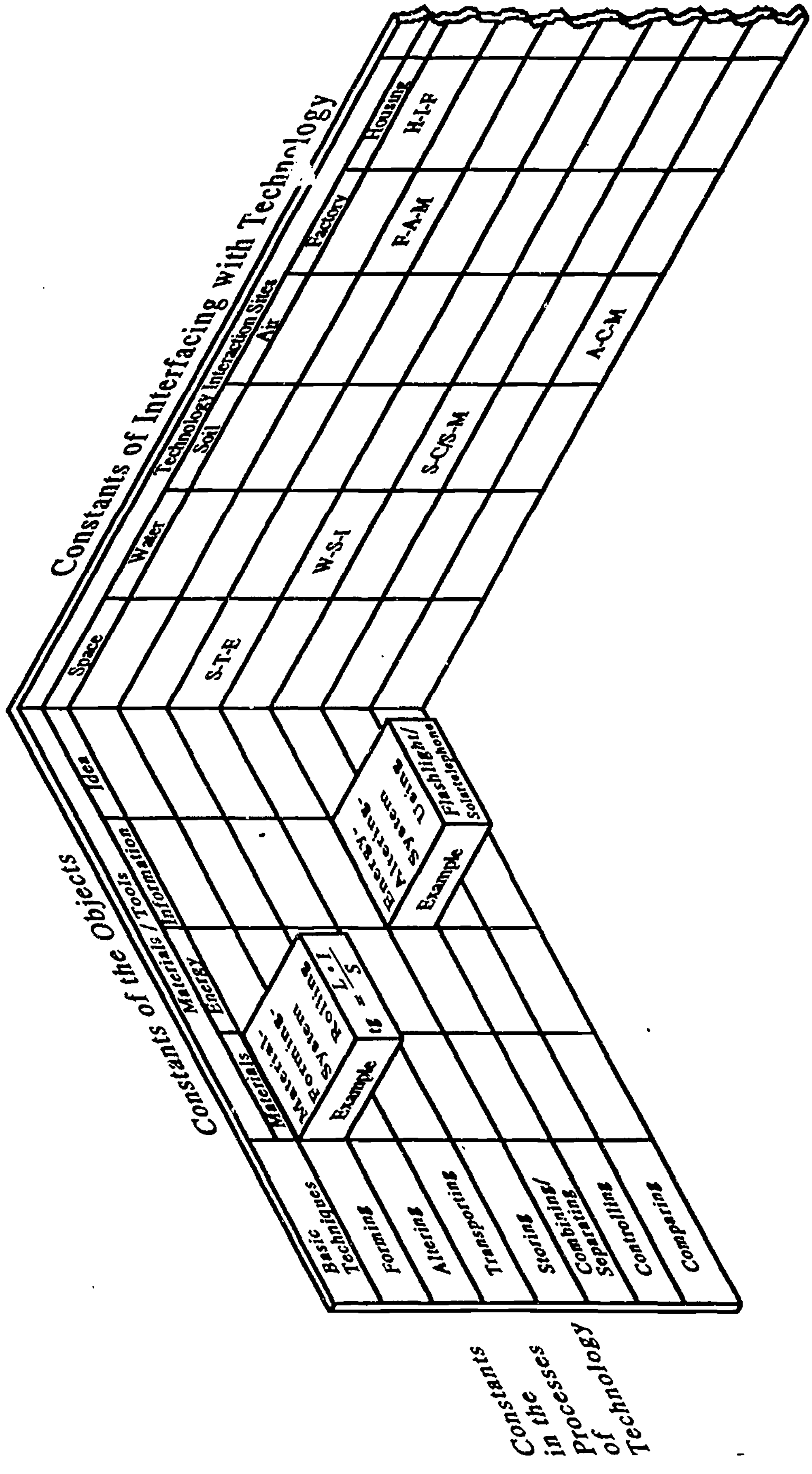


Figure 10. Model planes 2 and 3: Constants of technological processes vs objects vs interaction sites

Types of laws	Changing conditions or situations, Z_1, Z_2, Z_n	The process, ΔZ	Location and point of time characteristics	The technical artifacts/means
Structural laws	Coupling Feedback Parallelity	Structure of active principles • Form • Energy • Movement • Location • State	Degrees of freedom Flexibility Hierarchy Variability Adaptation	Flows are closed Σ Material = 0 Σ Energy = 0 Σ Information = 0
Development laws	Integration of function Continuous/ Intermittent Integration of present production with new developments	Increase of energy density, Integration of production and recycling	Shortening of the information flows Reduction in changeover time Increased variability of mass-produced items	Flexible workstations Increased output per unit mass Multiple use components

Blandow/Dyrenfurth 1991

Figure 11. Types of laws for understanding the structure and development of production processes.

6. The predominant focus of each domains of activity involved in the production process is depicted in Figure 12.

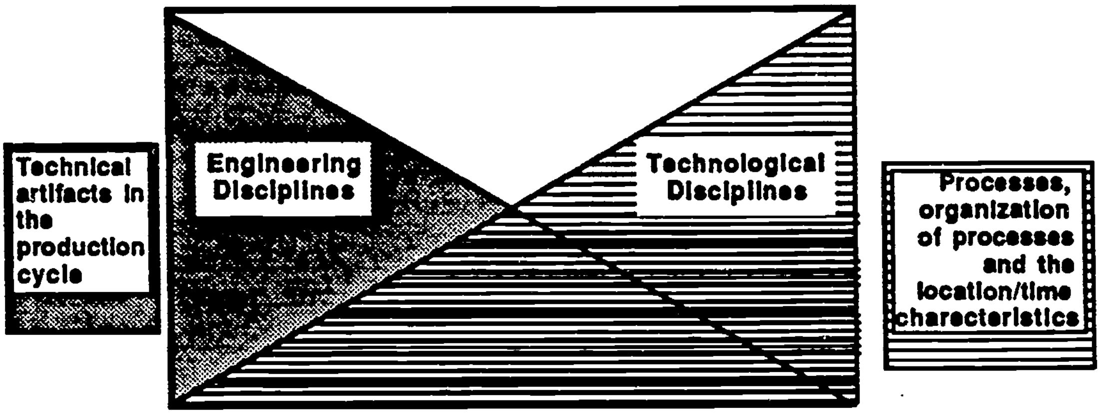


Figure 12. The dominant focus of engineering and technological disciplines

7. For instructional purposes, eight groups of themes emerged as important:
   a. Principles for determining the structure of technical and technological processes with respect to:
      - Structure of processes
      - Changing conditions
      - Location and time characteristics
      - Structure of technical artifacts
   b. Principles of development of technical and technological conditions:
      - Structure of processes
      - Changing conditions
      - Location and time characteristics
      - Structure of technical artifacts

2. The understanding of the strategies and structure of innovation

The recognition and solution of technological problems, the purposeful development of technical artifacts, the strategies, methods and tools of assessment are the alternative to a technical education, which is based on various traditional disciplines. This new element will involve the perception of systems and principles from single fields, will necessarily lead to connection, will train creativity and competence for decision of the personality etc.

Whenever one generation succeeds the other, even within product generations, innovation will be based on nearly the same principle, the Multiplicity in Unity. The example of ICARUS, Figure 13, points out that important concept. He was forced to learn to survive and to translate his wish for freedom into activities to keep busy. It was his vision of a palatable future, stimulated by the example of the freedom of birds flying over him, that triggered his innovation--his modeling of their wings.

Figure 13. The fable of Icarus

Gilbert's 'Icarus'. Reproduced by courtesy of A. & C. Black Ltd.

He builds wings and attempted to escape. The conclusion is known. This example's lessons for today's situation is shown in Figure 14.

Problematic situation (thought initiator) → Overcoming thought barriers → envisioning possible solutions → model development (resolution of contradictions) → development of approach strategies → development of time and activity plan → execution of the plan → evaluation of the results (mostly through experiments) → new situation/problematic situation.

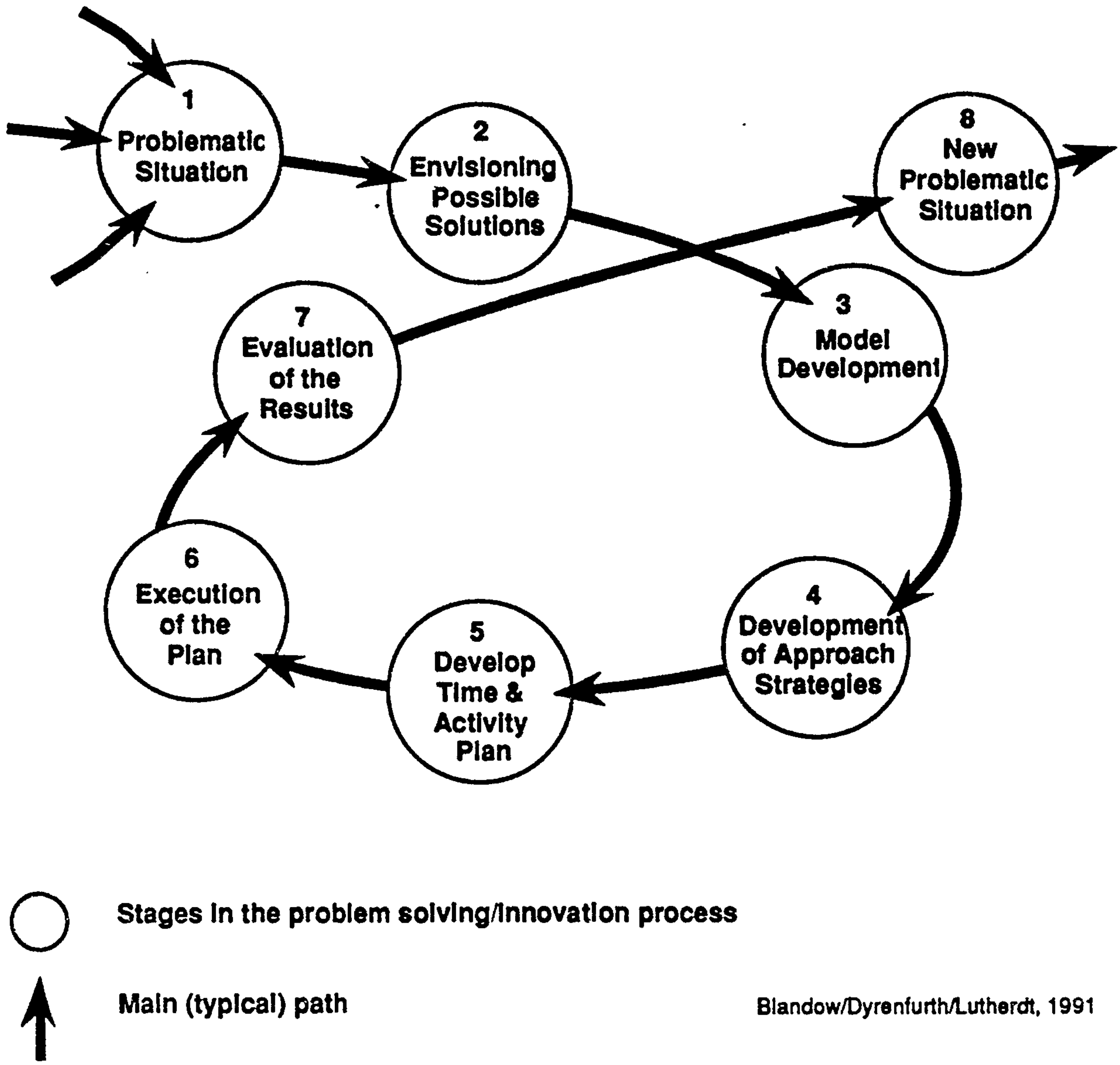


Figure 14. Stages in the problem solving/innovation process

The cycle is important today. The example from the fable shows us today, as it did in the past, the relationships between the tangible world, our mental concepts of it, the initiating value of our concepts/visions and the power of translating our ideas into practice via a systematic strategy. In further figures we depict the same concepts albeit with addition of time and economics as factors[1,2] (see Figure 15).

