Implications and Consequences
(All reasoning leads somewhere. It has implications and,
when acted upon, has consequences.)

Primary Standards: (1) Significance, (2) Logicality, (3) Clarity, (4) Precision,
(5) Completeness

Common Problems: (1) Unimportant, (2) Unrealistic, (3) Unclear, (4)
Imprecise, (5) Incomplete

Principle: To reason well through an issue, you might think through the
implications that follow from your reasoning. You must think
through the consequences likely to flow from the decisions you
make.

<table>
<thead>
<tr>
<th>Skilled Thinkers...</th>
<th>Unskilled Thinkers...</th>
<th>Critical Reflections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trace out a number of significant potential implications and consequences of their reasoning.</td>
<td>Trace out few or none of the implications of holding a position or making a decision.</td>
<td>Did I spell out all the significant consequences of the action I am advocating?</td>
</tr>
<tr>
<td>Clearly and precisely articulate the possible implications and consequences.</td>
<td>Are unclear and imprecise in the possible consequences they articulate.</td>
<td>Have I delineated clearly and precisely the consequences likely to follow from my chosen actions?</td>
</tr>
<tr>
<td>Search for potentially negative as well as potentially positive consequences.</td>
<td>Trace out only the consequence they had in mind at the beginning, either positive or negative, but usually not both.</td>
<td>I may have done a good job of spelling out some positive implications of the decision I am about to make, but what are some of the possible negative implications or consequences?</td>
</tr>
<tr>
<td>Anticipate the likelihood of unexpected negative and positive implications.</td>
<td>Are surprised when their decisions have unexpected consequences.</td>
<td>If I make this decision, what are some possible unexpected implications? What are some of the variables out of my control that might lead to negative consequences?</td>
</tr>
<tr>
<td>Considers the reactions of all parties.</td>
<td>Assumes the outcomes and products will be welcomed by other parties.</td>
<td>What measures are appropriate to inform the community or marketplace? What opinion leaders should be involved?</td>
</tr>
</tbody>
</table>

The Questioning Mind in Engineering: The Wright Brothers

Throughout history, there has been a plethora of engineers who were not only clear thinkers but stunning visionaries as well. In the preindustrial age, many who were important scientists were also engineers (Da Vinci, Galileo, Franklin, Fulton). Indeed, the ancient artifacts of many brilliant engineers grace the landscapes of China, Egypt, and Rome’s Empire. For our brief purpose, two exemplars will suffice to illustrate highly skilled engineering reasoning. Orville and Wilbur Wright rank among history’s most influential personalities, having profoundly contributed to our modern lifestyles.

We all recognize the photo of Orville’s first flight, theFlyer hanging in air, the expectant Wilbur poised, watching. This 1903 snapshot represents a six-year campaign from the 1899 spark of the Wright brothers’ interest in aeronautics to theirfirst practical airplane in 1905.

6 Sources: Jakab P. Visions of a Flying Machine; McFarland MW (ed.). The Papers of Wilbur and Orville Wright; and Anderson J. The History of Aerodynamics. Photograph: public domain.
The Wrights had broad foresight, realizing that they needed to be both inventors and pilots. They devoted 1,000 glider flights to learning to fly prior to the first powered flight. Their progress represented numerous intermediate conclusions and inferences drawn from their progressive learning—each year’s variant drawing heavily on the lessons learned from the prior year’s flying and experiments. They were cognizant of implications, giving particular attention to managing the hazards associated with flight tests, ensuring that they would survive the inevitable crashes.

They distinguished themselves from others pursuing the same goal by the breadth and depth of the questions they posed and pursued. They did not see their challenge as a narrow aerodynamic or technical one, but broadly, as a complex challenge involving multiple technologies. The comical footage we see of others’ halting attempts at powered flight reveals ignorance of its complexities. Competitors ignored stability, or drag, or weight, or embraced shallow and erroneous concepts of flight. Others’ designs seem to cry, “Surely if it flaps like a bird, it will fly like a bird.” In contrast, the Wrights’ papers indicate a methodical integrated series of questions and answers posed from diverse points of view as inventors, scientists, businessmen, and pilots. Herein lay their success.

---

The Cost of Thinking Gone Awry

On February 1, 2003, the space shuttle Columbia disintegrated over the southern U.S., killing its crew of seven. The Columbia Accident Investigation Board (CAIB) met over the months that followed to identify the direct and indirect causes, and provide both NASA and the U.S. Congress with concrete direction with respect to the future of both the shuttle program and American manned space flight. The direct technical causes of this tragedy have been widely publicized. More significantly, the CAIB reserved its most scathing findings for an institutional culture within NASA fraught with poor thinking practices that appeared to have learned nothing from the 1986 loss of the space shuttle Challenger.

