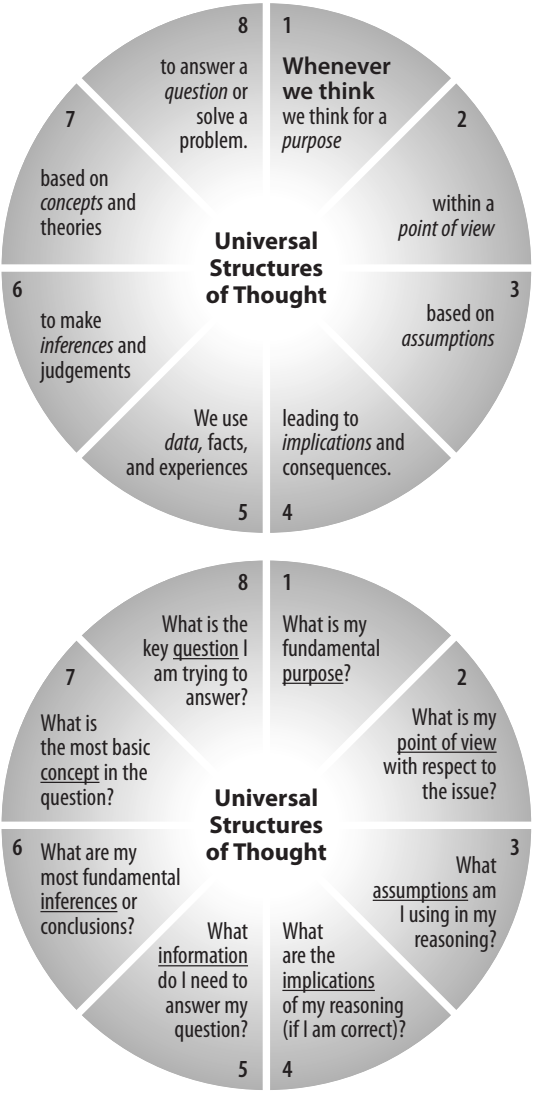
To Analyze Thinking We Must Learn to Identify and Question its Elemental Structures



Note: When we understand the structures of thought, we ask important questions implied by these structures.

Analyzing a Design Using the Elements of Thought

Engineering purpose	What is the purpose of this design? What are the market opportunities or mission requirements? Who defines market opportunities/mission requirements? Who is the customer?
Question at hand	What system/product/process will best satisfy the customer's performance, cost, and schedule requirements? How does the customer define "value"? Is a new design or new technology required? Can an existing design be adapted? How important is time-to-market?
Point of view	A design and manufacturing point of view is typically presumed. What other points of view deserve consideration? Stockholders? Component vendors/suppliers? Marketing/sales? Customers? Maintenance/repair/parts? Regulators? Community affairs? Politicians? Environmentalists?
Assumptions	What environmental or operating conditions are assumed? What programmatic, financial, market or technical risks have been considered acceptable to date? What market/economic/competitive environment is assumed? What safety/environmental assumptions are we making? Are these assumptions acceptable? What maturity level or maturation timeline is assumed for emerging technologies? What happens if we change or discard an assumption? What criteria have historically been assumed in defining a "best" or "optimum" solution? What assumptions have been made on the availability of materials? What manufacturing capability was assumed? What workforce skills or attributes have been assumed?

Analyzing a Design Using the Elements of Thought (cont'd)

Engineering information	What is the source of supporting information (handbook, archival literature, experimentation, corporate knowledge, building codes, government regulation)?
	What information do we lack? How can we get it? Analysis? Simulation? Component testing? Prototypes?
	What experiments should be conducted?
	Have we considered all relevant sources?
	What legacy solutions, shortcomings, or problems should be studied and evaluated?
	Is the available information sufficient? Do we need more data? What is the best way to collect it?
	Have analytical or experimental results been confirmed?
	What insights and experiences can the shop floor provide?
Concepts	What concepts or theories are applicable to this problem?
	Are there competing models?
	What emerging theory might provide insight?
	What available technologies or theories are appropriate?
	What emerging technologies might soon be applicable?
Inferences	What is the set of viable candidate solutions?
	Why were other candidate solutions rejected?
	Is there another way to interpret the information?
	Is the conclusion practicable and affordable?
Implications	What are some important implications of the data we have gathered?
	What are the most important market implications of the technology?
	What are the most important implications of a key technology not maturing on time?
	How important is after-market sustainability?
	Is there a path for future design evolution and upgrade?
	Are there disposal/end-of-service-life issues we need to consider?
	What are the most important implications of product failure?
	What design features if changed, profoundly affect other design features?
	What design features are insensitive to other changes?
	What potential benefits do by-products offer?
	Should social reaction and change management issues be addressed?