But this example also shows us, which barriers we experience in our thought processes and how difficult it is to overcome them[2,3]. The main point, however, is that we can now complete the modular concept from the activity point of view. With the seven key stages identified by analysis of over 100 documents, and our knowledge of the characteristics of the typical barriers, we are able to genuinely help people develop the thought processes necessary for effective technological problem solving/innovation.

All over the world, from Icarus to today, the problematic situation is the starting point for all activities. But today, internationally, up to 60 percent of the total development and lifetime of a product are used to overcome the 1st and 2nd barriers (the recognition of trends and the definition of function, contradictions and ideal systems). Therefore, consequences for technology education concerning the need--aim--motive and problem transformation are inevitable (see Figure 16, 17, 18, 19)

[1]Dyrenfurth, M. J. (1990). Rethinking technology education in the secondary school: Missouri's approach to technological literacy. Paper prepared for the Landesfachkonferenz Polytechnic--Arbeitslehre, Thüringen, German Democratic Republic, April 27-30, 1990.

[2] Dyrenfurth, M. J., et al. (1988). Resources for industrial technology education programs. Technology Education Division, ITEMS 1. Alexandria, VA: American Vocational Association.

[2]Klix, F. (1980). Erwachendes Denken. Berlin, FRG: Deutscher Verlag de Wissenschaften.

[3]Rubinstein, S. L. (1968). Das Denken und die Wege seiner Erforschung. Berlin, FRG: Deutscher Verlag de Wissenschaften.

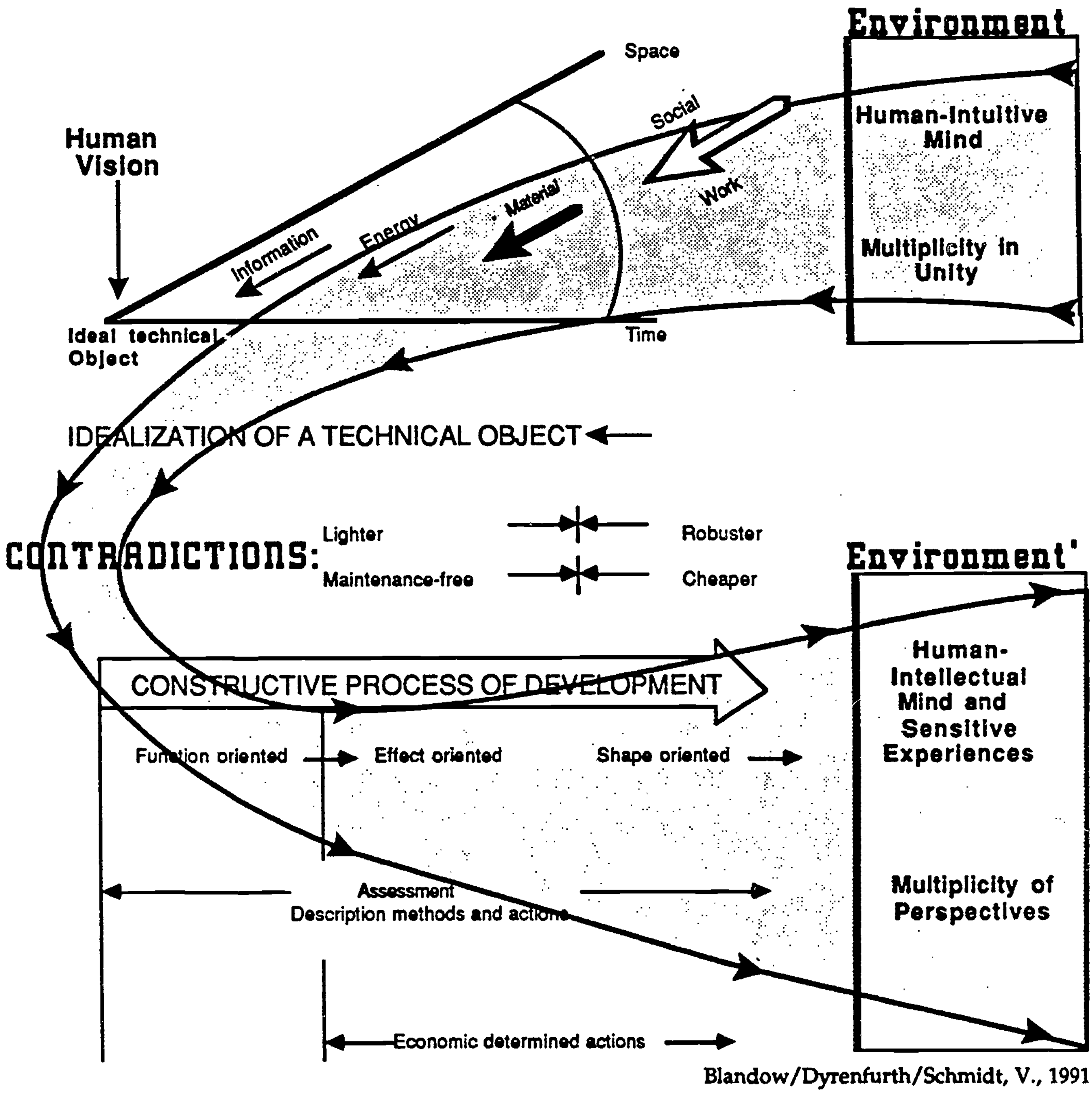


Figure 15. Concrete-abstract-concrete' -- The routes of technical thinking

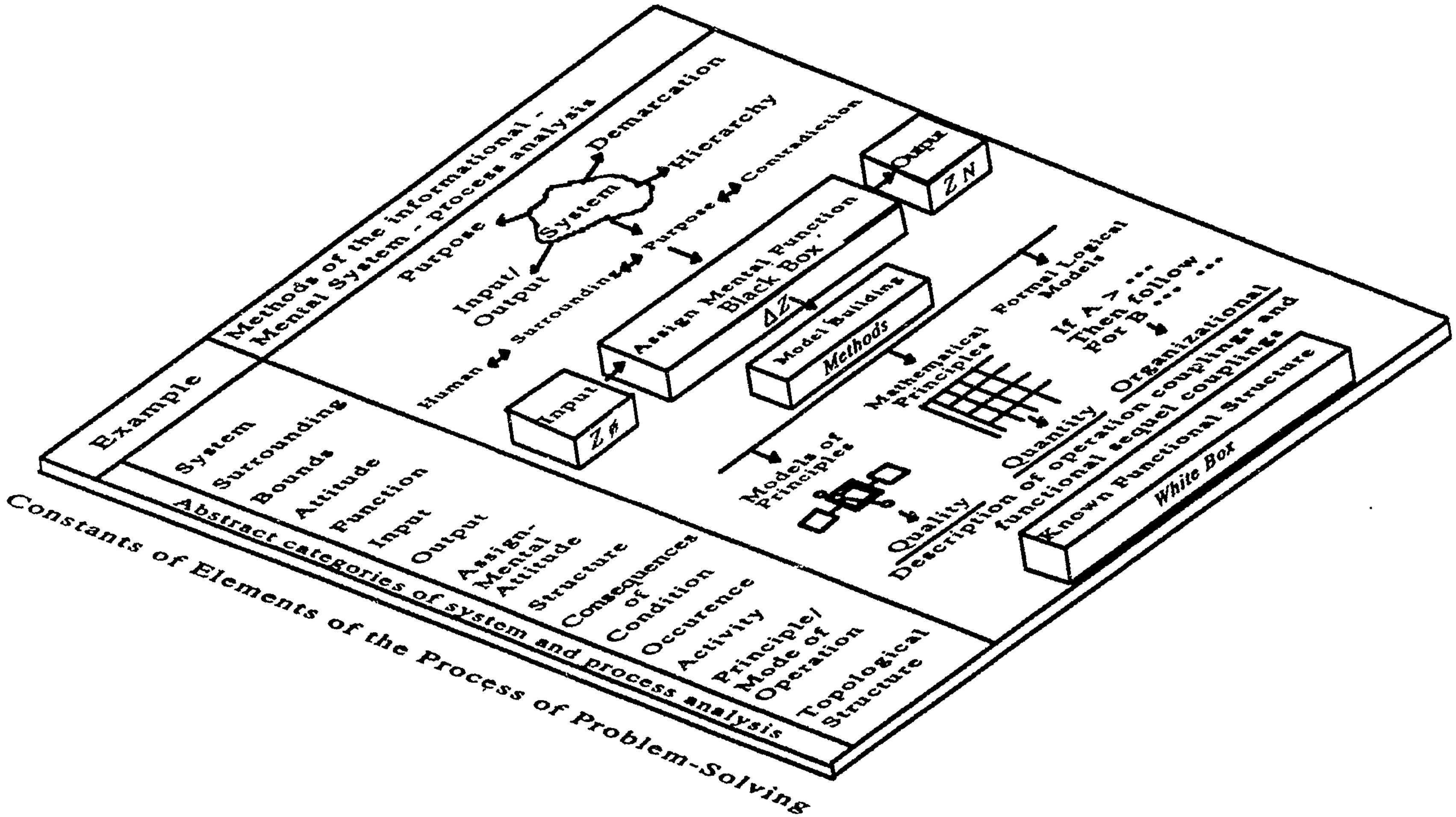
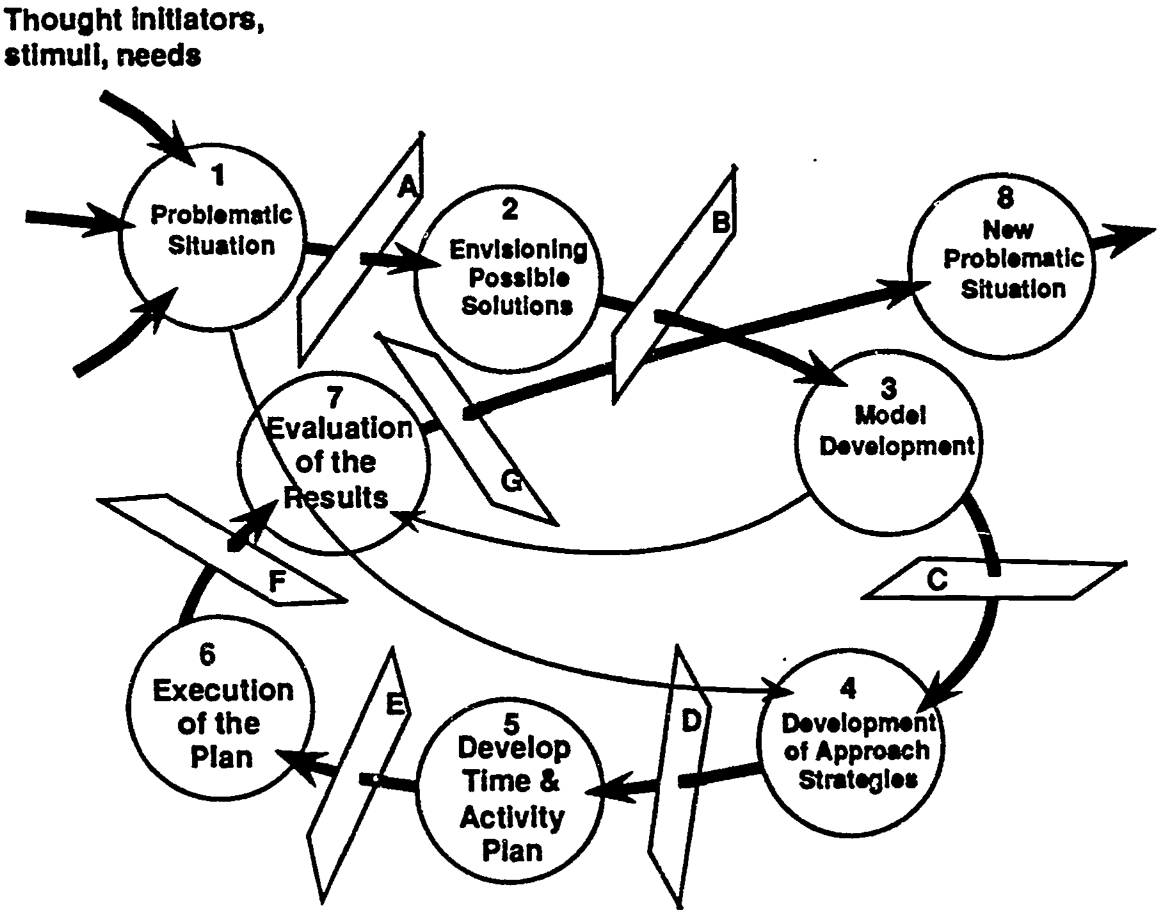