Note the use of our critical thinking vocabulary in the following causal factors identified by the CAIB report, and rife throughout NASA and its contractors.

- Failure to challenge assumptions or patterns
- Unsupported/historical inferences
- Assumptions confused with inferences
- Suppression/dismissal of dissenting views
- Failure to evaluate data quality or recognize data deficits
- Failure to weigh the full range of implications
- Narrow points of view
- Confused purposes
- Failure to pose the appropriate questions
- Application of irrelevant data and concepts
- Vague, equivocal language

The CAIB report specifically charged NASA leadership with a reformation of their culture to improve and encourage good thinking across the agency and its supporting contractors. The promotion of good thinking practices was to be designed into the organizational structure.

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Noteworthy Connections and Distinctions

People often view science and engineering as almost synonymous, likely due to the criticality of science to most engineering work and the content of an engineering education. We have already noted a number of distinctions and similarities between the kinds of questions posed by the scientist and engineer. The topics in this section give rise to additional interesting questions at the junction of the engineer's role and that of others with whom engineers might work.

Creativity in Engineering
Engineering is a creative enterprise. Even the simplest engineering jobs require analysis and assessment, yet will also demand ingenuity and creativity in applying concepts, tools, and materials to the problem at hand. Problems with unique solutions are rare, requiring judgment to discern the strengths and weaknesses of candidate solutions. Design requirements are frequently in tension, necessitating creativity and keen insight into the customer's application to appropriately balance those tensions. True technical innovation permits the creation of systems or products with novel capabilities.

- Do the technical requirements require a new approach or technology?
- What is the market for, cost of, or schedule risk of innovation on this project?
- What opportunity does innovation create in this project?

Engineering and Aesthetics
It's not all about the numbers. Unattractive products usually don't sell. Consequently, the skilled engineer cannot ignore the aesthetic implications of their finished work. Indeed, in many engineering enterprises, engineering teams will either include or consult professional designers to ensure a product's aesthetic appeal. History is replete with engineers who were keenly aware of the importance of aesthetics, leaving us with bridges, buildings, steam locomotives, ships, and so on, in which form and function harmoniously and attractively served one another.

- To what extent should I be concerned with the design's aesthetic appeal? Does the marketing department agree? Does the customer agree?
- Is professional design consultation appropriate to this project?

Engineering and Technicians
While both engineers and technicians are technologists, in the sense that their work is technologically based, there are significant differences in how the two words are commonly used. “Technician” typically applies to those skilled trades involved with the manufacture, maintenance, or repair of technical systems. An engineering degree is seldom required of a technician (nor math beyond algebra and trigonometry). However, considerable postsecondary training may be required for technicians in many fields. In many situations, it is common to find technicians and engineers working together within teams. Technicians might commonly ask, “How do I restore the equipment to its optimum operating condition?” The in-service engineer working with him might instead ask, “How can the equipment be redesigned to avoid this failure in the future or facilitate future repair?”

Engineers and Craftsmen
Overlap exists between the role of the engineer and a craftsman. “Craftsman” typically connotes technical skill blended with artistry, and might well express technical work in innovative ways. The craftsman might consider many of the factors about which engineers are concerned. For example, a cabinet maker might carefully select the materials for a particular application on the basis of strength and durability, selecting joints and fasteners based upon the anticipated load. The engineer would typically approach a similar task by way of numerical analysis, whereas a craftsman might generally approach the task intuitively, based on experience with both the materials and usage. Many engineers have little direct fabrication experience, while craftsmanship typically connotes direct fabrication of a product. Orville and Wilbur Wright provide an interesting example. As inventors of the airplane, carefully calculating the required elements of each part of the design, they were "thinking" as engineers. As bicycle makers, primarily relying upon intuition and past experience, they appear to have been "thinking" as craftsmen.

