CATEGORIES OF KNOWLEDGE

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1. Introduction

While the word 'knowledge' is extensively used by all, there is no single agreed definition of 'knowledge' at present, nor any prospect of one. Knowledge is a term that has been actively and continually defined. Knowledge is a complex of several related ideas. Consider some of the definitions.

Knowledge is relationships, facts, assumptions, heuristics and models derived through the formal and informal analysis or interpretation of data. (Information Society Technologies. http://cordis.europa.eu/ist/ka1/ administrations/publications/glossary.htm).

Knowledge is defined as remembering previously learned material. This may involve the recall of specific facts or complete theories, but all that is required is the rote memory of the appropriate information. Knowledge represents the lowest and most basic level of learning. www.drdan.org/Hnadout%2017.htm

Knowledge is the internalization of information, data and experience home.earthlink.net/~ddstuhlman/defin1.htm.

Knowledge is the psychological result of perception of learning and reasoning http://wordnetweb.princeton.edu/perl/webwn?s=knowledge.

Knowledge is accumulated external and explicit information belonging to the community, being leveraged by tacit intrinsic insights which originate within individuals who then may act alone or cooperatively in order to control or integrate with their environment http://www.pacrimcross.com/kmguidelines/ defknow.html.

Knowledge is defined (Oxford English Dictionary) variously as expertise, and skills acquired by a person through experience or education; the theoretical or practical understanding of a subject what is known in a particular field or in total; facts and information awareness or familiarity gained by experience of a fact or situation

A branch of philosophy, called **'**epistemology**'**, is dedicated to the study of knowledge, and its sources, varieties and limits. In any branch of philosophy, there are at least two competing views. In epistemology, one view, referred to as **'**empiricism**'**, holds that knowledge is derived from experience; whereas 'apriorism' considers that knowledge is innate. The extreme form of empiricism is referred to as 'positivism' or 'logical positivism', and holds that nothing is innate, and that only that which can be measured is worth worrying about. The extreme form of apriorism denies the very idea of knowledge existing outside the individual mind. The conventional attitude adopted by non-philosophers is a kind of truce between the two extremes.

The Second half of the twentieth century has witnessed many new turns in the epistemic scenario, the latest among which is a turn towards situated knowledge/cognition. In stark contrast to the traditional epistemology where knowledge was and still is construed as individual, rational, abstract, aperspectival and value-neutral, situated epistemology upholds knowledge to be social, not insulated from emotion, concrete, perspectival and value-endowed. More specifically, the concept of situated cognition is a cluster-concept and its degree of situatedness depends on how many traits of 'situatedness' have been reflected in a piece of cognition. The said cluster includes three theses: (a) cognition depends not just on the mind/brain but also on the body (the embodiment thesis) (b) cognitive activities routinely exploit structures of the natural and social environment (the embedding thesis) and (c) the boundaries of cognition extend beyond the boundaries of individual organism (the extension thesis).

The perspective of knowledge, as considered here, is based on the current perspectives in cognitive science and cognitive psychology on knowledge presentation. We do not adhere to simple behaviorist view that knowledge is best represented as an accumulation of association between stimuli and responses or merely a quantitative increase in bits of information. Rather, our perspective reflects the idea that knowledge is organized and structured by the learner in line with a rationalist-constructivist tradition. Based on cognitive science research on the development of expertise, expert thinking, and problem solving, our perspective is that knowledge is domain specific and contextualized. Our understanding of knowledge should reflect this domain specificity and the role that social experiences and context play in the construction and development of knowledge.

2. Types of Knowledge

There are many different types of knowledge and seemingly even more terms used to describe them. Some of the terms are: conceptual knowledge, conditional knowledge, content knowledge, declarative knowledge, disciplinary knowledge, discourse knowledge, domain knowledge, episodic knowledge, explicit knowledge, factual knowledge, metacognitive knowledge, prior knowledge, procedural knowledge, semantic knowledge, situational knowledge, sociocultural knowledge, strategic knowledge, and tacit knowledge. Some of the different terms signify important differences among the varieties of knowledge, whereas others are apparently just different labels for the same knowledge category. Considering several constraints to categorization and the need for simplicity and ease of use, four general types of knowledge (Anderson et. al., 2001) are proposed relevant across all disciplines:

- Factual Knowledge
- Conceptual Knowledge
- Procedural Knowledge
- Metacognitive Knowledge

Factual knowledge refers to specific content elements such as terms and facts (bits of information). *Conceptual knowledge* refers to more general concepts, principles, models or theories. *Procedural knowledge* is the "knowledge of how" to do something. The "something" might range from completing fairly routine exercises to solving novel problems. Current cognitive and social constructivist models of learning emphasize ideas such as consciousness, awareness, self-reflection, self-regulation, and thinking about and controlling one's own thinking and learning, which were generally excluded by behaviorist psychology models. Because these activities focus on cognition itself, the prefix *meta* is added to reflect that metacognition is 'about' or 'above' cognition. Both cognitive and constructivist models agree about the importance of facilitating students' thinking about their own thinking. Here we define "*metacogntive knowledge*" as "knowledge about cognition". Learners can activate the relevant situational, conditional, or cultural knowledge for solving a problem in a certain context.

These four categories of knowledge are applicable to all disciplines, but do not constitute a complete set. There are categories of knowledge specific to Engineering, Social Sciences, Computing, Management, Economics etc. While categories of knowledge specific to Social Sciences, Computing, Management and Economics are not annunciated definitively, the categories of knowledge specific to Engineering have been identified (Vincenti 1990).

The four general types of knowledge and their sub-types are explored further in the following sections.

2.1 Factual Knowledge: Factual knowledge contains the basic elements students must know if they are to be acquainted with the discipline or solve any of the problems in it. The elements are usually symbols associated with some concrete referents, or "strings of symbols" that convey important information. For the most part, Factual Knowledge exists at a relatively low level of abstraction. As our knowledge increases in all fields of inquiry, even experts in these fields have difficulty keeping up with all the new elements. Consequently, some selection for educational purposes is almost always required. The two subtypes of *Factual Knowledge* are *knowledge of terminology* and *knowledge of specific details and elements*.

Knowledge of terminology includes of specific verbal and nonverbal labels and symbols (e.g., words, numerals, signs, pictures). Each subject matter contains a large number of labels and symbols, both verbal and nonverbal that have particular referents. They are the basic language of the discipline – shorthand used by experts to express what they know. The novice learner must be cognizant of these labels and symbols and learn the generally accepted referents that are attached to them. Some examples of knowledge of terminology are

- Knowledge of the alphabet and numbers
- Knowledge of engineering or technical terms
- Knowledge of physical and chemical constants
- Knowledge of mathematical and graphic representations
- Knowledge of specific details and elements refers to knowledge of events, locations, people, dates, sources of information, and the like.

It may include very precise and specific information, such as the exact date of an event or the exact magnitude of a phenomenon, which could be descriptive or prescriptive in nature. It may also include approximate information, such as a time period in which an event occurred or the general order of magnitude of the phenomenon. Specific facts are those that can be isolated as separate, discrete elements in contrast to those that can be known only in a larger context. Knowledge of specific facts and knowledge of the sources of the facts of a given subject belong to this category. However, the tremendous number of specific facts forces educators (curriculum specialists, textbook authors and teachers) to make choices about what is basic and what is of secondary importance or of importance primarily to experts. Some examples of knowledge of specific details and elements are:

- Knowledge of products, companies, and major stakeholders related to computing
- Knowledge of important events people in the evolution of computing
- Knowledge of important features of different types of computers
- Knowledge of currently used semiconductor devices and technologies used for fabricating them.
- Knowledge of performance characteristics of commercially available integrated circuits

2.2 Conceptual Knowledge: A concept denotes all of the entities, phenomena, and/or relations in a given category or class by using definitions. Concepts are abstract in that they omit the differences of the things in their extension, treating the members of the extension as if they were identical. Classical concepts are universal in that they apply equally to everything in their extension. Concepts are also the basic elements of propositions, much the same way a word is the basic semantic element of a sentence. Unlike perceptions, which are particular images of individual objects, concepts cannot be visualized. Because they are not themselves individual perceptions, concepts are discursive and result from reason. Concepts are bearers of meaning, as opposed to agents of meaning. A single concept can be expressed by any number of languages. The concept of DOG can be expressed as *dog* in English, *Hund* in German, *Nayi* in Kannada, and *Kuttha* in Hindi. The fact that concepts are in some sense independent of language makes translation possible - words in various languages have identical meaning, because they express one and the same concept.

