TEXTBOOK

Engineering Quality Assurance

From Fundamentals to Industrial Excellence

Dr. Ahsan Rahman

Engineering Excellence Series

TEXTBOOK

Engineering Quality Assurance

From Fundamentals to Industrial Excellence

Theory • Practice • Standards • Industrial Applications • Certification

Dr. Ahsan Rahman

Engineering Excellence Series • Book 1 of 2

AR Resources

AR Resources

Author: Ahsan Rahman
Series: Engineering Excellence Series — Book 1: Engineering Quality Assurance
First edition • 2026 • ahsanrahman.com

To the engineers who choose to do it right when no one is watching — quality begins there.

Preface

Quality is one of those words everyone uses and few define the same way. To a customer it means a product that simply works. To a regulator it means conformance to a published requirement. To an accountant it means avoided cost. To an engineer it should mean something more precise and more demanding: the disciplined, evidence-based practice of building things that meet their requirements every time, by design rather than by luck.

This book is the first of a two-volume Engineering Excellence Series. It treats quality assurance not as paperwork bolted onto a finished product, but as an engineering discipline in its own right — one with its own theory, mathematics, standards, tools, and professional pathways. It is written for university students meeting the subject formally for the first time, for practising engineers who have inherited a quality system they were never taught, and for professionals preparing for certification who want the reasoning behind the clauses, not just the clauses.

The companion volume, Engineering Safety, shares this book's philosophy and many of its tools — risk thinking, root-cause analysis, audits, reliability, and the digital methods of Industry 4.0. Wherever the two subjects meet, a cross-reference points the way, because in real engineering organisations quality and safety are managed by the same people using the same disciplines.

Every chapter follows the same rhythm: objectives, theory and the mathematics behind it, the international standards that govern practice, worked industrial examples, a case study, and a generous bank of review questions, laboratory activities, projects, interview questions, and certification practice. The aim is a single, self-contained learning pathway from beginner to capable practitioner.

Quality, in the end, is a habit of mind before it is a procedure. I hope this book helps you build that habit.

— Dr. Ahsan Rahman

How to Use This Book

The book is organised into six parts that move from first principles to industrial application. You can read it cover to cover as a course, or enter at the part you need as a reference. Each chapter is designed to stand on its own while pointing to the chapters it depends on.

Recurring features

- Learning Objectives and Key Concepts open every chapter so you know the destination before you start.
- Standards boxes (teal, left-barred panels) summarise the relevant ISO, IEC, IEEE, and sector standards in plain language.
- Worked Examples and Numerical Problems turn theory into calculation; do them with a pen, not just your eyes.
- Case Studies show the method working — or failing — in a real industrial setting.
- Review Questions are graded across four tiers: Recall, Application, Analysis, and Design.
- Certification Practice questions mirror the style of CQE, Six Sigma, and ISO 9001 auditor examinations, with explained answers.
- A See also line at the end of each chapter links to the companion Engineering Safety volume.

A note on standards: clause numbers and requirements are summarised for learning. Before applying any standard professionally, obtain and read its current official text — standards are revised, and this book is a guide to understanding, not a substitute for the source.

Contents

PART I

Foundations of Engineering Quality

What quality means, where the discipline came from, and the language, economics, and customer focus that underpin everything that follows.

PART I — FOUNDATIONS OF ENGINEERING QUALITY

Chapter 1 — The Meaning and Evolution of Quality

Learning Objectives

Define quality from the five classical viewpoints and explain why a single definition is never enough.

Describe Garvin's eight dimensions of product quality and apply them to an engineered product.

Trace the evolution of quality from inspection to Quality 4.0 and explain what shifted at each stage.

Distinguish quality planning, assurance, control, and improvement, and place them on the PDCA cycle.

Build and interpret a Cost-of-Quality (PAF) model and compute the cost of poor quality for a process.

Recognise how quality principles apply across electrical, civil, mechanical, software, and manufacturing domains.

Key Concepts

- Quality as fitness for purpose and conformance to requirements.
- Garvin's eight dimensions; the transcendent, product-, user-, manufacturing-, and value-based definitions.
- Inspection → SQC → QA/QMS → TQM → Six Sigma/Lean → Quality 4.0.
- Quality planning, assurance (QA), control (QC), and improvement; the PDCA cycle.
- Prevention–Appraisal–Failure (PAF) model and the cost-of-quality iceberg.

1.1 What Do We Mean by "Quality"?

Ask ten engineers to define quality and you will get ten answers, most of them correct and none of them complete. That is not sloppiness; it reflects the fact that quality is a multidimensional idea that looks different depending on where you stand. David Garvin, writing in the Harvard Business Review in 1984, organised these viewpoints into five classical definitions that remain the clearest starting point for any engineer.