Engineering and Public Policy
Public policy frequently influences the practice of engineering. This can result from the regulation of some perceived public or consumer hazard, or the export control of a defense-sensitive technology. In these cases, policy may constrain or oppose good engineering practice. In others, public policy may foster engineering activity or innovation in the form of contracts, research grants, or tax credits. The engineer working in the public domain must have intellectual empathy, must be able to grasp the concerns and interests expressed by agents of public entities (regulators, lawmakers, contracting officers), who may not have technical education or experience. It is commonplace for policy requirements or specifications designed to reduce or eliminate hazards to instead hinder or constrain developing technologies or the work of the engineer. It is therefore frequently appropriate for the engineer to probe with questions of relevance when technology has moved faster than the public policy, or when public interest is not served by overzealous policy (e.g., consider the often excessively large number of rules and regulations in building).
**Ethics and Engineering**

The work of engineering has implications for helping or harming living creatures, and for improving or diminishing the quality of life on earth. Therefore, the highly skilled engineer is concerned with the ethical implications of engineering discoveries and inventions, and the potential of engineering for both good and ill.

The ethical responsibilities of engineers are similar to that of scientists, because the implications of engineering are often similar to implications of science. It is useful to consider the transformation that Einstein underwent in his views regarding the ethical responsibilities of scientist. “From regarding scientists as a group almost aloof from the rest of the world, he began to consider them first as having responsibilities and rights level with the rest of men, and finally as a group whose exceptional position demanded the exercise of exceptional responsibilities.” In 1948, after the United States dropped atomic bombs on Hiroshima and Nagasaki, Einstein wrote this message to the World Congress of Intellectuals.

We scientists, whose tragic destiny it has been to help make the methods of annihilation ever more gruesome and more effective, must consider it our solemn and transcendent duty to do all in our power in preventing these weapons from being used for the brutal purpose for which they were invented. What task could possibly be more important to us? What social aim could be closer to our hearts? 8

It is critical that engineers keep the ethical implications of their work near the forefront of their decisions. This includes thinking through ethical implications of normal operations, possible failure modes, and even situations in which a product might be misused by the customer (e.g., situations, conditions, or applications not intended by the designer). The capacity for harm motivates governmental regulation and licensure of engineers in many fields. However, while many engineering responsibilities may be codified in applicable law, ethical duty exists even where legal obligation does not. 9

**Humanitarian Responsibility and Product Safety**

All engineers bear an obvious ethical responsibility to avoid compromising the health and welfare of those who purchase their products, as well as those who might come into contact with their product, whether it is a consumer product or a suspension bridge. Moreover, while all engineers presumably make products with beneficial purposes, some engineers have positive ethical opportunities to dramatically contribute to the health, welfare, and economic vitality of individuals and communities.


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**Environmental Responsibility**

Large-scale catastrophes such as Bhopal or Chernobyl draw the principal attention as exemplars of the power of engineers for destructive impacts on communities, regions, and nations. In these cases, a single product failure broadly devastated lives, livelihoods, and property. As substantial, however, are the recurring cumulative effects of normally functioning products whose count may number in the tens of thousands, but whose pollutant products, consumption of resources, or disposal challenges impose detrimental environmental and/or economic effects over time.

In short, where there are ethical implications of an engineer’s work for the health and sustainability of the earth, the engineer has inescapable ethical obligations.

**Fiduciary Responsibility**

Engineers have fiduciary responsibilities to customers, company leadership, and stockholders. However, neither customers nor stockholders have detailed insight into the engineer’s daily activity or design decisions. Consequently, it is the engineer’s duty to safeguard the interests and points of view of these stakeholders, as a matter of ethical responsibility.
Engineering Reasoning Objectives

The CDIO (Conceive–Design–Implement–Operate) consortium has developed a comprehensive syllabus for an engineering education, ratified by diverse international industry and academic leaders.\(^{10}\) The syllabus articulates a diverse range of learning objectives, many of which explicitly employ the language of critical thinking. This list is of principle benefit to educators seeking to catalog program educational outcomes.

**Engineering Affective Dimensions**
- Exercising independent thought and judgment (2.4.2)\(^{11}\)
- Exercising reciprocity (2.4.2)
- Welcoming ingenuity and innovation (2.4.1, 2.4.3)
- Recognizing diverse stakeholder points of view (2.3.1, 4.1.6)
- Suspending judgment (2.4.2)
- Developing insight into egocentrism and sociocentrism (2.4.2)

**Cognitive Dimensions: Engineering Macro-Abilities**
- Selecting critical questions to be answered (2.2.1)
- Clarifying technical issues and claims (2.2.1)
- Clarifying technological ideas (2.1.2, 3.2)
- Developing criteria for technical evaluation (4.4.6)
- Evaluating scientific/engineering authorities (2.2.2)
- Raising and pursuing root questions (2.2.1)
- Evaluating technical arguments (2.4.4)
- Generating and assessing solutions to engineering problems (2.1)
- Identifying and clarifying relevant points of view (4.2)
- Engaging in Socratic discussion and dialectical thinking on engineering issues
- Avoiding oversimplification of issues
- Developing engineering perspective (4.x)

