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INFORMATION – A TAXONOMY AND INTERPRETATION

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1. Objectives

This paper was stimulated by a contribution from Vajna [2002], which implies that the main elements of individual, internalized contributions are “experience” and “knowledge” connected by activities of induction and deduction, and the externally available elements are “information” and “data” connected by activities of synthesis and analysis. The elements of knowledge and information in that model are connected by rules and meta-rules. The resulting model (referred to by Vajna as a “taxonomy of knowledge”) seems in many respects to need additional discussion.
In an attempt to expand the model presented by Vajna [2002], this paper presents the authors’ opinions on the nature of information, in part as a synthesis of other published opinions. The words ‘knowledge’, ‘information’, ‘data’, and others are relative concepts, and thus can hardly be defined in any absolute sense, but they are useful heuristics [Koen 2003]. Distinctions between different terms can be under-stood with characteristics of (presence or absence of) meaning, context and application [Ahmed 1999].

2. Methods

The discussions that follow are a result of an extensive literature survey, including the 465 references in [Hubka 1996], 214 in [Hubka 1988a], and 254 in [Hubka 1992] (although several of these appear in more than one of our books). Reflection and systematic thought by the authors during practical experience of design engineering for technical systems of various kinds in industry, writing these books, and many papers for conferences and journals, have now led to a needed synthesis and systematization as outlined in the taxonomy in this paper.

3. Results

3.1 Information, general

We will use ‘*information*’ as a general term for all instances of this phenomenon. The contents of information can concern tangible objects, process objects, and cognitive objects (conceptual objects, e.g. thoughts, ideas, intuitions, feelings, etc. about tangible or process objects). Typical subjects for information are biology, sociology, physics, mathematics, agriculture, history, arts, geography (global and local), etc., and design engineering. Process objects in turn can be sub-divided according to whether the intention is (a) for a useful application, manufacturing, distributing or disposing of a tangible or process object, or (b) for designing a tangible or process object [Eder 2003]. Various processes form the relationships among these constituents – e.g. forms of information can be *transformed* and *codified*.

Figure 1 shows a generalized model of a transformation system (TrfS), with its processes (TrfP) and their technologies (Tg), its operators: human systems (HuS), technical systems (TS), information systems (IS), management and goals systems (M&GS), and environment systems (EnvS). Inputs to the transformation system include the operands that are to be transformed in the process from their initial state (Od1), assisting inputs and secondary inputs (mostly disturbances) to the process, and to the operators. Outputs from the transformation system include the operands in their ending state (Od2), and secondary outputs (including those from the operators), some of which can be beneficial, some can be re-used for other purposes, and some are disturbances, pollutants, and other negative influences on the active (and general) environment. Feedback usually exists from outputs (measurements, comparisons with desired outcomes) to inputs to adjust the outputs closer to the desired states.