Figure 16. Constants in the elements of the process of problem solving/innovation



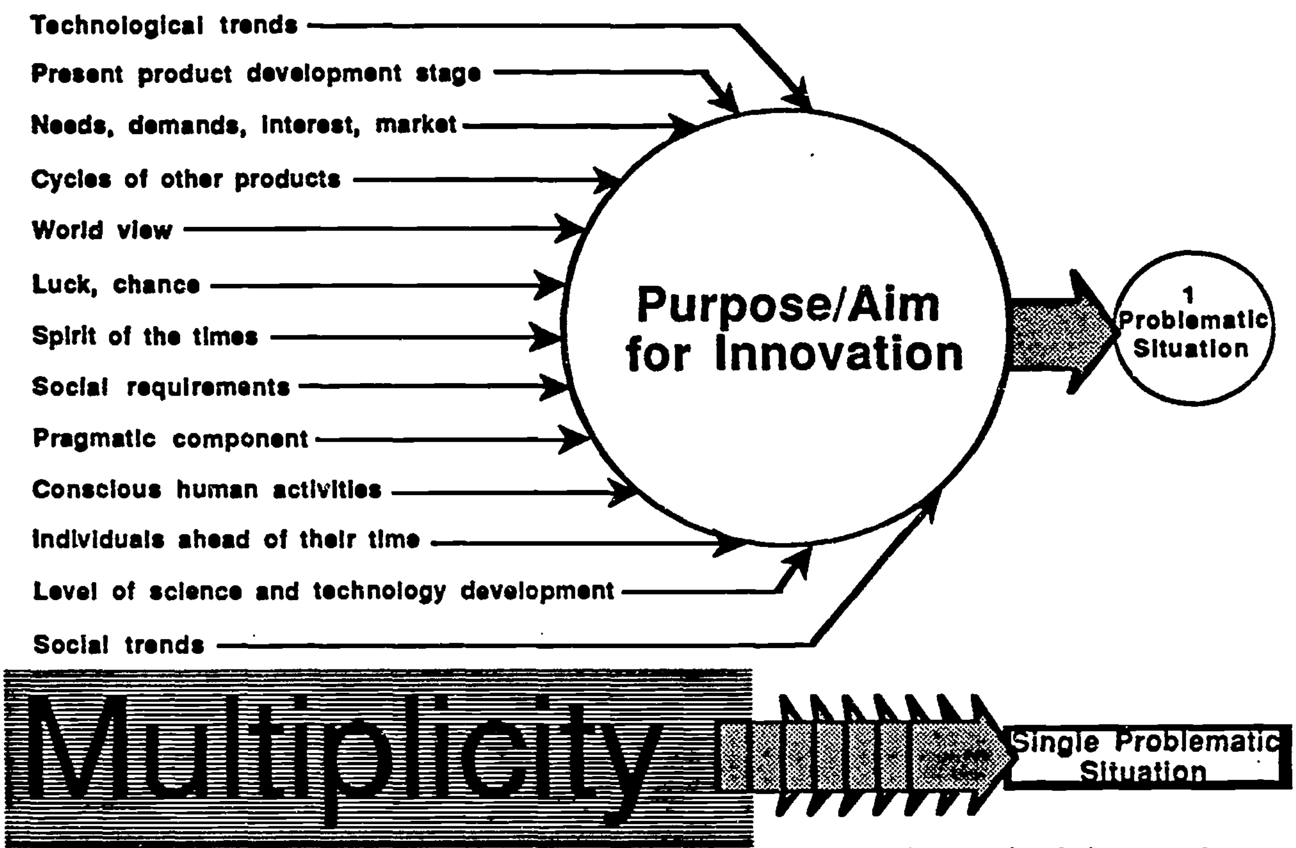
A. Recognition of trends, needs, ...
B. Definition of function, contradictions, ideal system
C. Solution of contradictions, variables, exploration of natural laws
D. Realizing of principles, development of material/energy/information system
E. Dimensioning of the elements/ manufacturing/testing
F. Modifying/optimizing the solution
G. Recognition of solution's weak points

○ Stages in the problem solving/innovation process — Main (typical) path

▱ Barriers to the problem solving/innovation process — Alternative paths

Blandow/Dyrenfurth/Lutherdt, 1991

Figure 17. Stages of problem solving/innovation, barriers and paths



Blandow/Dyrenfurth/Lutherdt, 1991

Figure 18. Strategies for overcoming need-aim barriers

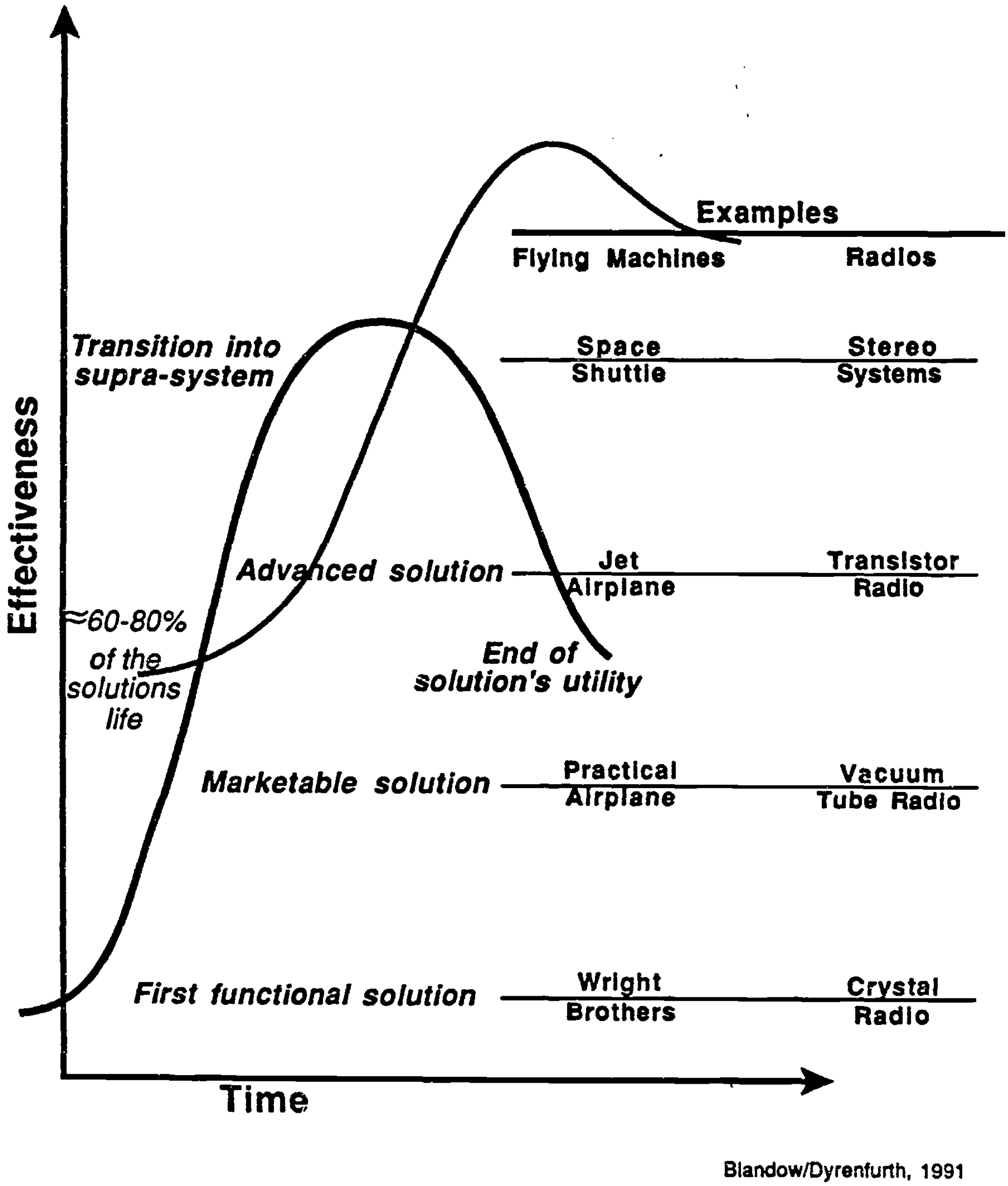


Figure 19. Developmental stages of products

Consequences of point 2

1. The approach used to define a problem or task is most decisive because along this route of abstraction and decomposition creative solutions will be generated by observing technical/technological principles and the reality given:
   - consideration of trends and formation of ideals,
   - using contradiction as a heuristic means,
   - planing, put into practice and evaluating experiments
   - initiative spirit situations (brain-wave, association,...)