**Cognitive Dimensions: Engineering Micro-Skills**
- Evaluating data (2.1.1)
- Analyzing assumptions (2.1.1)
- Identifying and applying appropriate models (2.1.2)
- Explaining generalizations (2.1.3)
- Questioning incomplete or ambiguous information (2.1.4)
- Analyzing essential results of solutions and test data (2.1.5)
- Reconciling discrepancies in results (2.1.5)
- Making plausible engineering inferences (2.1)
- Supplying appropriate evidence for a design conclusion (4.4)
- Recognizing contradictions
- Recognizing technical, legal/regulatory, economic, environmental, and safety implications and consequences (4.1.1)
- Distinguishing facts from engineering principles, values, and ideas

---

**Evaluating Student Work in Engineering**

**The Grade of F**

F-level work fails to display an understanding of the basic nature of engineering reasoning, and in any case does not display the engineering skills and abilities, which are at the heart of this course. The work at the end of the course is as vague, imprecise, and unreasonable as it was in the beginning. There is little evidence that the student is genuinely engaged in the task of taking charge of his or her engineering reasoning. Many assignments appear to have been done pro forma, the student simply going through the motions without really putting any significant effort into thinking his or her way through them. Consequently, the student is not analyzing engineering problems clearly, not formulating information accurately, not distinguishing relevant from irrelevant information, not identifying key questionable assumptions, not clarifying key concepts, not reasoning carefully from clearly stated premises, or tracing implications and consequences. The student’s work does not display discernable engineering reasoning and problem-solving skills.

**The Grade of D**

D-level work shows only a minimal level understanding of what engineering is, along with the development of some, but very little, engineering skills or abilities. D-level work at the end of the course shows occasional engineering reasoning, but frequent uncritical thinking. Most assignments are poorly done. There is little evidence that the student is “reasoning” through the assignment. Often the student seems to be merely going through the motions of the assignment, carrying out the form without getting into the spirit of it. D-level work rarely shows any effort to take charge of ideas, assumptions, inferences, and intellectual processes. In general, D-level thinking lacks discipline and clarity. In D-level work, the student rarely analyzes engineering problems clearly and precisely, almost never formulates information accurately, rarely distinguishes the relevant from the irrelevant, rarely recognizes key assumptions, almost never describes key concepts effectively, frequently fails to use engineering vocabulary in keeping with established professional usage, and seldom reasons carefully from clearly stated premises, or recognizes important implications and consequences. D-level work frequently displays poor engineering reasoning and problem-solving skills.

**The Grade of C**

C-level work illustrates inconsistent achievement in grasping what engineering is, along with the development of modest engineering skills or abilities. C-level work at the end of the course shows some emerging engineering skills, but also pronounced weaknesses as well. Though some assignments are reasonably well done, others are poorly done; or at best are mediocre. There are more than occasional lapses in reasoning. Though engineering terms and distinctions are sometimes used effectively, sometimes they are used quite ineffectively. Only on occasion does C-level work display a mind taking charge of its own ideas,
assumptions, inferences, and intellectual processes. Only occasionally does C-level work display intellectual discipline and clarity. The C-level student only occasionally analyzes problems clearly and precisely, formulates information accurately, distinguishes the relevant from the irrelevant, recognizes key questionable assumptions, clarifies key concepts effectively, uses vocabulary in keeping with established professional usage, and reasons carefully from clearly stated premises, or recognizes important engineering implications and consequences. Sometimes the C-level student seems to be simply going through the motions of the assignment, carrying out the form without getting into the spirit of it. On the whole, C-level work shows only modest and inconsistent engineering reasoning and problem-solving skills.

The Grade of B

B-level work represents demonstrable achievement in grasping what engineering is, along with the clear demonstration of a range of specific engineering skills or abilities. B-level work at the end of the course is, on the whole, clear, precise, and well-reasoned, though with occasional lapses into weak reasoning. Overall, engineering terms and distinctions are used effectively. The work demonstrates a mind beginning to take charge of its own ideas, assumptions, inferences, and intellectual processes. The student often analyzes engineering problems clearly and precisely, often formulates information accurately, usually distinguishes the relevant from the irrelevant, and often recognizes key questionable assumptions, usually clarifies key concepts effectively. The student typically uses engineering language in keeping with established professional usage, and shows a general tendency to reason carefully from clearly stated premises, as well as noticeable sensitivity to important implications and consequences. B-level work displays good engineering reasoning and problem-solving skills.