Universal Intellectual Standards Essential to Sound Engineering Reasoning

Clarity	Could you elaborate further? Could you give me an example? Could you illustrate what you mean?
Accuracy	How could we check on that? How could we find out if that is true? How could we verify or test that?
Precision	Could you be more specific? Could you give me more details? Could you be more exact?
Relevance	How does that relate to the problem? How does that bear on the question? How does that help us with the issue?
Depth	What factors make this a difficult problem? What are some of the complexities of this question? What are some of the difficulties we need to deal with?
Breadth	Do we need to look at this from another perspective? Do we need to consider another point of view? Do we need to look at this in other ways?
Logic	Does all this make sense together? Are we taking a reasonable approach to the problem? Does what you say follow from the evidence?
Significance	Is this the most important problem to consider? Is this the central idea to focus on? Which of these facts are most important?
Fairness	Am I considering the views of others in good faith? Am I accurately representing the viewpoints of others? Is there an ethical component to this issue that we are avoiding for reasons of vested interest?

Skilled Engineers Consentingly Adhere to Intellectual Standards

Universal intellectual standards must be applied to thinking whenever one is evaluating the quality of reasoning as one reasons through problems, issues, and questions. These standards are not unique to engineering, but are universal to all domains of thinking. To think as a highly skilled engineer entails having command of these standards and regularly applying them to thought. While there are a number of universal standards, we focus here on some of the most significant.

Clarity: Understandable; the meaning can be grasped

Clarity is a gateway standard. If a statement is unclear, we cannot determine whether it is accurate or relevant. In fact, we cannot tell anything about it because we do not yet know what it is saying.

Questions targeting clarity include the following.

- Could you elaborate further on that point?
- Could you express that point in another way?
- Could you give me an illustration or example?
- Are the market/mission requirements clearly stated?
- Have terms and symbols been clearly defined?
- Which requirements have priority and which can be relaxed if required?
- Have the assumptions been clearly stated?
- Is specialized terminology either defined, or being used in keeping with educated usage?
- Do drawings/graphs/photos and supporting annotations clearly portray important relationships?[3]
- How do the affected stakeholders define "value"?

Accuracy: Free from errors or distortions; true

A statement can be clear but not accurate, as in "Most creatures with a spine are over 300 pounds in weight."

Questions targeting accuracy include the following.

- Is that really true?
- How could we check that?
- How could we find out if that is true?
- What is your confidence in that data?
- Has the test equipment been calibrated? How or when?

[3] See pp. 27-28 for further questions that target the assessment of graphics through intellectual standards. Students and faculty interested in clarity of graphical communication are urged to read these three books by Edward Tufte: *Visual Explanations, Envisioning Information*, and *The Visual Display of Quantitative Information*. Published by Graphics Press, Cheshire, Connecticut.

- How have simulation models been validated?
- Have assumptions been challenged for legitimacy?
- What if the environment is other than we had expected (e.g., hotter, colder, dusty, humid)?
- Are there hidden or unstated assumptions that should be challenged?

Precision: Exact to the necessary level of detail

A statement can be both clear and accurate, but not precise, as in "The solution in the beaker is hot." (We don't know how hot it is.)

Engineering questions targeting precision include the following.

- Could you give me more details?
- Could you be more specific?
- What are acceptable tolerances for diverse pieces of information?
- What are the error bars or confidence bounds on experimental, handbook or analytical data?
- At what threshold do details or additional features no longer add value?