The results of our findings are also summarized in Figures 20, 21[1]. As was stated previously, the problem solving/innovation process necessitates the overcoming of transition barriers which requires the access to and proper utilization of, different information-masses. These information-masses are each unique in terms of hierarchy structure, nature of information and accessing method. Remember that not all steps in the problem solving/innovation process need to be used in every situation. The logical consequence of this is also that not all barriers are encountered every time.

How to find contradictions and to define them will be demonstrated in the *Worksheet for the formulation of contradictions to trigger innovation*. The heart of the matter involves the identification of the requirements, their grouping by appropriate characteristic, and the framing of the key contradictions.

Thinking in contradictions will help the people in charge, by their own creative characteristics, to find new orders for answering their purpose.

They will continue to restructure and rearrange their thoughts which will also be kept in tension and motion due to verbal operations such as formulating the contradictions.

[1]Blandow, D. (1988). The system of polytechnic education in the GDR. In J. Raat, R. van der Bergh, F. de Klerk Wolters & M. de Vries, (Eds.), Basic Principles of School Technology, Volume 1, pp. 116-136. Eindhoven, The Netherlands: Eindhoven University of Technology.

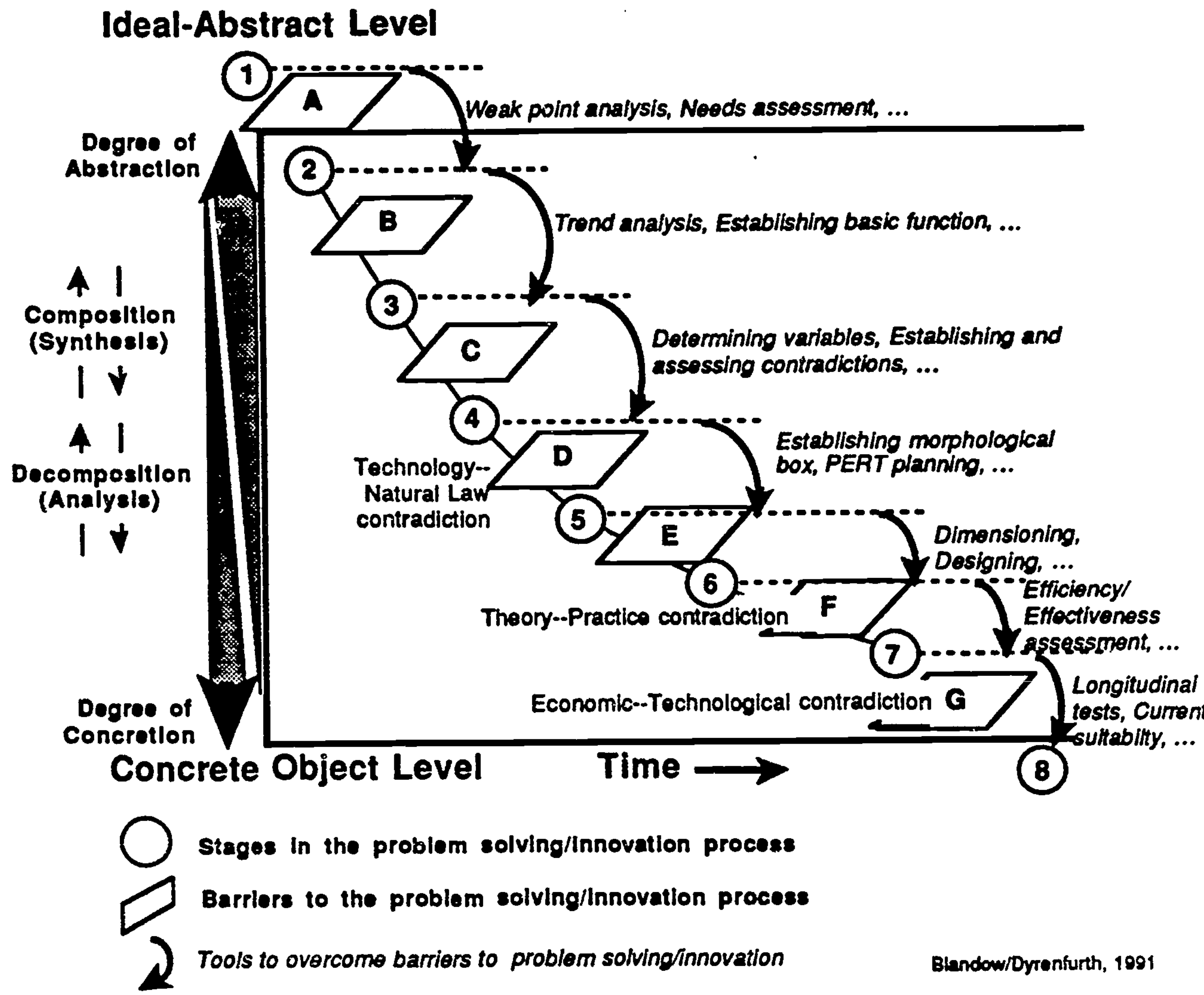


Figure 20. Tools for overcoming barriers to problem solving/innovation when moving from abstract to concrete and from concrete to abstract, continues

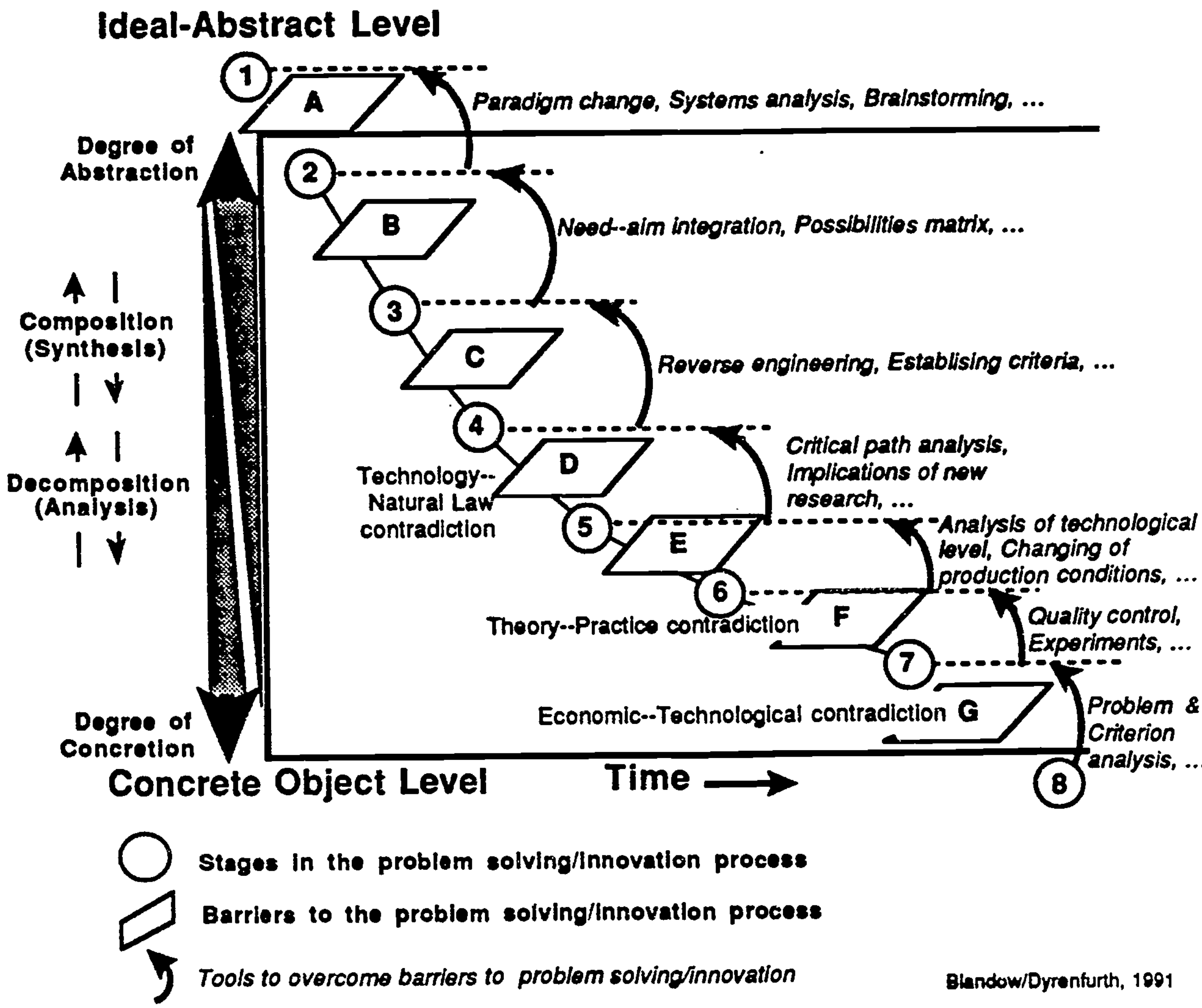


Figure 20. Tools for overcoming barriers to problem solving/innovation when moving from abstract to concrete and from concrete to abstract