Conceptual knowledge includes knowledge of categories and classifications, and the relationships between and among them – more complex, organized knowledge forms. Conceptual knowledge includes schemas, mental models, or implicit or explicit theories in different cognitive psychological models. These schemas and models, and theories represent the knowledge an individual has about how a particular subject matter is organized and structured how the different parts or bits of information are interconnected and interrelated in a more systematic manner, and how these parts function together. For example the mental model of how a computer works may include ideas about how information can be represented in binary form, Boolean algebra, logical expressions, registers, instructions, control unit, ALU, primary memory, secondary memory, storage media, display of information, keyboards, printers etc. This type of conceptual knowledge might be one aspect of what is termed "disciplinary knowledge".

Conceptual knowledge includes three subtypes: *knowledge of classifications and categories, knowledge of principles and generalization*, and *knowledge of theories, models, and structures*. Classification and categories form the basis for principles and generalizations. These, in turn, form the basis for theories, models, and structures. These three subtypes should capture a great deal of the knowledge that is generated within al the different disciplines.

Knowledge of Classification and Categories includes specific categories, classes, divisions, and arrangements that are used in different subject matters. This type of knowledge is somewhat more general and often more abstract than the knowledge of terminology and specific facts. Each subject matter has a set of categories that are used to discover new elements as well as to deal with them once they are discovered. Classification and categories differ from terminology and facts in that they form the connecting links between and among specific elements. When one is concerned with realizing a logic expression, for example, the major concepts include 'binary variables' 'logic functions', 'truth-tables', 'hardware logic units', 'assertion levels' etc.

Sometimes it is difficult to distinguish knowledge of classifications and categories from factual knowledge. Basic classifications and categories can be placed into larger, more comprehensive classifications and categories. For example, binary, hex, octal, and decimal systems can be placed into the category of number systems.

Knowledge of classifications and categories is an important aspect of developing expertise in an academic discipline. Proper classification of information and experience into appropriate categories is a classic sign of learning and development. Some examples of knowledge of classification and categories are

- Knowledge of number systems
- Knowledge of sequential systems
- Knowledge of different IC packages
- Knowledge different passive networks

Principles and Generalizations are composed of classifications and categories. Principles and generalizations tend to dominate an academic discipline and are used to study phenomena or solve problems in the discipline. These include abstractions that summarize observations of phenomena, and have greatest value in describing, predicting, explaining, or determining the most appropriate and relevant action or direction to be taken. Principles and generalizations bring together large number of specific facts and events, describe the processes and interrelationships among these specific details (thus forming classifications and categories, and, furthermore, describe processes and interrelationships and among the classifications and categories). Principles and generalizations enable us to organize the whole in a parsimonious and coherent manner. Examples of knowledge of principles and generalizations are

- Knowledge of fundamental laws of physics
- Knowledge of fundamental relationships in electrical networks
- Knowledge of Boolean algebra
- Knowledge of the principles that govern arithmetic operations

Knowledge of Theories, Models and Structures include different paradigms, and epistemologies that disciplines have for structuring inquiry. Students should come to know these different ways of conceptualizing and organizing subject matter and areas of research within the subject matter. For example, the relevant operating characteristics of electrical and electronic devices are adequately described through currents and voltages as time functions at appropriately selected points or point pairs. An expert in a discipline knows not only the different disciplinary theories, models, and structures but also their relative strengths and weaknesses and can think "within" and one of them as well as "outside" any of them. Examples of knowledge of theories, models and structures are

- Knowledge of network theory
- Knowledge of graph theory
- Knowledge of field theory

- Knowledge of control theory
- Knowledge of behavioral, cognitive and social constructivist theories of learning
- Knowledge of systems view of organizations

2.3 Procedural Knowledge: Procedural knowledge is the "knowledge of how" to do something. The "something" might range from completing fairly routine exercises to solving novel problems. Procedural knowledge often takes the form of a series or sequence of steps to be followed. It includes knowledge of skills, algorithms, techniques, and methods, collectively known as procedures. Procedural knowledge also includes knowledge of the criteria used to determine when to use various procedures. In fact it was noted, not only do experts have a great deal of knowledge about the subject matter, but their knowledge is "conditionalized" so that they know when and where to use it.