Concision: Brief in form while comprehensive in scope, implies the elimination of unnecessary details to clarify thought

Concision does not connote eliminating words for brevity's sake (the sound bite), but rather an economy of thoughts whereby the thinking is deep and significant, and clarity is actually enhanced by the limited use of words. The question – or questions – at issue, and the context within which the question is situated, determine the amount of detail needed to clarify or guide thought in a given situation. In other words the question, and its context, drive the level of detail (precision/concision) needed. In the hours building to the loss of the Space Shuttle Challenger, engineers understood the peril faced by launching at extremely low temperatures. Yet, they buried their management in insignificant details such that their message was missed; their signal was lost in self-generated noise. "Clear and concise" appear routinely in business writing guides as almost inseparable expectations of business leaders. In his Principia, Isaac Newton remarked, "More is vain when less will serve."

Questions targeting concision include the following:

- What can I remove that will boost the clarity of my point?
- Do I need to eliminate any distracting details?
- Should I move some of the relevant data to an appendix where it is available but less distracting (because less important)?
- Can a graph more concisely present this tabulated data, and boost the clarity of the data being presented and the variables being considered?

Relevance: Relating to the matter at hand

A statement can be clear, accurate, and precise, but not relevant to the question at issue. A technical report might mention the time of day and phase of the moon

at which the test was conducted. This would be relevant if the system under test were a night vision device. It would be irrelevant if it were a microwave oven.

Questions targeting relevance include the following.

- How is that connected to the question?
- How does that bear on the issue?
- Have all relevant factors been weighed (e.g., environmental, or marketplace)?
- Are there unnecessary details obscuring the dominant factors?
- Has irrelevant data been included?
- Have important interrelationships been identified and studied?
- Have features and capabilities (and hence costs) been included which the customer neither needs nor wants?

Depth: Containing complexities and multiple interrelationships

A statement can be clear, accurate, precise, and relevant, but superficial. For example, the statement, "Radioactive waste from nuclear reactors threatens the environment," is clear, accurate, and relevant. Nevertheless, more details and further reasoning need to be added to transform the initial statement into the beginnings of a deep analysis.

Questions targeting depth include the following.

- How does your analysis address the complexities in the question?
- How are you taking into account the problems in the question?
- Is that dealing with the most significant factors?
- Does this design model have adequate complexity and detail, given its counterpart in reality?

Breadth: Encompassing multiple viewpoints

A line of reasoning may be clear, accurate, precise, relevant, and deep, but lack breadth (as in an argument from either of two conflicting theories, both consistent with available evidence).

Questions targeting multiple viewpoints include the following.

- Do we need to consider another point of view?
- Is there another way to look at this question?
- What would this look like from the point of view of a conflicting theory, hypothesis, or conceptual scheme?
- Have the full range of options been explored?
- Have interactions with other systems been fully considered?

Logic: The parts make sense together, no contradictions

When we think, we bring a variety of thoughts together into some order. The thinking is "logical" when the conclusion follows from the supporting data or

Questions/Statements targeting logic include the following.

- Does this really make sense?
- Does that follow from what you said? How does that follow?
- But earlier you implied this and now you are saying that. I don't see how both can be true.
- Are the design decisions supported by logical analysis?

Fairness: Justifiable, not self-serving or one-sided

Fairness is particularly at play where more than one viewpoint is relevant to understanding and reasoning through an issue (conflicting conceptual systems), or where there are conflicting interests among stakeholders. Fairness gives all relevant perspectives a voice, while recognizing that not all perspectives may be equally valuable or important.

Questions targeting fairness include the following.

- Have other points of view been considered (stock holders, manufacturing, sales, customers, maintenance, public citizens, community interests, and so on)?
- Are vested interests inappropriately influencing the design?
- Are divergent views within the design team given fair consideration?
- Have the environmental/safety impacts been appropriately weighed?
- Have we fully considered the public interest?
- Have we thought through the ethical implications in this decision?

Significance: Important, of consequence

Our thought can be clear, accurate, precise, and relevant, yet be trivial, or fail to focus on significant issues or problems. Engineering frequently entails problems with multiple relevant independent variables, and yet one or two out of a half dozen may outstrip the others in importance or significance. Students can grasp at anything that comes to mind that's relevant, and yet miss the significant. This is also common in poorly run meetings, in which minor matters consume inordinate time, and vital issues get short shrift or are ignored entirely. Attentiveness to the significant results in recognizing the most important information, issues and implications in engineering reasoning.

Questions targeting significance include the following:

- Have we identified the most important questions at the heart of the issue?
- What are the most influential factors?
- What are the important variables that need to be considered?
- What are the most significant implications that must be reasoned through as we design this project?