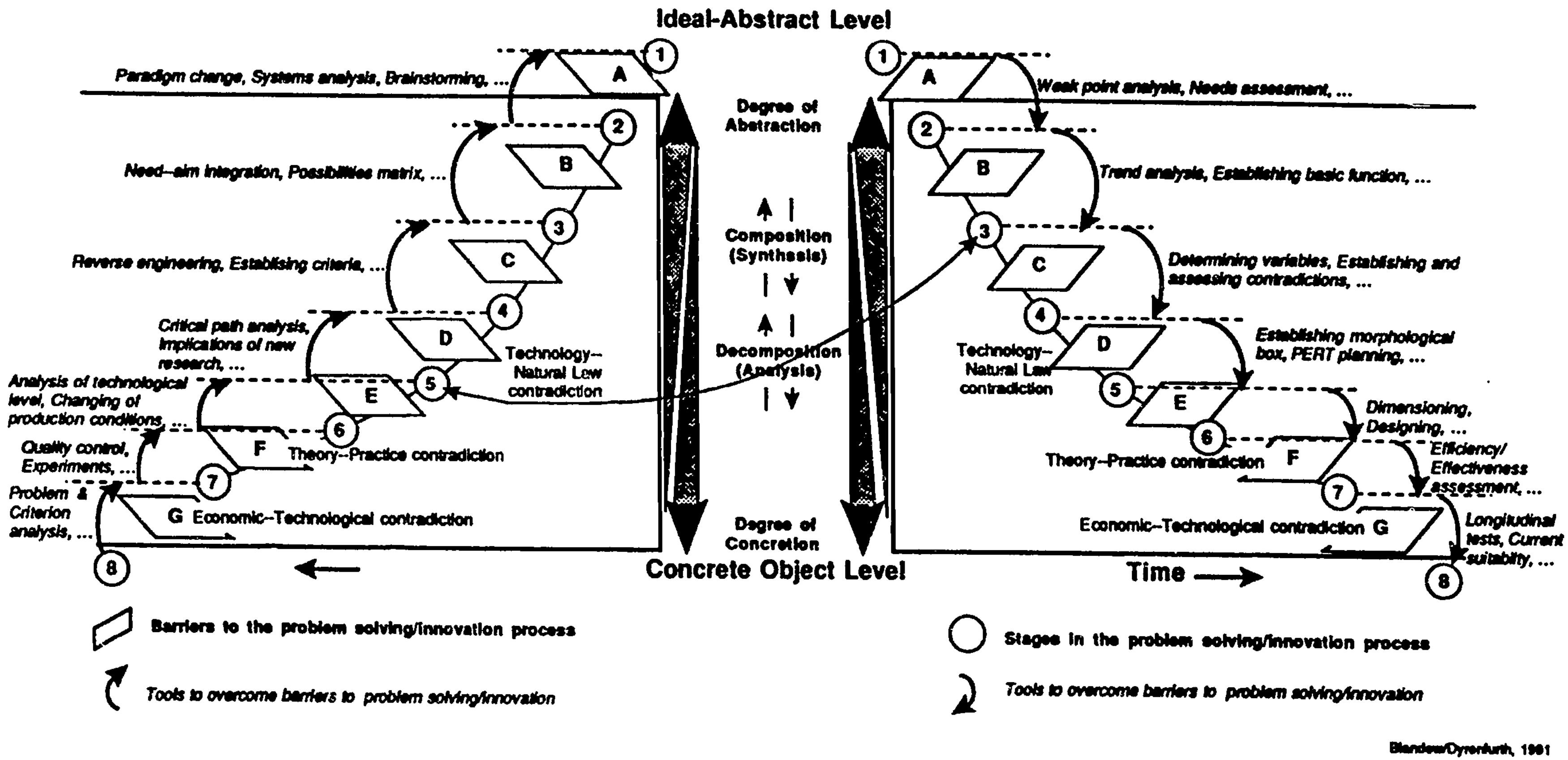


Figure 21. Overview of problem solving/innovation stages, barriers and characteristic tools to enable establishment of solution strategies

2. Recognition and solution of technical problems will happen in sequence of emerging of technical contradictions, their solution and further emergence. The first step taken in working on contradictions will be abstraction[1]. In a heuristic way, we will find on our road to determine the tasks, levels of abstractions (related to the above explained four elements of production).

   - social-economic-technological contradictions for the completeness of the technical system to be developed

   - technological contradictions between the process ΔZ and the conditions Z_1, Z_2, Z_3, Z_n

   - technological- technical contradictions for any partial systems (partial function)

   - contradiction based on both, technology and nature within a partial system.

3. We have thought as contents of an innovation methodology laws of:

   - the development of social and individual needs,standards, resources,

   - the development of the market and of demands

   - laws of:
     -the structure and development of technical systems
     -the structure of technological assessment
     -the constants in the human technological interface

   - laws of:
     -the social creativity and the structure of information systems used on different levels in the process of problem solving

   - and so called heuristic principles, rules
     -principles of recognizing problems (of contradictions, of ideals)
     -principles of problem solving (association analogy, variation, combination,...)
     -principles of materialization (dimensioning, designing,...)

[1]Blandow, D., & Schneider, G. (1974). Polytechnische Bildung und Technikwissenschaft. Wissenschaftliche Zeitschrift der Pädagogischen Hochschule "Dr. Theodor Neubauer". 10(2), 33 ff. [Erfurt, Germany-East]

4. To arrive at solutions involves the problem solving process. The simplest views of problem solving may be depicted by a sequence and/or path network of alternative solution steps and solution stages as shown in Figure 22.

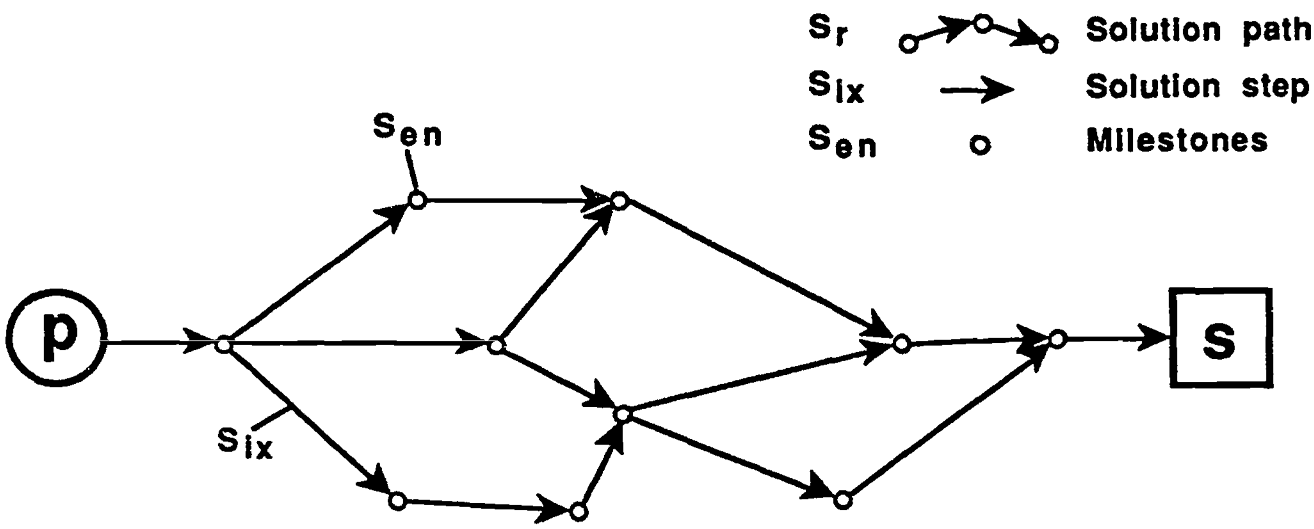


Figure 22. Problem - solution path alternatives

The way from p to s leads:

- along a solution road S_r - in data processing
- through a solution network S_n - set (strategies)
- with the solution steps S_i - program (algorithms)
- and the solution elements S_e - data (facts), milestones.

From this model we can come also to a hierarchically structured network of problem solving as well as to the modelling of the production process[1]. From the latter, we also come to the constants in the human-technological interface (see Figures 23 and 24).

[1]Blandow, D., Hille, H. & Lutherdt, M. (1988). Forschungsbericht der Forschungsgruppe Polytechnik-- Innovationsmethodik. Report to the Akademie der Pädagogischen Wissenschaften, Berlin. Erfurt, Bundesrepublik Deutschland: College of Education.

