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思想者指南系列丛书

ENGINEERING REASONING

2ND EDITION

（第2版）

什么是工科推理

（美）Richard Paul （美）Robert Niewoehner （美）Linda Elder 著

外语教学与研究出版社
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序　言

思辨能力或者批判性思维由两个维度组成，在情感态度层面包括勤学好问、相信理性、尊重事实、谨慎判断、公正评价、敏于探究、持之以恒地追求真理等一系列思维品质或心理倾向；在认知层面包括对证据、概念、方法、标准、背景等要素进行阐述、分析、评价、推理与解释的一系列技能。

思辨能力的重要性应该是不言而喻的。两千多年前的中国古代典籍《礼记·中庸》曰："博学之，审问之，慎思之，明辨之，笃行之。"古希腊哲人苏格拉底说："未经审视的人生不值得一过。"可以说，文明的诞生正是人类自觉运用思辨能力，不断适应并改造自然环境的结果。如果说游牧时代、农业时代以及现代早期，人类思辨能力虽然并不完善，也远未普及，但通过科学技术以及人文知识的不断积累创新，推动人类文明阔步前进，已经显示出不可抑制的巨大能量，那么，进入信息时代、知识经济时代和全球化时代，思辨能力对于人类文明整体可持续发展以及对于每一个体的生存和发展，其重要性将史无前例地彰显。

我们已进入一个加速变化、普遍联系和日益复杂的时代。随着交通技术和信息技术日新月异的发展，不同国家和文化空前紧密地联系在一起。这在促进合作的同时，导致了更多的冲突；人类所掌握的技术力量与日俱增，在不断提高物质生活质量的同时，也极大地破坏了我们赖以生存的自然环境；工业化、城市化和信息化的不断延伸，全方位扩大了人的自由空间，同时却削弱了维系社会秩序和稳定的价值体系与行为准则。这一切变化对人类的思辨能力和应变能力都提出了前所未有的要求。正如本套丛书作者理查德·保罗（Richard Paul）和琳达·埃尔德（Linda Elder）所创办的思辨研究中

心的“使命”所指出的，“我们身处其中的这个世界要求我们不断重新学习，习惯性重新思考我们的决定，周期性重新评价我们的工作和生活方式。简言之，我们面临一个全新的世界，在这个新世界，大脑掌控自己并经常进行自我分析的能力将日益决定我们工作的质量、生活的质量乃至我们的生存本身。”

遗憾的是，面临时代巨变对人类思辨能力提出的新挑战，我们的教育和社会都尚未做好充分准备。从小学到大学，在很大程度上我们的教育依然围绕知识的搬运而展开，学校周而复始的考试不断强化学生对标准答案的追求而不是对问题复杂性和探索过程的关注，全社会也尚未形成鼓励独立思辨与开拓创新的氛围。

我们知道，人类大脑并不具备天然遗传的思辨能力。事实上，在自然状态下，人们往往倾向于以自我为中心或随波逐流，容易被偏见左右，固守陈见，急于判断，为利益或情感所左右。因此，思辨能力需要通过后天的学习和训练得以提高，思辨能力培养也因此应该成为教育的不懈使命。

哈佛大学以培养学生“乐于发现和思辨”为根本追求；剑桥大学也把“鼓励怀疑精神”奉为宗旨。美国学者彼得·法乔恩（Peter Facione）一言以蔽之：“教育，不折不扣，就是学会思考。”

和任何其他技能的学习一样，学会思考也是有规律可循的。首先，学习者应该了解思辨的基本特点和理论框架。根据理查德·保罗和琳达·埃尔德的研究，所有的推理都有一个目的，都试图澄清或解决问题，都基于假设，都从某一视角展开，都基于数据、信息和证据，都通过概念和观念进行表达，都通过推理或阐释得出结论并对数据赋予意义，都会产生影响或后果。分析一个推理或论述的质量或有效性，意味着按照思辨的标准进行检验，这个标准由10个维度构成：清晰性、准确性、精确性、相关性、深刻性、宽广性、逻辑性、完整性、重要性、公正性。一个拥有思辨能力的人具备八