The Grade of A

A-level work demonstrates advanced achievement in grasping what engineering is, along with the comprehensive development of a range of specific engineering skills or abilities. The work at the end of the course is, on the whole, clear, precise, and well-reasoned, though with occasional lapses into weak reasoning. In A-level work, engineering terms and distinctions are used effectively. The work demonstrates a mind beginning to take charge of its own ideas, assumptions, inferences, and intellectual processes. The A-level student often analyzes engineering problems clearly and precisely, often formulates information accurately, usually distinguishes the relevant from the irrelevant, often recognizes key questionable assumptions, and usually clarifies key concepts effectively. The student typically uses engineering language in keeping with established professional usage, frequently identifies relevant competing points of view, and shows a general tendency to reason carefully from clearly stated premises, as well as noticeable sensitivity to important implications and consequences. A-level work displays excellent engineering reasoning and problem-solving skills. The A student’s work is consistently at a high level of intellectual excellence.

The Problem of Ego-centric Thinking

Ego-centric thinking results from the unfortunate fact that humans do not naturally consider the rights and needs of others. They do not naturally appreciate the point of view of others nor the limitations in their own point of view. They become explicitly aware of their ego-centric thinking only if trained to do so. They do not naturally recognize their ego-centric assumptions, the ego-centric way they use information, the ego-centric way they interpret data, the source of their ego-centric concepts and ideas, the implications of their ego-centric thought, and that they do not naturally recognize their self-serving perspective.

As humans they live with the unrealistic but confident sense that they have fundamentally figured out the way things actually are, and that they have done this objectively. They naturally believe in their intuitive perceptions—however inaccurate. Instead of using intellectual standards in thinking, they often use self-centered psychological standards to determine what to believe and what to reject. Here are the most commonly used psychological standards in human thinking.

“IT’S TRUE BECAUSE I BELIEVE IT.” Insecure egocentrism: I assume that what I believe is true even though I have never questioned the basis for many of my beliefs.

“IT’S TRUE BECAUSE WE BELIEVE IT.” Insecure sociocentrism: I assume that the dominant beliefs between the groups to which I belong are true even though I have never questioned the basis for many of these beliefs.

“IT’S TRUE BECAUSE I WANT TO BELIEVE IT.” Insecure wish fulfillment: I believe in, for example, accounts of behavior that put me (or the groups to which I belong) in a positive rather than a negative light even though I have not seriously considered the evidence for the more negative account. I believe what “feels good,” what supports my other beliefs, what does not require me to change my thinking in any significant way, what does not require me to admit I have been wrong.

“IT’S TRUE BECAUSE I HAVE ALWAYS BELIEVED IT.” Insecure self-validation: I have a strong desire to maintain beliefs that I have long held, even though I have not seriously considered the extent to which those beliefs are justified, given the evidence.

“IT’S TRUE BECAUSE IT IS IN MY SELFISH INTEREST TO BELIEVE IT.” Insecure selfishness: I hold fast to beliefs that justify my getting more power, money, or personal advantage even though these beliefs are not grounded in sound reasoning or evidence.

Because humans are naturally prone to assess thinking in keeping with the above criteria, it is not surprising that we, as a species, have not developed a significant interest in establishing and teaching legitimate intellectual standards. It is not surprising that our thinking is often flawed. We are truly the “self-deceived animal.”
Stages of Critical Thinking Development

Master Thinker
(Good habits of thought are becoming second nature)

Advanced Thinker
(We advance in keeping with our practice)

Practicing Thinker
(We recognize the need for regular practice)

Beginning thinker
(We try to improve but without regular practice)

Challenged Thinker
(We are faced with significant problems in our thinking)

Unreflective Thinker
(We are unaware of significant problems in our thinking)

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Christina Bushman

From: Eric G. Eddings [eric.eddings@utah.edu]
Sent: Monday, January 22, 2007 6:31 PM
To: 'Christina Bushman'
Subject: Solutions manual copying

Christina:

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I need to also get PDF copies of a few problems in Chapter 3 - these are 3.2, 3.7, 3.8 and 3.11. These are in addition to problems 2.4, 2.7, 2.10 and 2.12 in Chapter 2.

I will be traveling the rest of this week, but will still be able to receive e-mails.

Thanks,
Eric