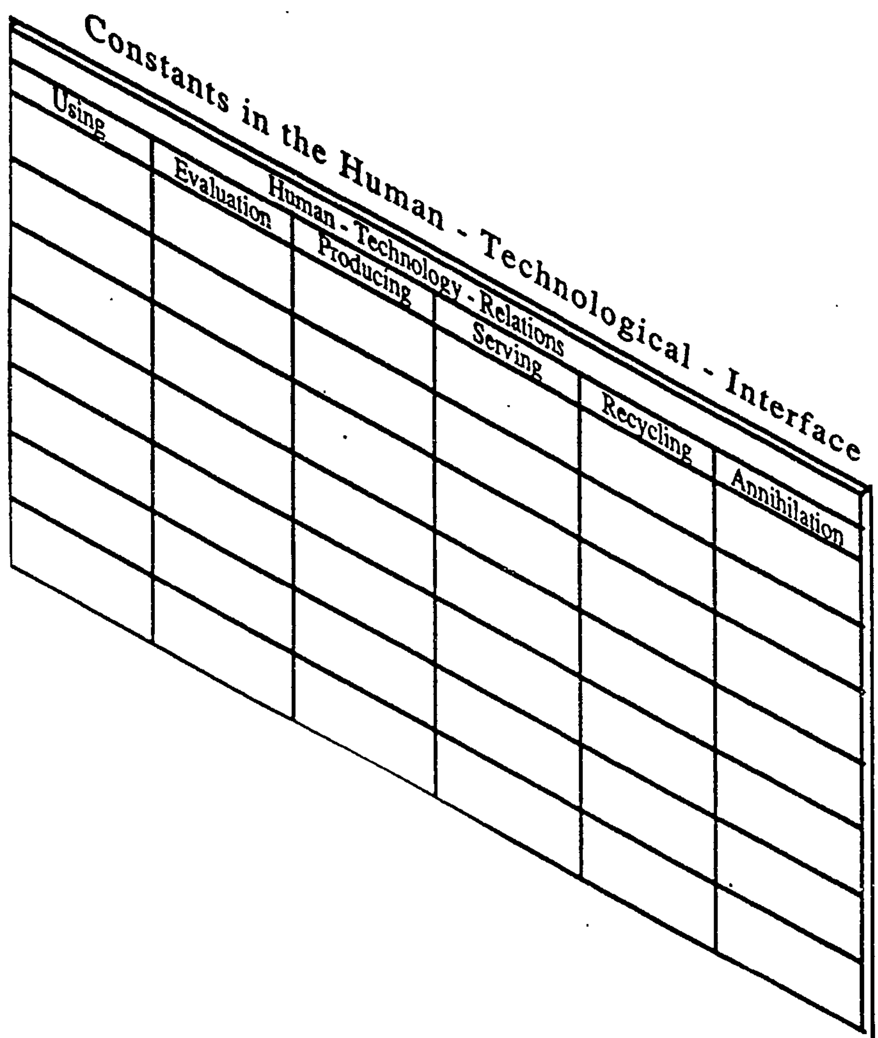


Figure 23. Constants in the Human-Technology interface

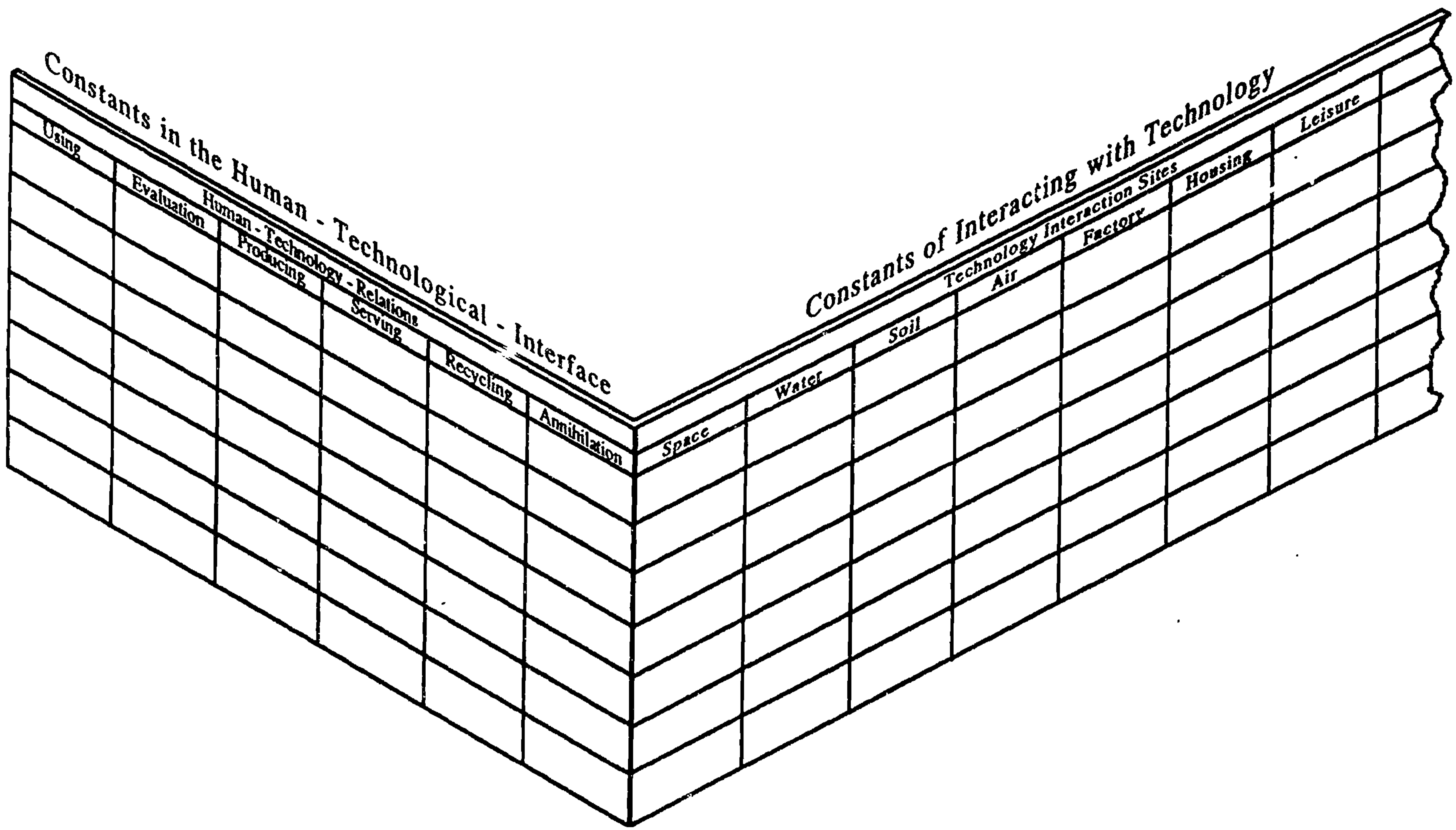


Figure 24. Constants of objects vs processes of technology vs interaction sites

39

40

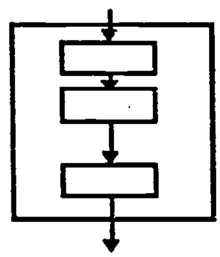
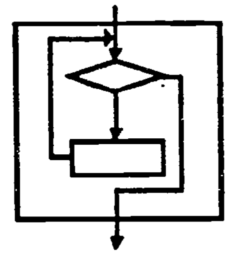
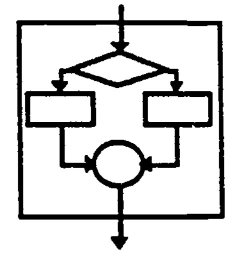
Basic Structure	Sequence	Feedback	Alternative
			
• Knowledge	....	If Next...	If Then ...
• Comprehension	Go To ...	....	....
• Application	....	...	...
• Analysis	....	...	...
•	....	...	...
• ...	....	...	...

Illustration: Tim Trogden Blandow/Dyrenfurth, 1991

Figure 25. Basic types of human activities

5. The constants in the Human-environment relationship, such as using, evaluating, etc. can be folded against the other planes of my technology model to create new interaction fields. With such a concept of modular planes one has a useful instrument/methodology to organize the multiplicity of technological applications/examples and on the other hand, it enables teachers and teacher educators to generate thousands of ideas and examples for teaching activities, insights and the furthering of innovative thinking (see Figure 26).

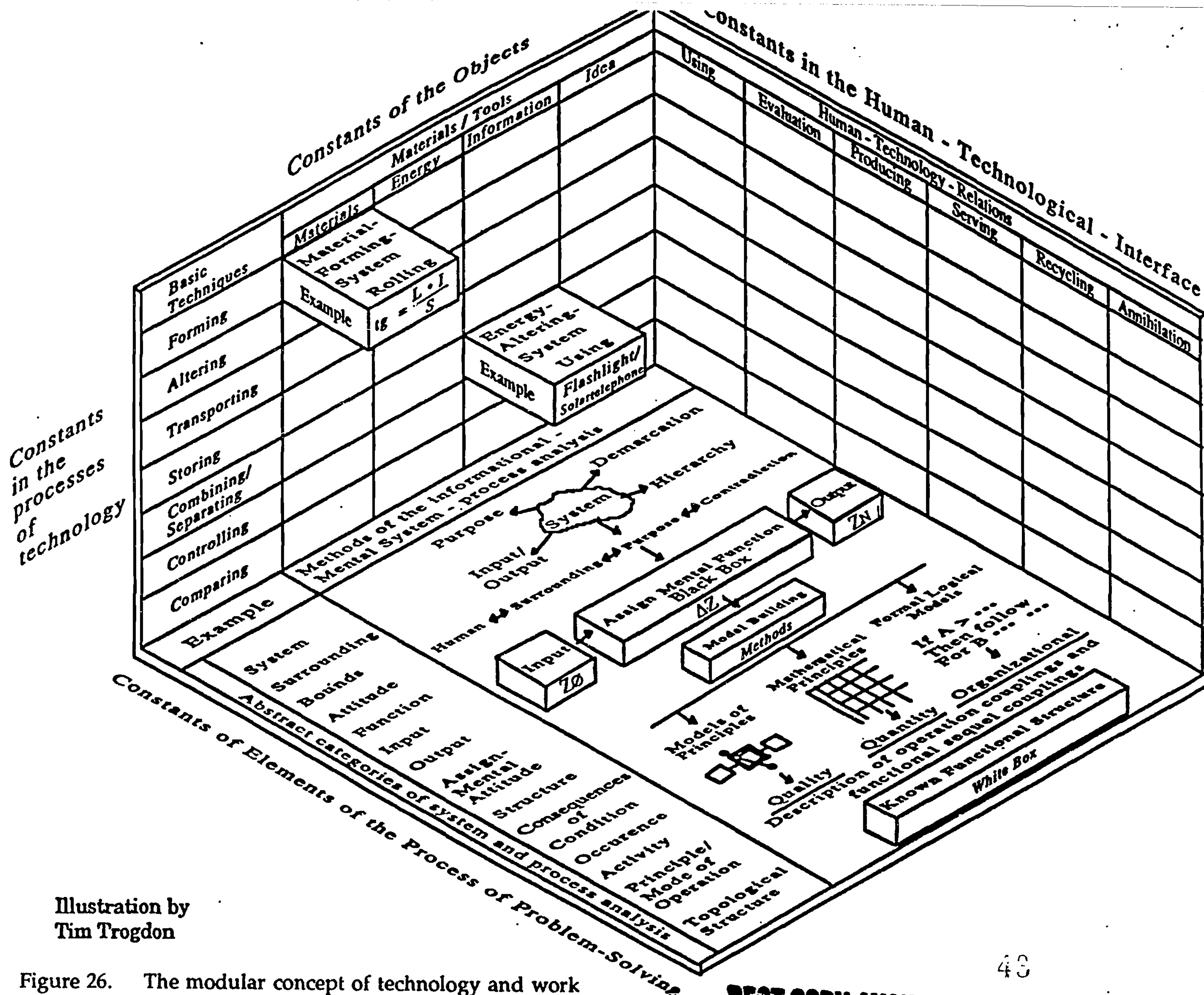


Illustration by
Tim Trogdon

Figure 26. The modular concept of technology and work

BEST COPY AVAILABLE

3. New information-masses as a part of innovative thinking

The Human-Technology relationships are curious (see Figure 15). As more and more insights are developed and put into practice, each generation finds it increasingly difficult to work with these accumulated practices because of their exponentially increasing number and complexity. The main evidence of this, the well known knowledge--time problem, makes itself particularly visible in the information explosion. To overcome this problem, capabilities such as the following are being addressed:

- Information interpretation (no sequence implied)
- Information structuring
- Information elimination
- Information acquisition
- Information reduction
- Information production
- Information combination
- Information selection
- Information ...

To understand the fundamental process of the irreversible Human--Technology relationship, one must first change paradigms and acknowledge information both as a product and as a key target for assessment. For our strategy-oriented concept (see Figures 1 and 15), it is important to note that each barrier and the strategy necessary to overcome it requires mastery of its own information-mass. In this paper we are providing only selected examples of our theory. A more completely detailed explication of the theory will be presented as a foundation paper for the International Conference on the Concept and Strategy of Technology Education as a Part of General Education[1], which will be held in Germany-East, in April 1992.

Consequences of point 3

To demonstrate the application of the theory, and to heighten your interest, we have provided three examples.

- Information-mass to overcome the Function--Ideal Model barrier (see Figure 27).
- Information-mass to overcome the Function--Structure barrier (see Figure 28[2]).
- Worksheets for overcoming the Environment-Need barrier (see Figures, 29, 30[3]).

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[1]To receive the call for papers and further information about this conference, contact Dr. D. Blandow, College of Education, Nordhäuser-Strasse 63, 5063 Erfurt, Germany-East or Dr. Michael J. Dyrenfurth, 103 London Hall, University of Missouri-Columbia, Columbia, MO 65211, Fax: 314-882-5071, BITNET: PAVTMIKE@UMCVMB.