大品质，包括：诚实、谦虚、相信理性、坚忍不拔、公正、勇气、同理心、独立思考。

其次，学习者应该掌握具体的思辨方法。如：如何阐释和理解文本信息与观点？如何解析文本结构？如何评价论述的有效性？如何把已有理论和方法运用于新的场景？如何收集和鉴别信息和证据？如何论证说理？如何识别逻辑谬误？如何提问？如何对自己的思维进行反思和矫正？等等等等。

最后，思辨能力的提高必须经过系统的训练。思辨能力的发展是一个从低级思维向高级思维发展的过程，必须运用思辨的标准一以贯之地训练思辨的各要素，在各门课程的学习中练习思辨，在实际工作中使用思辨，在日常生活中体验思辨，最终使良好的思维习惯成为第二本能。

“思想者指南系列丛书”旨在为教师教授思辨方法、学生学习思辨技能和社会大众提高思辨能力提供最为简明和最为实用的操作指南。该套丛书直接从西方最具影响力的思辨能力研究和培训机构（The Foundation for Critical Thinking）原版引进，共21册，包括“基础篇”：《批判性思维术语手册》、《批判性思维概念与方法手册》、《大脑的奥秘》、《批判性思维与创造性思维》、《什么是批判性思维》、《什么是分析性思维》；“大众篇”：《识别逻辑谬误》、《思维的标准》、《如何提问》、《像苏格拉底一样提问》、《什么是伦理推理》、《什么是工科推理》、《什么是科学思维》；“教学篇”：《透视教育时尚》、《思辨能力评价标准》、《思辨阅读与写作测评》、《如何促进主动学习与合作学习》、《如何提升学生的学习能力》、《如何通过思辨学好一门学科》、《如何进行思辨性阅读》、《如何进行思辨性写作》。

由理查德·保罗和琳达·埃尔德两位思辨能力研究领域的全球顶级大师领衔研发的“思想者指南系列丛书”，享誉北美乃至全球，销售数百万册，被美国中小学、高等学校乃至公司和政府部门普遍用于

教学、培训和人才选拔。该套丛书具有如下特点：其一，语言简洁明快，具有一般英文水平的读者都能阅读；其二，内容生动易懂，运用大量的具体例子解释思辨的理论和方法；其三，针对性和操作性极强，教师可以从“教学篇”子系列中获取指导教学改革的思辨教学策略与方法，学生也可从“教学篇”子系列中找到提高不同学科学习能力的思辨技巧；一般社会人士可以通过“大众篇”子系列掌握思辨的通用技巧，提高在社会场景中分析问题和解决问题的能力；各类读者都可以通过“基础篇”子系列掌握思维的基本规律和思辨的基本理论。

总之，思辨能力的高下将决定一个人学业的优劣、事业的成败乃至一个民族的兴衰。在此意义上，我向全国中小学教师、高等学校教师和学生以及社会大众郑重推荐“思想者指南系列丛书”。相信该套丛书的普及阅读和学习运用，必将有利于促进教育改革，提高人才培养质量，提升大众思辨能力，为创新型国家建设和社会文明进步作出深远的贡献。

孙有中

2016年春于北京外国语大学

Foreword

I am delighted to recommend *Engineering Reasoning* for engineering instructors, students, and engineers alike. This guide is a very useful addition to the arsenal of engineering education tools. I believe it fills a gap that has been largely ignored in engineering instruction. It covers an important area of competence that we so often presume students will acquire, but traditionally (and sadly) do not sufficiently address, if at all.