Procedural knowledge is specific or germane to particular subject matters or academic disciplines. In mathematics, for example, there are algorithms to find the local minimum value of a function, to determine the determinant of a square matrix etc. In digital systems, there are methods to prepare a truth-table from a logic expression, to minimize a given logic expression, to do state assignment etc. The subcategories of procedural knowledge are:

- Knowledge of subject specific skills and algorithms
- Knowledge of subject-specific techniques and methods
- Knowledge of criteria for determining when to use appropriate procedures

Knowledge of subject specific skills and algorithms can be expressed as a series or a sequence of steps. Sometimes the steps are followed in a fixed order; at other times decisions must be made which step to perform next. The end result is generally considered fixed in this type of knowledge. Examples of this category of knowledge include

- Knowledge of algorithms used with mathematics exercises
- Knowledge of algorithms for minimizing logic expressions
- Knowledge of algorithms for processing analog and digital signals
- Knowledge of pattern-search algorithms in Artificial Intelligence

Knowledge of subject-specific techniques and methods includes knowledge that is largely the result of consensus, agreement, or disciplinary norms rather than knowledge that is more directly an outcome of observation, experimentation, or discovery. This subtype of knowledge generally reflects how experts in the field or discipline think and attack problems. Examples of this category of knowledge include

- Knowledge of methods of management research
- Knowledge of system dynamics methods to model complex sociotechnical systems
- Knowledge of feedback control methods to improve the performance of a dynamic system.
- Knowledge of free-body diagrams to analyze problems of mechanics

Knowledge of criteria for determining when to use appropriate procedures involves knowing the ways they have been used in the past. Systematization is used by subject matter experts as they solve problems in their field. Experts know when and where to apply their knowledge. They have criteria that help them make decisions about when and where to use different types of subject-specific procedural-knowledge. Their knowledge is "conditionalized", in that they know the conditions under which a given procedure is to be applied. Initially, these criteria are likely to appear complex and abstract to students; they acquire meaning as they are related to concrete situations and problems. Examples of this category of knowledge include

- Knowledge of the criteria for determining whether to use time-domain methods or frequency-domain methods in analyzing a given electrical circuit.
- Knowledge of the criteria for determining which statistical procedure to use with the data collected in a particular experiment.
- Knowledge of the criteria for determining which transformation to be applied in a particular signal processing problem.

2.4 Metacognitive Knowledge: Meta cognitive knowledge is knowledge about cognition in general as well as awareness of and knowledge about one's own cognition. Regardless of their theoretical perspective, researchers generally agree that with development students will become more aware of their own thinking as well as more knowledgeable about cognition in general, and as they act on this awareness they will learn better (Bransford, Brown, and Cocking, 1999). The labels for this general developmental trend vary from theory to theory but include metacognitive knowledge, metacognitive awareness, self-awareness, self-reflection, and self-regulation. An important distinction in the field is between knowledge of cognition and the monitoring, control, and regulation of cognition. Flavell (1979) suggested the metacongition included knowledge of strategy, task, and person variables. These are categorized here as

- Strategic knowledge
- Knowledge about cognitive tasks
- Self-knowledge

Strategic knowledge is knowledge of the general strategies for learning, thinking and problem solving. The strategies in this subtype can be used across many different tasks and subject matters. This subtype includes knowledge of the variety of strategies that students might use to memorize material, extract meaning from text, or comprehend what they hear in classrooms or read in books and other course materials. These learning strategies can be grouped into three general categories: *rehearsal, elaboration*, and *organizational* (Weinstein and Mayer 1986).

- *Rehearsal* strategies involve repeating words or terms to be recalled over and over to oneself; they are generally not the most effective strategies for deeper levels of learning and comprehension.
- *Elaboration* strategies include the use of various mnemonics for memory tasks as well as techniques such as summarizing, paraphrasing, and selecting the main idea from texts. Elaboration strategies foster deeper processing of the material to be learned and result in better comprehension and learning than do rehearsal strategies.
- *Organizational* strategies include various forms of outlining, drawing "cognitive maps", mind mapping or concept mapping, and note taking; students transform the material from one form

to another. Organizational strategies usually result in better comprehension and learning than do rehearsal strategies.