1. Transcendent: quality as innate excellence — you know it when you see it, but it resists measurement. Useful for marketing, useless for engineering.
2. Product-based: quality as a measurable quantity of some desirable attribute (more load capacity, longer life, tighter tolerance). Quality becomes an axis you can put numbers on.

3. User-based: quality as fitness for use — the product satisfies the needs of the person who uses it. This is Juran's famous definition and it puts the customer at the centre.
4. Manufacturing-based: quality as conformance to requirements — Crosby's definition. The specification is the law; a part is good if and only if it meets the spec.
5. Value-based: quality as performance at an acceptable price, or conformance at an acceptable cost. Quality is judged against what it costs to deliver.

An engineer needs all five. The user-based view tells us what to build; the product-based view lets us specify it numerically; the manufacturing-based view lets us verify it; and the value-based view keeps us honest about cost. The transcendent view, meanwhile, is a reminder that some quality is felt before it is measured.

Two definitions deserve to be committed to memory because the rest of the book leans on them. ISO 9000 defines quality as the degree to which a set of inherent characteristics fulfils requirements. Joseph Juran defined it as fitness for use. The first is precise and auditable; the second is human and strategic. Hold both.

Garvin's eight dimensions of quality

To make quality something you can actually specify and inspect, Garvin decomposed it into eight independent dimensions. A product can score high on some and low on others, and a deliberate quality strategy chooses which dimensions to compete on.

Figure 1.2 Garvin's eight dimensions of product quality.

Dimension	What it captures	Engineering example
Performance	Primary operating characteristics	A motor's rated torque and efficiency
Features	Secondary 'extras' that supplement function	Soft-start and diagnostics on a drive
Reliability	Probability of failure-free operation over	MTBF of a controller in service

Dimension	What it captures	Engineering example
	time	
Conformance	Degree to which the product meets its spec	Shaft diameter within ±0.01 mm
Durability	Useful life before replacement	Bearing service life in hours
Serviceability	Speed, ease, and cost of repair	Mean time to repair, parts availability
Aesthetics	Look, feel, sound, and finish	Surface finish and panel fit
Perceived quality	Reputation and brand inference	Trust earned from past reliability

1.2 The Evolution of Quality

Quality assurance did not arrive fully formed; it evolved over more than a century as production grew in scale and complexity. Understanding that evolution is not a history lesson — it explains why modern standards are built the way they are, and it shows the unmistakable direction of travel: from catching defects late and cheaply to preventing them early, and now to predicting them before they occur.

Figure 1.1 From inspection to Quality 4.0 — the changing focus of the discipline.

Era	Approx. period	Central idea	Limitation it exposed
Inspection	Early 1900s	Sort good from bad after production	Finds defects but cannot prevent them
Statistical QC	1920s–1940s	Use statistics to control the process	Focused on production, not the whole system
Quality Assurance	1950s–1980s	Build quality in through a documented system	Could become bureaucratic and paper-bound
TQM	1980s–1990s	Everyone owns quality; obsess over the customer	Hard to sustain without data discipline
Six Sigma / Lean	1990s–2000s	Reduce variation and waste with hard data	Can be tool-heavy and project-siloed
Quality 4.0	2010s→	AI, IIoT, and digital twins predict	Demands new data, OT-security,

Era	Approx. period	Central idea	Limitation it exposed
		quality	and skills

Notice the through-line. Each era did not discard the last; it absorbed it. A Quality 4.0 plant still inspects, still uses control charts, still runs a documented QMS, still cultivates a quality culture, and still runs improvement projects — but it now does all of this on a foundation of connected, real-time data. The tools accumulate; they do not replace one another.

Standards Spotlight — the ISO 9000 family

ISO 9000 defines the vocabulary and seven quality-management principles.

ISO 9001 is the certifiable requirements standard for a quality-management system (covered in Chapter 5).

ISO 9004 gives guidance for sustained success beyond the minimum of ISO 9001.

These are generic: the same framework governs an aerospace machine shop, a water utility, and a software house.

1.3 Quality, Assurance, and Control: Clearing Up the Vocabulary

Three terms are constantly confused in industry, and the confusion is expensive because it leads organisations to do one when they think they are doing another. The distinction is worth fixing precisely.

- Quality Control (QC) is reactive and product-oriented: it inspects, tests, and measures the output to detect defects. QC asks, "is this unit good?"
- Quality Assurance (QA) is proactive and process-oriented: it builds and verifies the system that produces good output, so that defects are prevented. QA asks, "is our process capable of producing good units?"
- Quality Management (QM) is the umbrella: the coordinated activities to direct and control an organisation with regard to quality, including policy, objectives, planning, QA, QC, and improvement.