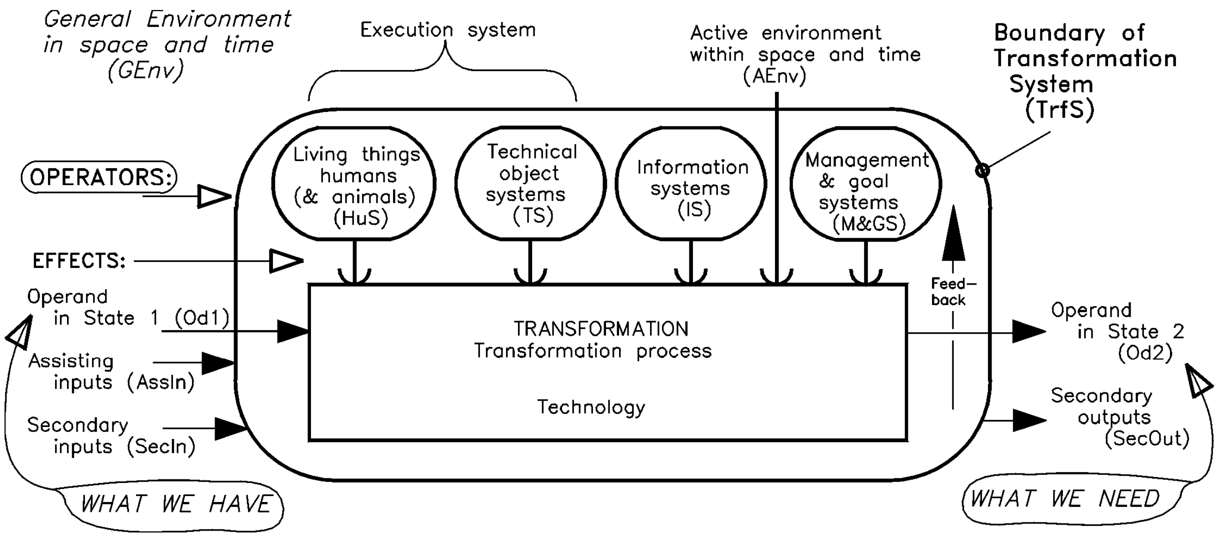

Figure 1. General model of transformation system

The constituents of information include data, observations, evidence, rules, theories, knowledge, experience, etc. Such information can constitute (a) a narrative description with little theoretical basis, (b) a descriptive-theoretical discourse, (c) a prescription (not compulsory) for action, or (d) a normative (compulsory by law) statement.

Information can thus act as *operator* of a transformation process, an element of a transformation system. In this role, information mainly provides guidance and instructions to the other operators. Any information system consists of elements (of information), relationships among those elements (internal) and across the system boundaries (to the environment, surroundings – external). This information may be more or less structured, i.e. range from an informal collection to a more or less formalized (formulated, codified) and verified system. Human operators (but also computers as technical systems programmed by humans) rely on information in the form of currently accepted *true belief*, 'truth' as agreed understandings and abstractions (e.g. of science), and as recognized useful understandings based on other experience – both of which are used by designers as heuristics [Koen 2003]. Information ranges over fact, observation, guideline, belief, myth, prejudice, hearsay, to deliberate mis-information.

Information can also act as *operand* of a transformation process – it can be processed. The changes can affect the content and structure (internal) of information, its form (verbal, graphical, symbolic), its location (internalized, externalized), and its time dimension.

3.2 Information, recorded

If you can express and/or formulate it (e.g. a thought, a theory, a hunch, an imagination) into words, images and/or symbols, you can transfer it (more or less accurately) to a tangible medium. Even feelings can (to some extent) be expressed. Without such expression, communication is unlikely. In general, information can be captured and *recorded*, and placed in available repositories, stored in tangible records in an accessible form, unordered to ordered and classified in some way, e.g. scientific. It can then be retrieved – if a suitable method of classification is available, or by navigating and searching/querying in a wider context. This is in large part the role of libraries, including computer-resident files. Classification is usually performed by defining hierarchies of classes, but many of the relationships among items of information are thereby lost. Better classification systems result from a 'flow-chart' or multi-subject matrix approach. Records can cover all forms of information, including data, explanations, heuristics, generalizations, hypotheses, and theories and their verification or proof.