In addition to these general learning strategies, students can have knowledge of various *metacognitive strategies* that are useful in planning, monitoring, and regulating their cognition. Students can eventually use these strategies to plan their cognition (e.g., set subgoals), monitor their cognition (e.g., ask themselves questions as they read a piece of text, check their answer to a math problem) and regulate their cognition (e.g., re-read something they don't understand, go back and "repair" their calculating mistake in a math problem).

This subtype of knowledge also includes general strategies for problem solving and thinking (Baron, 1994; Nickerson, Perkins, and Smith, 1985; Sternberg, 1985). These strategies represent the various general heuristics students can use to solve problems, particularly ill-defined problems that have no definitive solution method. Examples of heuristics are means-ends analysis and working backward from the desired goal state. In addition to problem-solving strategies, there are general strategies for deductive and inductive thinking (including evaluating the validity of different logical statements, avoiding circularity in arguments, making appropriate inferences from different sources of data and heuristic – making decisions from convenient instead of representative symbols).

The third subtype includes knowledge about cognitive tasks, including contextual and conditional knowledge. Different cognitive tasks can be more or less difficult, and may make differential demands on the cognitive system, and may require different cognitive strategies. For example recall task is more difficult than recognition task. As students develop knowledge of different learning and thinking strategies, this knowledge reflects both what general strategies to use and how to use them. Students also need to develop the conditional knowledge for these general cognitive strategies; in other words, they need to develop some knowledge about when and why of using these strategies appropriately. All these different strategies may not be appropriate for all situations, and the learner must develop some knowledge of different conditions and tasks for which the different strategies are most appropriate. Conditional knowledge refers to knowledge of the situations in which students may use Metacognitive knowledge

If one thinks of strategies as cognitive "tools" that help students construct understanding, then different cognitive tasks require different tools. An important aspect of learning about strategies is the conditional knowledge of when and why to use them appropriately. Another important aspect of conditional knowledge is the local situational and general, conventional, and cultural norms for using different strategies. For example, the strategies used in a classroom learning situation may not be most appropriate ones to use in a work setting.

Self-knowledge includes knowledge of one's strength and weaknesses in relation to cognition and learning. One hall-mark of experts is that they know when they do not know something and they then have some general strategies for finding the needed and appropriate information. Self-awareness of the breadth and depth of one's own knowledge base is an important aspect of self-knowledge. Students need to be aware of the different types of general strategies they are likely to rely on in different situations. An awareness that one tends to over rely on a particular strategy, when there may be other more adaptive strategies for the task, could lead to a change in strategy use.

In addition to knowledge of one's own general cognition, individuals have beliefs about their motivation. Motivation is a complicated and confusing area. A consensus has emerged, however, around general social cognitive models of motivation that propose three sets of motivational beliefs.

- Self efficacy beliefs, that is, students' judgments of their capability to accomplish a specific task.
- Beliefs about goals or reasons students have for pursuing a specific task (e.g., learning vs. getting a good grade).
- Students' perception of their personal interest (liking) for a task as well their judgments of how important and useful the task is to them.

Just as students need to develop self-knowledge and awareness about their own knowledge and cognition, they also need to develop self knowledge and awareness about their own motivation. Again, awareness of these different motivational beliefs may enable the learners to monitor and regulate their behavior in learning situations in a more adaptive manner.

Self-knowledge is important aspect Metacogntive knowledge, but the accuracy of self-knowledge seems to be most crucial for learning. The role of the teacher is to help students make accurate assessment of their self-knowledge and not attempt to inflate students' academic self-esteem.

3. Categories of Engineering Knowledge

Engineering knowledge is pursued at great effort and expense in schools of engineering. Many scholars tend to think of it as applied science. Modern engineering is seen as taking over its knowledge from scientists and, by some occasionally dramatic probably intellectually uninteresting process, using this knowledge to fashion material artifacts. From this standpoint of view, studying the epistemology of science should automatically subsume the knowledge content of engineering. Engineers know from experience that this view is untrue. In view of several historians, technology and engineering appear not as derivatives from science, but autonomous bodies of knowledge, identifiably different from the scientific knowledge with which they interact. Engineering has its own significant component of thought, though different in its specifics, resembles scientific thought in being creative and constructive; it is not simply routine and deductive as assumed in the applied-science model. In this view, engineering, though it may apply science, is not the same as or entirely applied science.