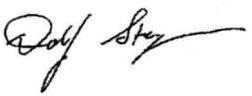
An isolated focus on technical skill delivery, or on one skill area, did not work in the past, currently fails and will not meet tomorrow's needs. It is important for the field of engineering to be understood as systems of overlapping and interrelated ideas, rather than isolated and different fields of knowledge. Moreover, it is important to recognize and effectively deal with the multiple environmental, social and ethical aspects that complicate responsible engineering. Accordingly, it is time for engineering educators to realize that effective engineering instruction cannot be based in memorization or technical calculation alone. Rather, it is essential that engineering students develop the generalizable critical thinking skills and dispositions necessary for effectively and professionally reasoning through the complex engineering issues and questions they will face as engineers. The authors outline and detail these skills and dispositions quite effectively in this guide.

I am further delighted to note the level of detailed sub distinctions covered in the guide. I believe it is Dave Merrill who originally claimed that expertise is defined by the number of detailed sub-divisions clearly made and qualified. As such, the authors have proven mastery!

Growing industry dissatisfaction with deficient engineering education has led to the inception of the CDIO™ Initiative. This international design addresses engineering education reform in its broader context. Active student participation forms an integral part of this solution. While not the exclusive aim or application of this guide, its potential

to compliment such institutional reforms by equipping the student to step up to the challenges of independent reasoning, is particularly beneficial.

Engineering Reasoning is not only a must-read publication for engineering educators, but a vital guide and career long companion for students and engineers alike.



Dr. AB Steyn
University of Pretoria
South Africa
May 2006

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Introduction

Why a Thinker's Guide to Engineering Reasoning?

This thinker's guide is designed for administrators, faculty, and students. It contains the essence of engineering reasoning concepts and tools. For faculty it provides a shared concept and vocabulary. For students it is a thinking supplement to any textbook for any engineering course. Faculty can use it to design engineering instruction, assignments, and tests. Students can use it to improve their perspective in any domain of their engineering studies.

General critical thinking skills apply to all engineering disciplines. For example, engineering reasoners attempt to be clear as to the purpose at hand and the question at issue. They question information, conclusions, and points of view. They strive to be accurate, precise, and relevant. They seek to think beneath the surface, to be logical, and objective. They apply these skills to their reading and writing as well as to their speaking and listening. They apply them in professional and personal life.

When this guide is used as a supplement to the engineering textbook in multiple courses, students begin to perceive applications of engineering reasoning to many domains in their lives. In addition, if their instructors provide examples of the application of engineering thinking to life, students begin to see good thinking as a tool for improving the quality of their lives.

If you are a student using this guide, get in the habit of carrying it with you to every engineering class. Consult it frequently in analyzing and synthesizing what you are learning. Aim for deep internalization of the principles you find in it—until using them becomes second nature.

While this guide has much in common with *A Thinker's Guide to Scientific Thinking*, and engineers have much in common with scientists, engineers and scientists pursue different fundamental purposes and are engaged in distinctively different modes of inquiry. This should become apparent as you read this guide.

A Framework for Engineering Reasoning

The analysis and evaluation of our thinking as engineers requires a vocabulary of thinking and reasoning. The intellect requires a voice. The model on the facing page is not unique to engineering; indeed, its real power is its flexibility in adapting to any domain of life and thought. Other Thinkers' Guides in the Thinker's Guides Library apply this framework to other disciplines. Engineers and scientists are quite comfortable working within the context of conceptual models. We employ thermodynamic models, electrical models, mathematical models, computer models or even physical models fashioned from wood or clay. In this guide we apply a model or framework for thinking, an architecture whose purpose aids the analysis and evaluation of thought, through which we might improve our thought. A glance at other Thinkers' Guides reveals that only shifts of emphasis are required to apply this model to the sciences, the humanities, or the arts.

The framework depicted on the following page provides an overview of the entire guide, working from the base of the diagram up. The goal or endpoint is the development of the mature engineering thinker; therefore, that endpoint is described first with a brief discussion of the intellectual virtues as might be expressed in the practice of engineering.

Subsequently, the eight elements of thought are introduced. These are tools for the analysis of thinking in ones' own and others' thought. These elements are then exemplified and applied to analyzing texts, articles, reports, and entire engineering disciplines.