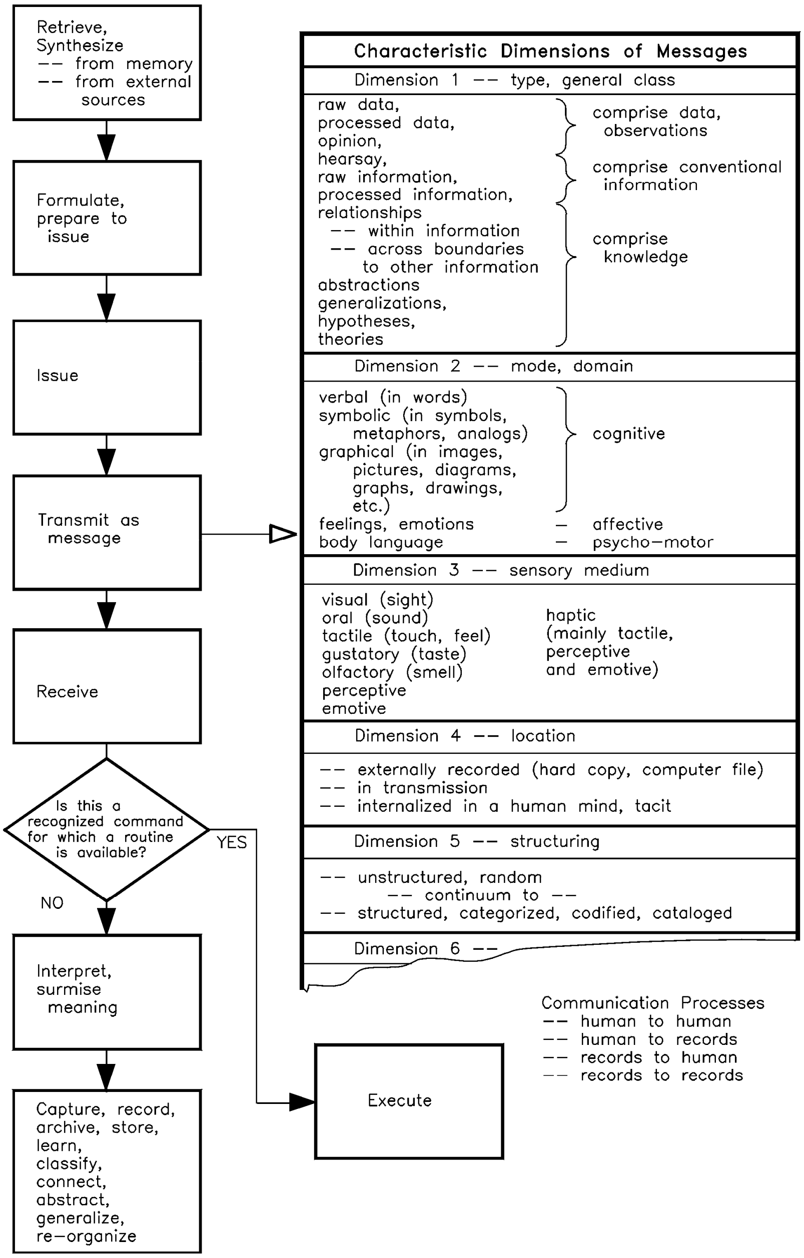

Figure 2. Model of communication

3.3 Information, transmission, communication

Based on the insights from Design Science [Hubka 1996], a model of *communication* that transmits messages is proposed. Information can be transmitted (as operand of a transmission process) from one person or record to another (often with the help of a technical system – a communications device), for which various processes are useful, see figure 2. Similar schemes may be found in other works, e.g.

[Vance 1998]. The first processes formulate the information into a message form that is suitable for the transmission media and conditions. The message form usually requires a sequencing of messages, i.e. a serial/linear or parallel/branched and interconnected set of messages. The last processes receive and interpret the received messages, either as executable commands, or as information to be understood by humans. Each message can be characterized by several dimensions, as indicated in figure 2.

3.4 Knowledge, general

Elements of information do not exist in isolation. The relationships reveal the structure among information elements. '*Knowledge*' is intended to imply information that has been processed in some way obtain an 'accepted true belief' (by an individual and/or a group) on the basis of evidence (or even a lack of it). Such processing often tries to generalize and summarize information – *abstracting* – and bring it into relationships with other information items – *codifying* and *structuring*. Knowledge is derived from information by processes of deduction, induction, reduction/abduction, or innoduction [Eekels 2000]. This includes scientific knowledge, but scientific knowledge is not the only sort of knowledge [Eder 1995]. Much of informally structured knowledge is of little interest for science, yet is necessary for technological (engineering) application. This includes knowledge gained directly from experience which may not have been (or may not even be capable of being) formalized and/or recorded in any suitable way, e.g. [Constant 1980, Vincenti 1990, Faires 1965, Spotts 1985, Ruiz 1970], standards and codes of practice, national and local laws, etc.

Processing usually progresses from (more or less) full contents (of information), through informal and general structuring – *typology* – to scientific categorization – *taxonomy*. Processing has various aims:

- holistic (comprehending an overall picture), vs. reductionist or atomistic(isolating elements);
- synthesizing (placing together in possible arrangements) vs. analyzing – the form and arrangement of information (subject to a facility for selective search such as a computer) for these two purposes should be different – analysis can use the arrangement of the traditional engineering sciences, synthesis usually needs an arrangement according to achieved output effects;
- system (functioning) vs. detail (components, constructional elements);
- among phenomena vs. among other information elements;
- in a progression via hypotheses, axioms, theorems, and corollaries, to theories.

Codified knowledge thus represents the generally accepted interpretation – accepted or warranted true belief – and description (narrative and theory) of phenomena, at that particular time.

3.5 Knowledge, recorded

Knowledge is derived from information by processing, abstracting, codifying, relating, hypothesizing, theorizing, etc. Such codified information held in tangible repositories can be called 'recorded knowledge'. This conforms to the usage of 'knowledge-based systems', which rely on some (artificial) intelligence, i.e. an interpretation of processed, stored, codified information.

3.6 Data

'*Data*' usually refers to concrete properties, especially measured values of specific properties of a TS or of other natural phenomena. Data seems to be generally regarded as context-free, although this doubtful.