A useful image: QC is the goalkeeper who stops shots; QA is the coaching and training system that means fewer shots reach the goal in the first place. You need both, but an organisation that relies only on QC is paying to find defects it has already manufactured.

The PDCA cycle — the engine of improvement

Walter Shewhart proposed, and W. Edwards Deming popularised, a four-step cycle that underlies virtually every modern quality and improvement method, from ISO 9001's structure to Six Sigma's DMAIC. Plan a change against an objective; Do it on a small scale; Check the results against the prediction; Act to standardise what worked or to adjust what did not — then turn the cycle again.

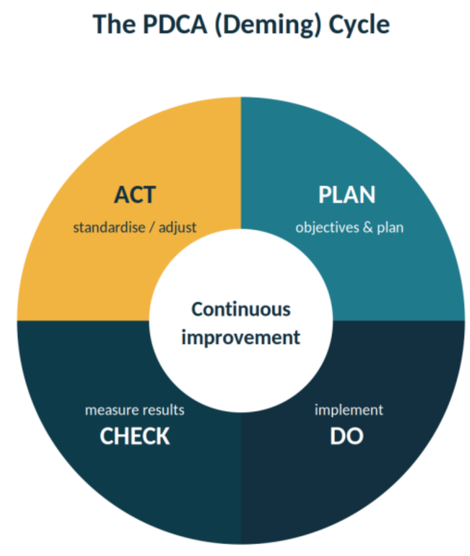

Figure 1.4 The PDCA (Plan–Do–Check–Act) cycle of continuous improvement.

1.4 The Cost of Quality

One of the most powerful ideas in the discipline is that quality is not a cost — poor quality is. The Cost-of-Quality (CoQ) model, developed by Feigenbaum and Juran, divides total quality-related spending into four categories grouped under the Prevention–Appraisal–Failure (PAF) framework.

- Prevention costs: spent to stop defects occurring — training, design reviews, FMEA, supplier development, process capability studies.
- Appraisal costs: spent to find defects — inspection, testing, calibration, audits.
- Internal failure costs: defects caught before the customer — scrap, rework, re-test, downtime.
- External failure costs: defects that reach the customer — warranty, returns, recalls, liability, lost reputation.

The strategic insight is the trade-off. Spending more on prevention typically reduces appraisal and failure costs by a far larger amount; the cheapest defect is the one that never happens. External failure is the most expensive category of all, much of it hidden — hence the iceberg.

Figure 1.3 The cost-of-quality iceberg: visible failure costs hide a much larger submerged mass.

Worked Example 1.1 — Cost of poor quality

Problem

A motor-drive line produces 40,000 units per year at a unit manufacturing cost of $120. Records show: scrap and rework (internal failure) = $384,000; warranty and returns (external failure) = $560,000; inspection and test (appraisal) = $180,000; training and FMEA (prevention) = $96,000. Compute the total cost of quality, the cost of poor quality, and CoQ as a percentage of production cost. If a $150,000 prevention investment is expected to cut failure costs by 45%, evaluate it.

Step 1 — Total Cost of Quality (CoQ) = Prevention + Appraisal + Internal + External = 96,000 + 180,000 + 384,000 + 560,000 = $1,220,000.

Step 2 — Cost of Poor Quality (CoPQ) = Internal + External failure = 384,000 + 560,000 = $944,000. This is the money lost purely because things were not right the first time.

Step 3 — Annual production cost = 40,000 × $120 = $4,800,000. CoQ as a percentage = 1,220,000 / 4,800,000 = 25.4%. (World-class operations typically run total CoQ near 2–4% of sales; 25% signals a failure-dominated, appraisal-heavy system — a classic symptom of relying on QC instead of QA.)

Step 4 — Evaluate the prevention investment. New prevention = 96,000 + 150,000 = $246,000. Failure costs fall 45%: new failure = 944,000 × 0.55 = $519,200. Assume appraisal can ease by 10% as the process stabilises: 180,000 × 0.9 = $162,000. New CoQ = 246,000 + 162,000 + 519,200 = $927,200, a saving of about $292,800 per year. A $150,000 spend returning ~$293,000 pays back in roughly six months — the textbook prevention dividend.

1.5 Quality Across the Engineering Disciplines

Although this book uses standardised methods, quality wears a different face in each discipline. The underlying principles — define the requirement, build to it, verify it, improve — are universal; the characteristics being controlled are not.