[2]Hill, B. (1987). Methoden des Erfindens und ihre Nutzung zur Förderung technisch begabter Schüler neunter Klassen. Thesis for Dissertation A. College of Education, Nordhäuser-Strasse 63, 5063 Erfurt, Germany-East

[3]Schmidt, V. (1989). Bewerten technischen Objekte--ein methodologischer Ansatz zur Erschliessung der Komplexität der Technik. Thesis for Dissertation B. College of Education, Nordhäuser-Strasse 63, 5063 Erfurt, Germany-East

Category	Trends	Examples
Space (volume)	Greater utilization Miniaturization More intensive use Greater effect/more results More variable space	Multilayer circuitboards VLSI Satellites, telemetry buoys Vertical storage warehousing Year-round schools Overhead conveyors Conference centers
Time	Parallel usage Greater effect/more results More elastic interrelationships Greater damage/problems when deviation occurs	Batch production Demand oriented support systems (e.g., airports) Just-in-time manufacturing Flexible manufacturing
Material	Application domains increase in range Increase in types Purity increases Smaller amounts New combinations Increased use of more characteristics Increased reuse	Thin-wall casting Composites Recycling Computerized layout Artificial aging Thermoglass Biological computers
Energy	Reduced transport loss Increase in storability Increased convertibility Greater recovery Increased intensity More co-generation More use of micro-processes in macro applications	Plasma-laser technic Bio-solar energy Co-generation, e.g., incinerator/power station Optical technology Superconductivity
Information	Increased processing speed Increased specialization/tailoring Increased storage volumes Increased vulnerability to mass errors Increased networking Simplified access Greater consequences of mistakes	Computer generation International databanks and communication networks Computer hackers/Viruses System-wide failures (blackouts) Privacy of information Super computers Personal computers Hierarchical networks

Continues

Blandow/Dyrenfurth/Schmidt, V., 1991

Figure 27. Trends of demands on technology to guide formulation of the effectiveness equation, continues

Category	Trends	Examples
Societal Values	Increased ecological concern	Automobile emissions laws, Environmental Protection Agency, Recycling initiatives, Land fill regulation
	Increased participation in life-long learning	Videotape delivered instruction, distance learning, Adult education, HRD programs
	Globalization/world perspectives	Ozone layer protection regulations, International economic competition, Rain forest protection
	Social consciousness	Old folks community, Barrier-free design, Noise control zones
	Resource consciousness	Energy conservation, Projection of resource supply, Incineration and compacting of waste, Reforesting prgrms.
Working Conditions	Ease of assembly	Simpler parts; Jigs & fixtures, New adhesives, New processes e.g, ultrasonic welding, Velcro
	Serviceability	Increased access by design, Computerized warehousing, Module replacement
	Ergonomics	QWERTY keyboard, Adjustable chairs and work surfaces, Redesign of jobs
	Reduced maintenance	Self-maintaining systems, Redesign of components, Throw-away parts/products
	Safer	Non-contact processing, Automated safety systems, Improved personal protective devices, ABS systems
	Ease of monitoring	Integrated system reporting, Error-only display, Recommendation suggestion, Artificial intelligence
	Less demanding (physically)	Power steering, Automatic transmission, Robotics

Blandow/Dyrenfurth/Schmidt, V., 1991

Figure 27. Trends of demands on technology to guide formulation of the effectiveness equation

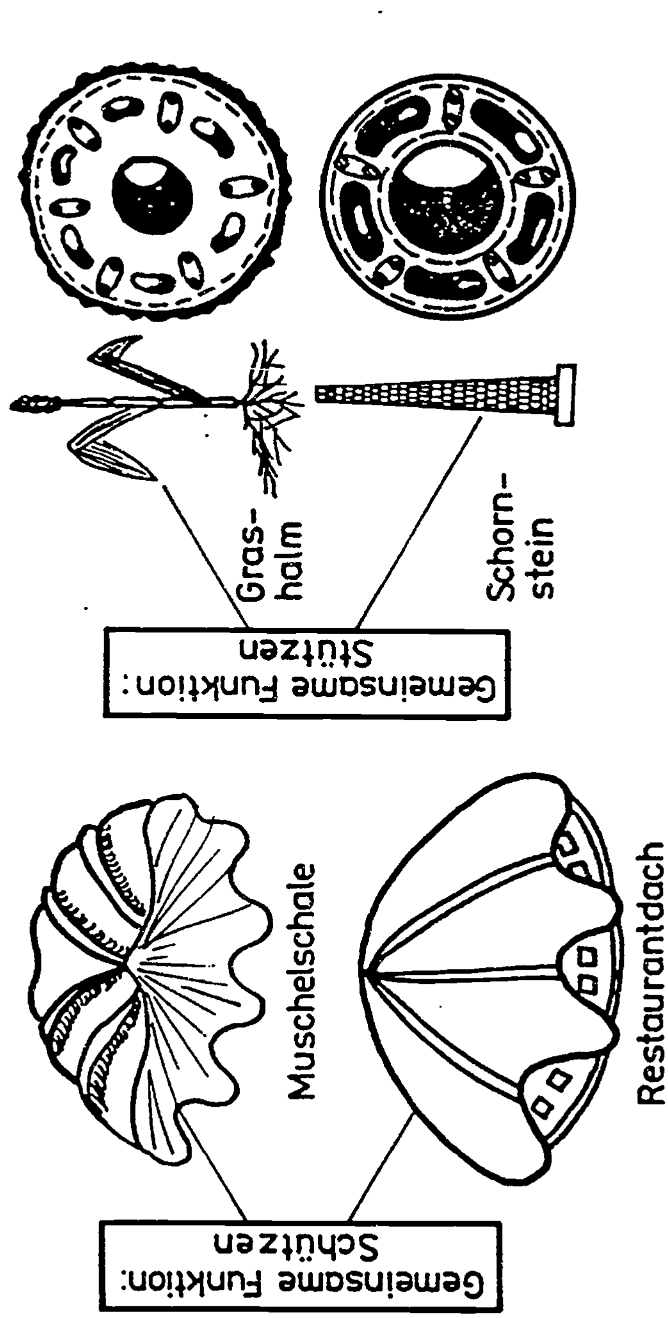
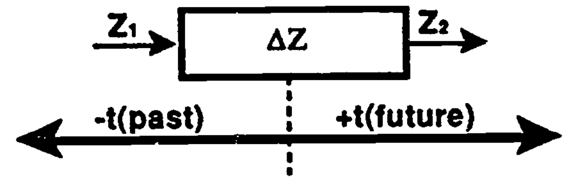


Figure 28. Example from the catalog of ideas to overcome the Function--Structure barrier

Worksheet for Trends Analysis

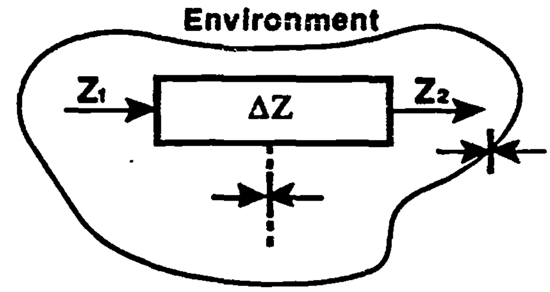


Structure	ΔZ, the ways and means of change (process) that changes the conditions/situations (Z_1, Z_2, Z_n,...) is charted in chronological sequence and the most likely next development is extrapolated on the basis of the trend curve.
Characteristic questions	How were the changes of conditions/situation (Z_1, Z_2, Z_n,...) accomplished? What technical means and/or processes (ΔZ) are likely developments along the trend line
Situation 1. Automobile radio station selection 2. Home windows	**Known Trends** 1. Faster travel, digital tuning, integrated controls, international symbols, error readouts, self-correcting circuits, ... 2. Greater durability, thermal-control/insulation, noise abating, stronger, easier cleaning, variable trim, light transmission control (amount and direction), ...
Potentially new examples	Automobile radio station selection: Steering wheel mounted controls; self-seeking according to type; emergency message superimposition; ... Home windows: Adjustable, i.e., thermostat-controlled heat absorption/rejection setting; variable light transmission and direction; image diffusion control;...
Your suggestions (any situation)	

Blandow/Dyrenfurth/Lutherdt, 1991

Figure 29. Worksheet for trend analysis

Worksheet for Identifying Contradictions



Structure	ΔZ, Effectiveness $= f$(Trends, needs, demands, ...) Factors E ⇑ $= f(e_1⇑, e_2⇑, \ldots, e_n⇑)$ Components $e_1⇑ = f(x_1⇑, x_2⇑, \ldots, x_5⇑)$ Components $e_2⇑ = f(y_1⇓, y_2⇑, \ldots, y_5⇓)$ E ⇑ $= f(x_5 \rightarrow \mid \leftarrow y_5)$ Identification of contradictions that operate within ΔZ and between the outcomes and the environment through analysis of factors and their composition
Characteristic questions	What contradictions operate within ΔZ and/or between its output and the environment? How can one counteract the individual effects, trends, demands, ...
Situation	**Known Examples and [Contradictions]**
1. Buildings	1. Pneumatic structures [Area vs Mass], Moving form construction [Size vs Time], ...
2. Ironing (clothes)	2. Teflon-soled irons [Friction vs Pressure], Temperature controlled iron [Fabric protection vs Operator intelligence]...
3. Bicycle lighting	3. Generator powered light [Light vs Effort], [Light vs maintenance], ...
Potentially new examples	1. Energy efficient buildings [Material mass vs Energy storage], Environmentally protective buildings [Internal oxygen generator vs Complexity] 2. Induction powered iron [Energy supply vs Mobility], Magnetically pressured iron [Downward force vs Operator fatigue] 3. Visibility to others [High visibility vs Power demand], Forward lighting [Energy source vs Operator effort]
Your suggestions (any situation)	

Blandow/Dyrenfurth/Lutherdt, 1991

Figure 30. Worksheet to identify contradictions

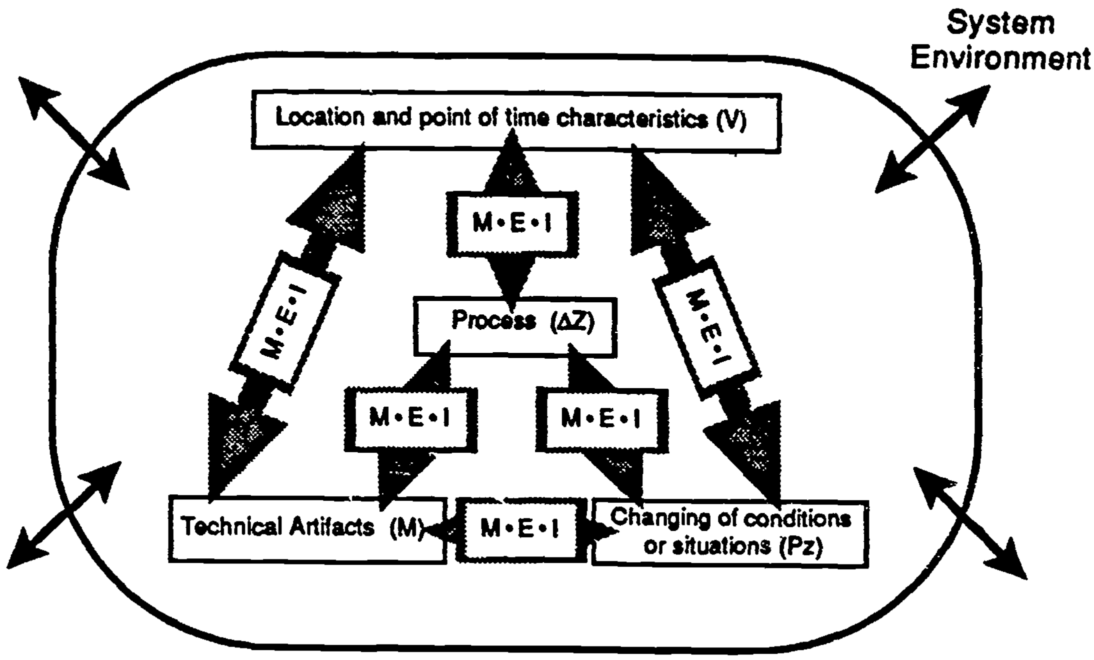
<table>
<tr><th colspan="3">Contradiction -->|<--</th><th>Examples</th></tr>
<tr><td>Stiff</td><td>->|<--</td><td>Elasticity</td><td>Spring, tree branch, tire</td></tr>
<tr><td>Porous</td><td>->|<--</td><td>Holder</td><td>Filter, unglazed clay pot, skin</td></tr>
<tr><td>Dry</td><td>->|<--</td><td>Humidity</td><td>Moss, Pampers, bandaids</td></tr>
<tr><td>Loose</td><td>->|<--</td><td>Rigidity</td><td>Polystyrene bead boards, ice cream</td></tr>
<tr><td>Open</td><td>->|<--</td><td>Enclosure</td><td>First law of thermodynamics, window</td></tr>
<tr><td>Accelerating</td><td>->|<--</td><td>Delay</td><td>Energy conservation systems (commuter trains, elevators)</td></tr>
<tr><td>Light</td><td>->|<--</td><td>Darkness</td><td>Infrared imaging, radar</td></tr>
<tr><td>...</td><td></td><td></td><td>...</td></tr>
<tr><td>...</td><td></td><td></td><td>...</td></tr>
</table>

Blandow/Dyrenfurth/Kahmann, 1991

Figure 31.. Worksheet for the formulation of contradictions to trigger innovation

To properly understand the problem solving/innovation process and to properly develop this capability in others, it is not sufficient to merely depict the key stages it involves--these are typically well known. One must also depict the information-masses that must be mastered and the barriers that must be overcome. Most important, however, is the learning of the intellectual tools and strategies (their organization) necessary to master each information-mass and surmount each barrier.