3.7 Information, internalized, tacit

The processes of using available information by a human lead to various forms of *knowing*, i.e. information learned, processed and stored in the human mind [Damasio 1994 & 1999, Gallagher 1996, Egan 1997, Glynn 1999]. It is internalized, tacit, mentally structured, and added in some way to that person's acquired experience; it is individual and idiosyncratic, therefore inaccessible to other persons. Each person develops his/her own internalized structure of knowing that is more or less different from that of any other. Various parts of the human brain contribute to storage, processing and recall of any item of information. Storage is thought to occur in 'chunks' of varying size and connectivity, and in

several different parts of the brain according to the senses and abilities that the mind possesses. Nevertheless, among humans the structures of knowing have much in common.
The human mind can act consciously (in short-term or long-term memory), sub-consciously (intuitively), or unconsciously (instinctively). Mental actions have been allocated to domains, i.e. cognitive [Bloom 1956] (pertaining to thought), affective [Krathwohl 1965] (pertaining to feelings), and psycho-motor (pertaining to physical actions and their control).
This tacit knowledge (e.g. conceptual objects) can also concern tangible objects or process objects, i.e. usage of such objects, or problem solving and designing [Eder 2003], or managing, etc., and mental constructs that result from association of ideas.
Internalized information as acquired (learned) from experience (including formal teaching/learning situations, and learning by doing) is 'stored' in the mind as *declarative* object knowledge consisting of information, data and experiences. Information and knowledge that has been learned well enough, such that the person no longer needs to think about it to use it, is termed *procedural* object knowledge.
From this internalized information, the human mind (not necessarily under conscious control, either unaided, or aided by sketching in graphical, verbal and/or symbolic media) produces mental constructs, including those that result from association of ideas (i.e. problem solving, designing, etc.), and procedural object knowledge (thinking, method applied to objects based on formal or informal-conjectured theory) by *reasoning*. Such reasoning may proceed in a 'forward' or 'backward' direction, e.g. from cause to consequence (causality), or from consequence to cause (finality). Usually, a combination of the two directions can be effective. The procedural object knowledge reappears as the sub-consciously applied procedural methods (compare [Klaus 1965], *'Both method and theory emerge from the phenomenon of the subject'*) which becomes evident in abilities (latent and developing skills), applicable skills, and competencies.

3.8 Knowledge, internalized, tacit, understanding

Experience and information deliberately searched out and interpreted can be the source of understanding. 'It seems that a large amount of knowledge has to be taken into account in a highly integrated way for *understanding* to take place' [Hofstadter 1999, p. 569]. This task involves interpreting, extracting meaning and importance, values, and recognizing relationships and patterns. Then various forms of research can further process this information, knowledge and understanding, usually based on hypotheses, and refine it to confirm it into a theory. This is part of the process of codifying the recorded and tacit information to produce the available recorded knowledge.
Processing information to develop understanding and knowledge is a human mental task, that can result in both tacit and recorded knowledge, and occasionally also wisdom. It also involves rearranging the information to make its use easier – different arrangements are needed for research (extending the scope of existing knowledge), for archival collection (searching for existing knowledge according to disciplinary categories), and for designing (searching for information to achieve specific desired effects). Examples of information, processed for designing are found in [Ferreirinha 1987 & 1988, Roth 1995].

3.9 Intelligence

This phenomenon is thought to arise from internalized processing information into knowing, with added capabilities of abstraction and association. Artificial intelligence attempts to mimic human processing of information in small areas of interest, often by heuristic programming, statistical inferences and combinations, to provide computer-generated advice for humans, or computer-control for machines.
In military jargon, "intelligence" refers to partially processed information about circumstances that may be of strategic, tactical or political importance to an executing authority.

3.10 Information, generating and using

As indicated in figure 3, the processes of generating and using information, including knowledge and data, can be shown in their relationships. Each of the processes (shown in rectangular boxes) consist of a sequencing of messages appropriately formulated on the basis of an initial result (in an elliptical box) to achieve another result. The upper section shows developments of knowledge and experience, often starting from observed or conjectured data. The lower section indicates how internalized knowledge ('knowing') can be applied to achieve other results. Knowing is supported by recorded information searched from sources and (usually by preference) from other knowing persons.