Treating science and technology (engineering) as separate spheres of knowledge, both man made, appears to fit the historical record better than treating science as revealed knowledge and technology as a collection of artifacts once constructed by trial and error

For engineers, in contrast to scientists, knowledge is not an end in itself or the central objective of their profession. Rather, it is a means to a utilitarian end – actually, several ends. G.F.C. Rogers (1983) states: engineering refers to the practice of organizing the design, construction and operation of any artifice which transforms the physical world around us to meet some recognized need". These terms may be interpreted as:

Organize	-	bringing into being, get together or arrange
Design	-	plans from which the artifice is built, as in many drawings or computer displays
Construction	-	production or manufacturing
Operation	-	employment of the artifice in meeting the recognized need

Design denotes both the content of a set of plans and the process by which those plans are produced. As a process, design involves tentative layout of the arrangement and dimensions of the artifice, checking of the candidate device by mathematical analysis or experimental test to see if it does not. Such procedure usually requires several iterations before finally dimensioned plans can be released for production. Events in doing are also more complicated than such a brief outline suggests. Numerous difficult tradeoffs may be required, calling for decisions on the basis of incomplete or uncertain knowledge. If available knowledge is inadequate, special research may have to be undertaken. The process is complicated and fascinating one that needs more historical analysis than it has received.

Design activity can be considered either as normal design or radical design. The engineer involved in normal design knows at the outset how the device in question works, what are its customary features, and that, if properly designed along such lines, it has good likelihood of accomplishing the desired task. The way a device should be arranged, or even its working is largely unknown in radical design. The designer has never seen such a device before ad has no resumption of success. The procedure is generally to design something that will function well enough to warrant further development. Normal design makes up by far the bulk of day-to-day engineering enterprise.

The knowledge required by normal design and radical design cannot be sharply separated; there are obviously middle levels of novelty where the distinction is difficult to make. Normal design is not routine and deductive and essentially static. Like technology as a whole, it is creative and constructive and changes over time as designers pursue ever more ambitious goals. The changes are incremental instead of essential; normal design is evolutionary rather than revolutionary, even within such limits the kinds of knowledge required are enormously diverse and complex. The activities that produce the knowledge, unlike the activity it is intended to support, are also sometimes far from normal and day-to-day.

Engineering knowledge reflects the fact that design does not take place for its own sake and in isolation. Artifactual design is a social activity directed at a practical set of goals intended bound up with economic, military, social, personal, and environmental needs and constraints. These needs and constraints are referred to as "contextual factors" that constitute the artifact's ambience. In normal design, this ambience exercises its greatest direct effect at the upper levels of hierarchy, where projects are defined and laid out. At the lower levels of design the contextual influence, though still present, tends to be weaker and less direct; at these levels, knowledge derives predominantly from the internal needs of design itself.

Some of the sources of engineering problems (Vincenti 1990) are:

1. Functional failure of current technologies
2. Extrapolation from past technological successes
3. Imbalances between related technological successes
4. Potential, rather than the actual technological failures
5. Perception of a new technological change
6. Internal logic of technology
7. Internal needs of design (Design necessities defining problems of knowledge generation that must be solved when necessary data and methods do not already exist. A vast amount of research effort arises out of problems from this source. Example: a better method to charge batteries, a new converter configuration)
8. Need for decreased uncertainty (Example: studies on noisy channel)

Whatever be the source of design problems, their solution depends on knowledge. The knowledge, however, need not be new. Even when resolution of a new problem is achieved, the problem does not disappear. Developments and refinements continue, of course, and solutions in individual cases may call for considerable ingenuity. Once understanding and information are established, however, solutions are typically devised without generation of a great deal of additional knowledge. What is needed is available in textbooks or manuals and can be looked up, taught to engineering students, or learned on the job.

When knowledge is not at hand it has to be generated. The needs of design impel, condition, and constrain the growth and nature of that knowledge. The new knowledge may be generated very close to design, rather far from it or some complicated combination of the two. Wherever its generation, the knowledge is judged in the end on the basis of whatever it helps to achieve a successful design.