Next, the intellectual standards are introduced and exemplified. These constitute the thinker's *evaluation* tools. They are then woven together with the elements in several formats to demonstrate application of these *evaluation* standards to the *analysis* of our thinking.

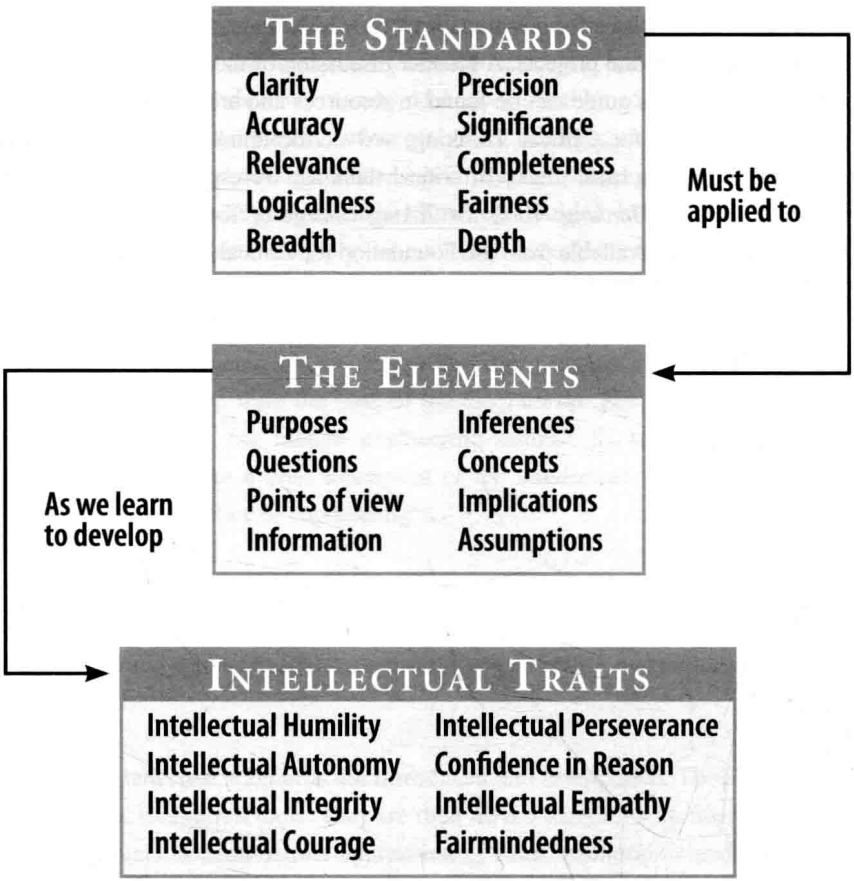
Finally, the guide includes several case studies of excellent thinking and deficient thinking in engineering. It then concludes by treating a number of

distinctive topics that touch on the engineering profession, such as aesthetics, ethics, and engineers' relationships with other professionals.

Using This Thinker's Guide

As with the other guides in the *Thinker's Guide* series, the content in this guide is not to be read as straight prose; it is predominantly composed of numerous examples, mostly probing questions, of a substantive critical thinking model applied to the engineering context. These examples may be used in class exercises, as reference material, or as templates for out-of-class work, which students adapt to their own courses, disciplines, and projects. A broader discussion of the approach to critical thinking used in this guide can be found in resources and articles on the website of the Foundation for Critical Thinking, www.criticalthinking.org. For deeper understanding of the basic theory of critical thinking, we especially recommend the book, *Critical Thinking: Tools for Taking Charge of Your Professional and Personal Life,* also available from the Foundation for Critical Thinking.

Engineers concerned with good thinking routinely apply *intellectual standards* to the *elements of thought* as they seek to develop the traits of a mature engineering mind.



Intellectual Traits Essential to Engineering Reasoning

No engineer can claim perfect objectivity; engineers'work is unavoidably influenced by many variables, including their education, experiences, attitudes, beliefs, and level of intellectual arrogance.