Some of the implications of the preceding for education about technology (in general education) may be seen in Figures 32 and 33. The first shows the overall structure of, and number of permutations possible in, our modular theory of technology and work. The second shows the relationship of individual specific competencies to overview competencies. This figure also depicts the relationship of knowledge of individual facts to knowledge of strategies. Through these, one can reestablish both the actual concept of foundations, as well as their manifestation, for education about technology.



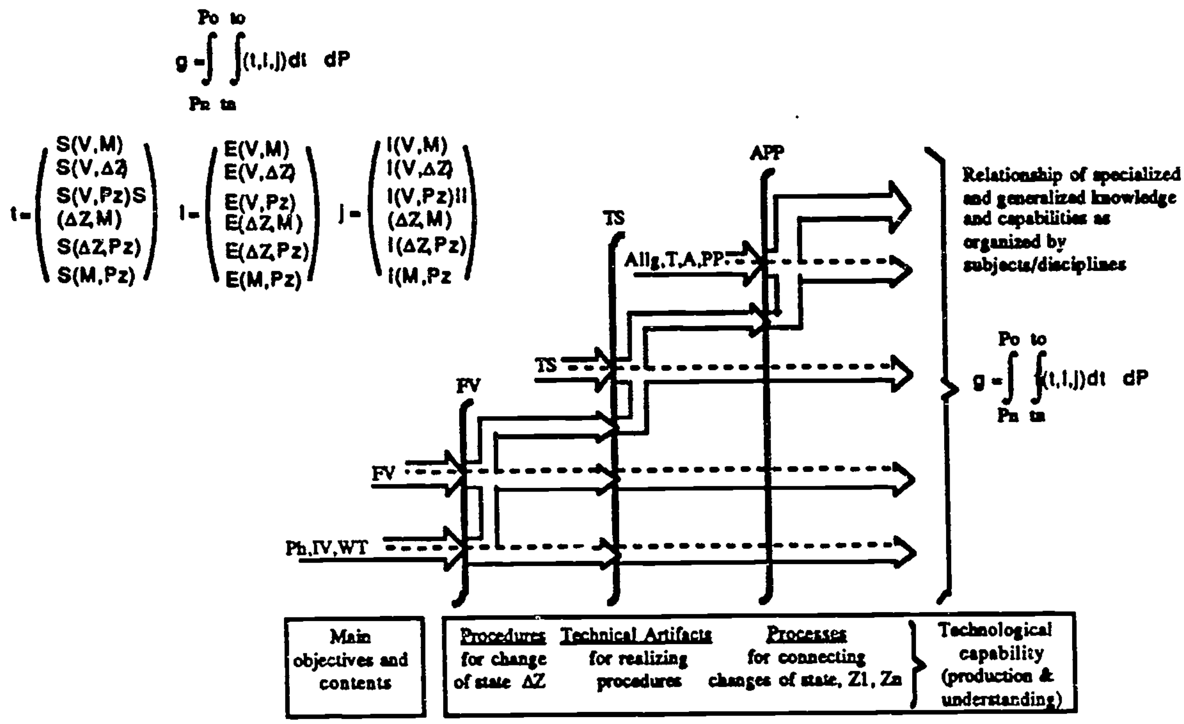
Legend

g	Product (material, energy, information, biological, synthetic)
⟷	Material, energy and information couplings
$\int_{Po}^{Pn}$	Stages of production
$\int_{to}^{tn}$	Location and/or point of time characteristics
⇒	Component of the curriculum that contributes overview, system understanding and generalization skills.
⇢	Specific competencies (e.g., occupational, technical, language...)
∫	Integration into human capability, a new quality (kind) is established
FV	Process of manufacture
Ph	Physics
IV	Informatics
WT	Properties of materials
TS	Technical subject/disciplines including mechanical engineering, technics of automation, electrotechnics/electronics, ...
Allg. T	General technology
APP	General production processes

Illustration: Tim Trogden Blandow/Dyrenfurth, 1991

Figure 32. Overall structure of, and number of permutations possible in, the modular theory of technology and work

Total function:



Legend

g — Product (material, energy, information, biological, synthetic)

Material, energy and information couplings

$\int_{Po}^{Pn}$ — Stages of production

$\int_{to}^{tn}$ — Location and/or point of time characteristics

Component of the curriculum that contributes overview, system understanding and generalization skills.

Specific competencies (e.g., occupational, technical, language...)

$\int$ — Integration into human capability, a new quality (kind) is established

FV — Process of manufacture

Ph — Physics

IV — Informatics

WT — Properties of materials

TS — Technical subject/disciplines including mechanical engineering, technics of automation, electrotechnics/electronics, ...

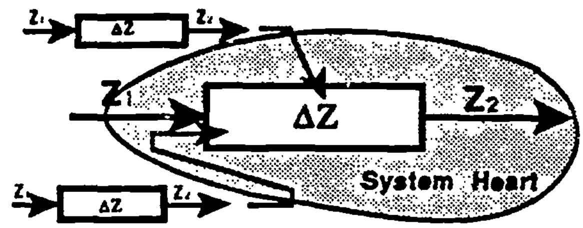
Allg. T — General technology

APP — General production processes

Illustration: Tim Trogden — Blandow/Dyrenfurth, 1991

Figure 33. Relationships between specialized and generalize understanding and capabilities in the education about technology

Worksheet for System Analysis



Structure	Determining of the location of ΔZ by specifying the environment, the system's hierarchial structure (sub- and supra systems), and the importance of the various processes (ΔZ)involved.
Characteristic questions	Where and how were the most important/characteristic changes of conditions/situation (Z_1, Z_2, Z_n,...) accomplished? What are the system's sub- and supra-systems and how are they related to the overall goal?
Situation	**Known Examples**
1. Automatic lathe	1. Automated work parameter maintenence via non-contact instrumentation and cybernetic control systems, ...
2. Coffee machine	2. Identification of variables that affect coffee taste and quality and their incorporation into an adjustable consumer product, ...
3. City traffic management	3. Identification of traffic flow streams and their influencing factors (including social ones) and their control via networked signals and work release announcements.
Potentially new examples	Furthering of automatic lathe by incorporating parameter-determined in-process tool sharpening and resetting of tool offset, ... Incorporation of individual taste control (as contrasted to strength);... Individually programmed routing systems for vehicles based on satellite mapping and traffic parameters.
Your suggestions (any situation)	

Blandow/Dyrenfurth, 1991

Summary and Conclusion

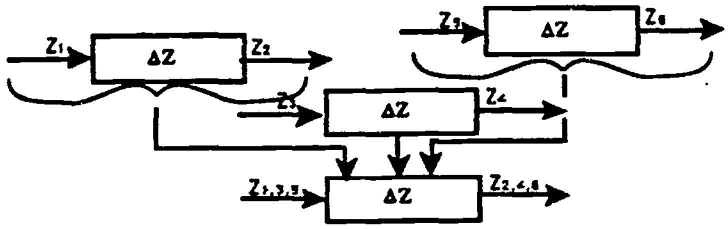
It was our goal to present an overview of the structure and the distinguishing features of technology. With the view of the developmental stages in traditional technical and technological disciplines; which evolved from the practical-oriented approaches, through knowledge-, process- and methodology-oriented approaches to the strategy-oriented approach; it should be emphasized that this involves a most critical change of paradigm from a subject- or discipline-oriented one to one that is much more focussed on goals to be accomplished. The specific problem to be surmounted is the predominant focus, not the individual disciplines that will make-up the solution. An integrative perspective is necessary, taking from each discipline what it has to offer and then synthesizing these contributions into a solution that addresses the problem in a new way.

From these point the key elements of modern structured technology were indicated. They were the process, the changing of conditions or situations, the location and point of time characteristics and the technical artifacts or means. These key elements are involved in all levels of hierarchically structured production processes. This also yielded the insight that such views of technology are useful in all of technology's arenas including those of agriculture, industry, chemical processes as well as in home economics for example. Also identified were the goals for the development of an organizational structure of processes. These served to guide the development of the elements of processes.

In the paper's second part the determining factor in the human-technology relationship--particularly in the field of production--is identified as the further development/advancement of capability -- not the mere satisfaction of need. From this point, new questions arise with respect to the handling of information-masses as well as the capabilities for choosing the appropriate storage and retrieval mechanisms. The development process involves seven key stages: Recognition of a problematic situation (thought initiator), overcoming thought barriers, envisioning possible solutions, model development (resolution of contradictions), development of approach strategies, development of time and activity plan, execution of the plan, evaluation of the results and recognition of the new situation/problematic situation.

Given the presented concept of a modular view of technology and work, we have synthesized two kinds of thinking. One is object-oriented thinking and the other is a kind of innovative thinking. By combining these two approaches with the modular concept, and then emphasizing the development of strategies, we hope that the result of our work can be used for a diverse set of problem situations--both industrial and educational as well!

Worksheet for Need--Aim Integration



Structure	Integration of several here-to-fore separate processes (ΔZ) that operated at different times, and at potentially different locations, into a single new process
Characteristic questions	What functions can be combined either with respect to time and/or location? How can the characteristics of the applicable materials, energy and information elements be used to trigger integration?
Situation	**Known Examples**
1. Reading	1. Illuminate magnifying glasses, ...
2. Mirrored vanity cabinet	2. Fan equipped vanity to prevent fogging,...
3. Automobile tire	3. Tubeless tires, ...
4. Urban planning	4. "Green-roofs" (terraced plantings)
Potentially new examples	1. Reading mechanisms equipped with text-to-voice conversion, light and copying/storage devices,... 2. Vanity equipped with temperature regulated (anti-fogging) mirror, television, telephone and dictation apparatus,... 3. Airless tires, Automatic, on-vehicle, pressure regulated tire inflation system 4. Solar/ecological domed cities, ...
Your suggestions (any situation)	

Blandow/Dyrenfurth, 1991