Engineering knowledge may be categorized (Vincenti 1990) into:

1. **Fundamental Design Concepts**: Operational principles of the devices. Operational principles also exist for the components within a device.
2. **Criteria and Specifications**: It is necessary to translate the qualitative goals for the device into specific, quantitative goals. Design criteria vary widely in perceptibility. Assignment of the values or limits is usually (but not always) particular design, and is best looked upon as part of the design process.
3. **Theoretical Tools**: Mathematical tools. Physical principles. Theories based on scientific principles but motivated by and limited to a technologically important class of phenomena or even to a specific device. Assortment of theories involving some central and ad hoc assumption about phenomena crucial to the problem that may be termed as phenomenological theories. Quantitative assumptions introduced for calculative expedience
4. **Quantitative Data**: Descriptive (physical constants) and prescriptive (how things should be) data.
5. **Practical Constraints**: These represent an array of less sharply defined considerations derived from experience in practice, considerations that frequently do not lend themselves to theorizing, tabulation, or programming into a computer.
6. **Design Instrumentalities**: These refer to the procedural knowledge. Instrumentalities of the process include the procedures, way of thinking, and judgmental skills by which it is done.

Let us consider some samples of engineering knowledge predominantly from the field of electrical engineering:

Fundamental Design Concepts

1. A device can perform a variety of tasks by incorporating memory into it.
2. A device that has two well defined states can be used as a memory unit.
3. Stepping movement can be created through interaction between two salient magnetic fields.
4. An aeroplane operates by propelling rigid surface forward through the resisting air, thus producing the upward force required to balance the aeroplane's weight.
5. An airfoil, by virtue of it shape, in particular its sharp trailing edge, generates lift when inclined at an angle to the air stream.
6. By controlling the phase angle of switching and allowing the switching device to get naturally commutated with the ac power supply it is possible to control the power to any load.

7. A conducting power switching device can be commutated by forcing current in the opposite direction.
8. The efficiency of power converter can be improved by switching the devices at zero current.

Criteria and Specifications

1. Any power converter should have efficiency above 95%.
2. A SMPS should not source of excessive electromagnetic disturbance.
3. The measurement of instantaneous power should be accurate.
4. The speed control unit for the dc motor should not create excessive harmonic distortion on the power line.
5. The SMPS output should have an output regulation of 0.5%.
6. The speed of the dc motor should be controlled over a speed range of 1 to 300 RPM with an accuracy of 0.05%.
7. The phase angle between the voltage and current waveforms should be measured with an accuracy of 0.1 degree.
8. Specification like overshoot, settling time, time constants, and steady state error.

Theoretical Tools

1. Kirchoff's laws.
2. Electromagnetic induction.
3. p-n junction theory.
4. p-n-p-n junction switching theory.
5. Theory of operation of MOSFET
6. Laplace transforms.
7. Fourier Transforms.
8. Concepts like force, torque, efficiency, feedback, and feed forward
9. High frequency models of transistors.
10. Model for the switching behavior of a power transistor.
11. Thermal resistance of switching device.
12. V-I characteristic of a diode.

Quantitative Data

1. The voltage across the switching device is 0.1 V.
2. Factors of safety.
3. Physical constants like acceleration of gravity and Plank's constant.
4. What does one micron mean when a simply supported beam deflects under load.
5. Properties of substances like failing strength of materials, electrical conductivity and thermal conductivity.

6. Electrical resistance of a human being.
7. Engineering standards with regard to absolute values and tolerances.

Practical Constraints

1. The drilling machine available can not drill holes larger than 0.5”.
2. The PCB should be compatible with PC motherboard.
3. The legend should be written above the switch on the front panel.
4. The indicator lamp should be above the switch.
5. The clearances that must be allowed between physical parts in equipment for tools and hands to reach different parts.
6. The design should be completed within two months.

Design Instrumentalities

1. Top-down approach to the design of a product.
2. Phasing of development of a product.
3. Structuring of an electronic product.
4. Design walkthroughs.
5. Identify all members of the team early on and include every member in the group communications from the outset.
6. Don’t be too proud to seek help from outside the project team. Go to extraordinary lengths to encourage team members to take risks.
7. Do not all ways call on management to solve problems!