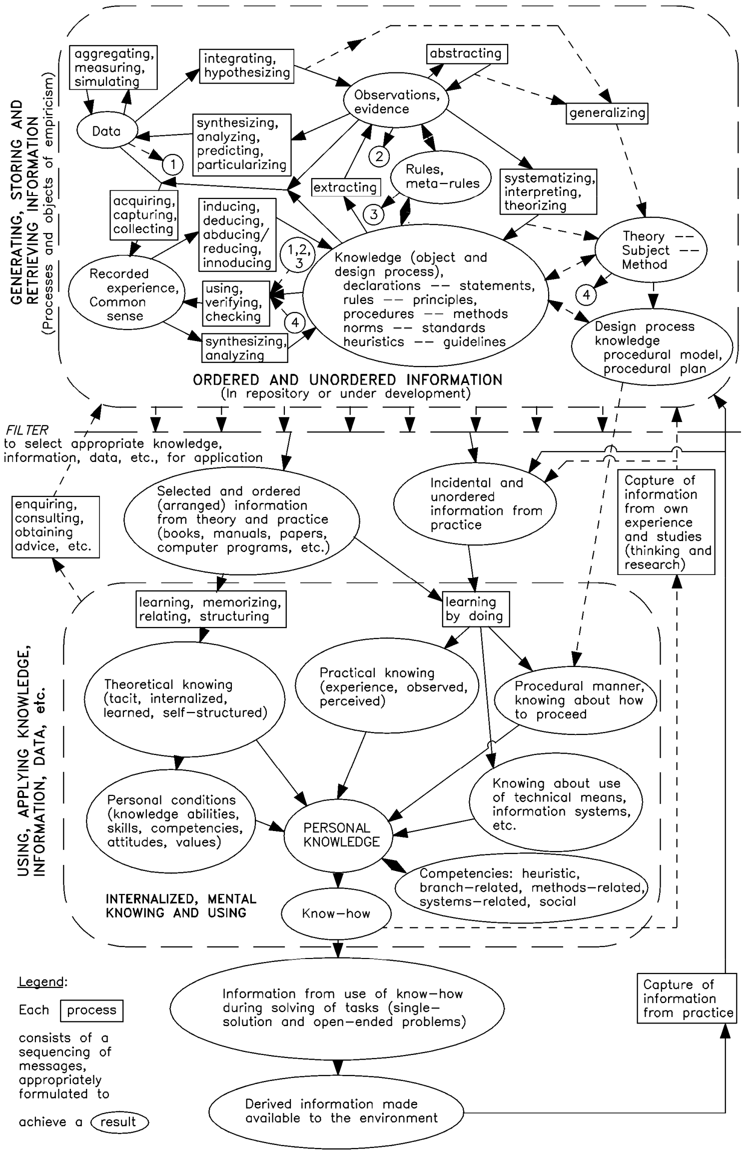

Figure 3. Characterization of information – processes and relationships

3.11 Summary

Many other words could have been included or expanded in this discussion, e.g. thinking, intellect, inspiration, serendipity, algorithmic, innovative, inventive, evolutionary, team work, problem solving, specialization, efficiency, effectiveness, etc. Table 1 attempts to summarize the contents of this paper.

Table 1. Information

Object		Design Process
Tangible	**Process**	
Science initiated (pure vs engineering)	Working (Usage)	Opportunistic, Intuitive
Science supported (pure vs engineering)	Mfg/planning	Reflective
Life process empirical	Disposal	Methodical, Systematic
Technological	Life Cycle	adopting, developing
Arbitrary, Data		adapting, combining method

X (i.e. three classes above, each divided as in classes below)

Recorded 'knowledge' Internalized tacit 'knowing'

Information

Descriptive-narrative, prescriptive and normative, theory-descriptive
Raw, abstracted, interpreted, codified
Drawn conclusions, recommendations, hypotheses, theories (verified)
Factual, conjectural, heuristic, fictional
Guidelines, codes of practice, mandated procedures and values

Knowledge of objects and physical phenomena: scientific, technological, experiential, societal, economic, etc.

Knowledge of human activity (physical, mental): strategies, methodologies; tactics, methods
informal; ad hoc, intuitive, explicit instructions, implicit (e.g. learned); formal, rational, discursive, systematic
conscious (personal, inter-personal); sub-conscious; unconscious (unacknowledged), etc.

Theories of human behavior: psychological, cognitive (routine, creative), affective, psycho-motor, personal, inter-personal (team), etc.

4. Closure

The subject of 'information' is complex. An attempt has been made to bring some order into this region, but much further discussion will be needed if a reasonable consensus is to be reached. Especially the quality of information to meet the needs of designing engineers must be addressed.

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