Highly skilled engineers recognize the importance of cultivating intellectual dispositions. These attributes are essential to excellence of thought. They determine with what insight and integrity one thinks.

Intellectual humility is knowledge of ignorance, sensitivity to what you know and what you do not know. It implies being aware of your biases, prejudices, self-deceptive tendencies, and the limitations of your viewpoint and experience. Licensure as a Professional Engineer (PE) explicitly demands that engineers self-consciously restrict their professional judgments to those domains in which they are truly qualified.[1] Questions that foster intellectual humility in engineering thinking include:

- What do I really know about the technological issue I am facing?
- To what extent do my prejudices, attitudes, or experiences bias my judgment? Does my experience really qualify me to handle this issue?
- Am I quick to admit when I am dealing with a domain beyond my expertise?
- Am I open to considering novel approaches to this problem, and willing to learn and study where warranted?

Intellectual courage is the disposition to question beliefs about which you feel strongly. It includes questioning the beliefs of your culture and any subculture to which you belong, and a willingness to express your views even when they are unpopular (with management, peers, subordinates, or customers). Questions that foster intellectual courage include:

- To what extent have I analyzed the beliefs I hold which may impede my

[1] National Society of Professional Engineers. 2003. Code of Ethics for Engineers.

ability to think critically?

- To what extent have I demonstrated a willingness to yield my positions when sufficient evidence is presented against them?
- To what extent am I willing to stand my ground against the majority (even though people ridicule me)?

Intellectual empathy is awareness of the need to actively entertain views that differ from your own, especially those with which you strongly disagree. It entails accurately reconstructing the viewpoints and reasoning of your opponents and reasoning from premises, assumptions, and ideas other than your own. Questions that foster intellectual empathy include:

- To what extent do I listen and seek to understand others' reasoning?
- To what extent do I accurately represent viewpoints with which I disagree?
- To what extent do I accurately represent opponents' views? Would they agree?
- To what extent do I recognize and appreciate insights in the technical views of others and recognize prejudices in my own?

Intellectual integrity consists in holding yourself to the same intellectual standards you expect others to honor (no double standards). Questions that foster intellectual integrity in engineering reasoning include:

- To what extent do I expect of myself what I expect of others?
- To what extent are there contradictions or inconsistencies in the way I deal with technical issues?
- To what extent do I strive to recognize and eliminate self-deception and bad faith in my thinking when reasoning through engineering issues?

Intellectual perseverance is the disposition to work your way through intellectual complexities despite frustrations inherent in the task. Questions that foster intellectual perseverance in engineering reasoning include:

- Am I willing to work my way through complexities in an engineering issue or

do I tend to give up when challenged?
- Can I think of a difficult engineering problem in which I have demonstrated patience and tenacity?
- Do I have strategies for dealing with complex engineering issues?

Confidence in reason is based on the belief that one's own higher interests and those of humankind at large are best served by giving the freest play to reason. It means using standards of reasonability as the fundamental criteria by which to judge whether to accept or reject any proposition or position. Questions that foster confidence in reason include:

- Am I willing to change my position when the evidence leads to a more reasonable position?
- Do I always try to follow the evidence, without regard to my own interests?
- Do I encourage others to come to their own conclusions or do I try to coerce agreement?

Intellectual autonomy is thinking for oneself while adhering to standards of rationality. It means thinking through issues using one's own thinking rather than uncritically accepting the viewpoints, opinions, and judgments of others. Questions that foster intellectual autonomy in engineering thinking include:

- To what extent do I uncritically accept what I am told (by my supervisors, peers, government, and so on)?
- To what extent do I uncritically accept traditional solutions to problems?
- Do I think through technical issues on my own or do I merely accept the conclusions or judgments of others?
- Having thought through an issue from a rational perspective, am I willing to stand alone against irrational criticism?

Fairmindedness is being conscious of the need to treat all viewpoints alike, without reference to one's own feelings or vested interests, or the feelings or vested interests of one's friends, company, community or nation. It implies adherence to intellectual standards without reference to one's own advantage