4. Conclusion

Four types of knowledge are factual, conceptual, procedural and metacognitive. Factual and conceptual knowledge are most similar in that they involve the knowledge of ‘what’, although conceptual knowledge is deeper more organized, integrated, and systemic knowledge than just knowledge of terminology and isolated facts. Procedural knowledge is the knowledge of ‘how’ to do something. Metacognitive knowledge, in simplest terms, is knowledge about cognition. However, there can be domain specific categories of knowledge.

While Vincenti identifies six categories of knowledge specific engineering, two of them can be subsumed under the general categories. It is believed that there are categories of knowledge specific to Social Sciences, Management, Computing, and Humanities.

The categories of knowledge including those specific to engineering are graphically presented in the figure1.

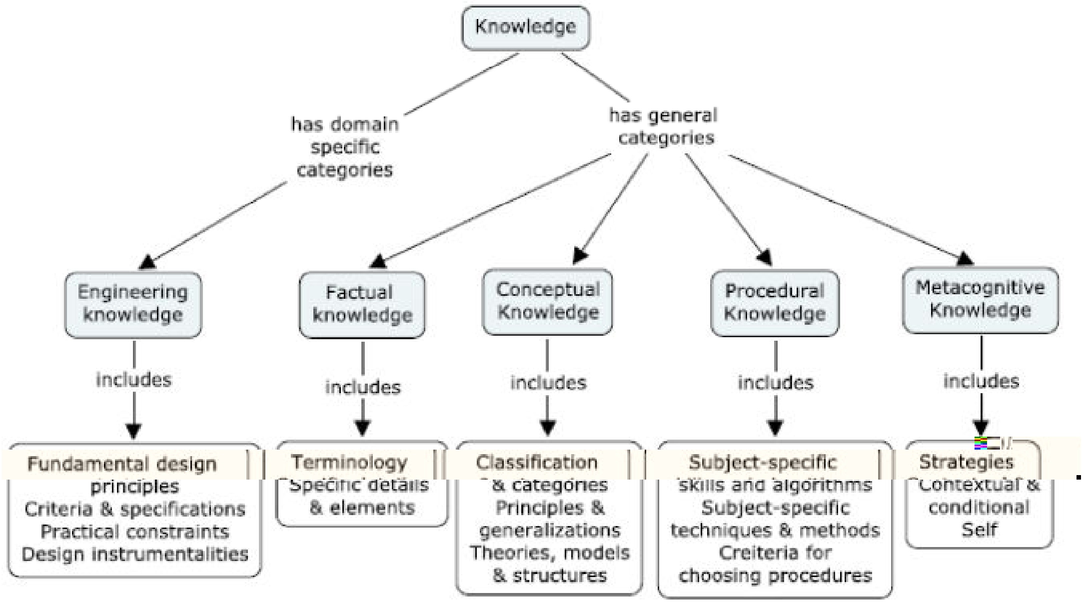

Fig. 1: Categories of knowledge of concern to engineering

References

1. Anderson L.W., Krathwohl D.R., Airasian P.W., Crushank K.A., Mayer R.E., Pintrich P.R., Raths J. and Wittrock M.C. (Editors): A Taxonomy for Learning, Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives, Longman, 2001
2. Baron, J., Thinking and deciding, Cambridge, UK: Cambridge University Press, 1994.
3. Flavell, J., Metacognition and cognitive monitoring: A new area of cognitive developmental inquiry. American Psychologist, 34, 906-911, 1979.
4. Nickerson, R., Perkins, D. and Smith, E., The teaching of thinking, Hillsdale, NJ: Earlbaum, 1985.
5. Rogers, G.F.C., The Nature of Engineering: A Philosophy of Technology, 1983
6. Sternberg, R., Beyond IQ: A triarchic theory of human intelligence, New York: Cambridge University Press, 1985.
7. Vincenti, W.G., What Engineers Know and They Know it, The Johns Hopkins University Press, 1990
8. Weinstein, C.E., and Mayer, R., The teaching of learning strategies in M. Wittrock (Ed.), Handbook of research on teaching, 3rd ed. (pp.315-327), new York, Macmillan, 1986
9. Wise, G., Science and Technology, Osiris, 2dser. 1, 1985