Discipline	A typical quality characteristic	A typical method
Electrical / power	Dielectric strength, harmonic distortion	Type testing, SPC on insulation
Civil / construction	Concrete compressive strength, alignment	Cube tests, survey acceptance
Mechanical	Dimensional tolerance, surface finish	CMM, Gauge R&R, capability study
Software / firmware	Defect density, MTBF, test coverage	Reviews, static analysis, CI testing
Manufacturing	Yield, first-pass rate, Cpk	SPC, FMEA, acceptance sampling

This multidisciplinary reach is the reason a single quality framework — ISO 9001 — can certify organisations as different as a semiconductor fab and a bridge contractor. The clauses speak about processes and requirements, not about transistors or concrete.

1.6 Industrial Case Study

Case Study 1.1 — The appraisal trap at a sensor assembler

A mid-sized electronics firm assembling industrial sensors was proud of its "zero-defect-to-customer" record, achieved through 100% final inspection by a 14-person test team. Margins, however, were vanishing. A CoQ study revealed total quality cost at 22% of sales, dominated by appraisal (the large inspection team) and internal failure (a 9% scrap rate at final test). Almost nothing was spent on prevention.

The defects clustered at one solder station whose temperature profile drifted across each shift. Inspection caught the bad boards but never asked why they were bad. The firm redirected effort upstream: SPC on the reflow profile, a short FMEA of the solder process, and operator training — classic prevention. Within two quarters the scrap rate fell from 9% to 1.6%, the inspection team was redeployed to process engineering, and total CoQ dropped below 8% of sales.

The lesson is the theme of this chapter: inspection finds defects; only prevention removes their cause. The firm had been doing QC and calling it quality.

1.7 Best Practices, Common Mistakes, and Troubleshooting

Best Practices

- Define quality in measurable, product-based terms before promising it — "good" is not a specification.
- Shift spending from appraisal and failure toward prevention; track the four CoQ categories monthly.

- Use PDCA explicitly on every improvement so learning is captured and standardised.
- Treat the customer's fitness-for-use as the requirement of record, not your internal convenience.

Common Mistakes

- Confusing QC with QA and inspecting quality in instead of building it in.
- Reporting only scrap and rework while ignoring the larger, hidden external-failure costs.
- Competing on every one of Garvin's dimensions at once instead of choosing deliberately.
- Treating ISO 9001 certification as the goal rather than as evidence of a capable system.

Troubleshooting

Symptom	Likely root cause	First action
High scrap despite heavy inspection	Reactive QC, no process control	Add SPC and an FMEA upstream (Ch 11, 16)
Warranty cost rising, internal metrics fine	External failure not measured	Build a full PAF cost model
'Quality' means different things per team	No agreed definition/requirement	Fix product-based specs and acceptance criteria (Ch 4)

Frequently Asked Questions

Q: Is zero defects a realistic goal? **A:** As a mindset and a target for designed-in prevention, yes — Crosby's point was cultural. As a literal statistical guarantee, it depends on tolerances and process capability (Chapters 11 and 13).

Q: Does more inspection improve quality? **A:** It improves detection, not quality. Quality is determined upstream, in design and process; inspection only sorts what has already been made.

Q: Where does Six Sigma fit in all this? **A:** It is a data-driven, project-based way of doing improvement — the 'Act/Plan' of PDCA at industrial scale. It is covered fully in Chapter 18.

Chapter Summary

Quality is multidimensional: five classical definitions and Garvin's eight dimensions together let engineers specify, build, and verify it. The discipline evolved from late inspection through statistical control, documented assurance, total quality management, and data-driven Six Sigma to today's predictive Quality 4.0 — each era absorbing the last. Quality control detects, quality assurance prevents, and quality management coordinates, all turning on the PDCA cycle. The cost-of-quality model proves the economic case: prevention is cheaper than appraisal, and far cheaper than failure. These principles apply across every engineering discipline, which is why one generic framework can govern them all.

Glossary

Quality — The degree to which inherent characteristics fulfil requirements (ISO 9000).

Quality assurance (QA) — Proactive, process-focused activities that build confidence requirements will be met.

Quality control (QC) — Reactive, product-focused activities that detect whether requirements were met.

Cost of quality (CoQ) — Total of prevention, appraisal, internal-failure, and external-failure costs.

PDCA — Plan–Do–Check–Act; the iterative cycle of continuous improvement.

Conformance — The degree to which a product meets its specification.

References and Suggested Reading

1. Garvin, D. A. (1984). What Does ‘Product Quality’ Really Mean? Sloan Management Review.
2. Juran, J. M. & De Feo, J. A. Juran’s Quality Handbook, 7th ed. McGraw-Hill.
3. ISO 9000:2015, Quality management systems — Fundamentals and vocabulary.
4. Crosby, P. B. (1979). Quality Is Free. McGraw-Hill.
5. Feigenbaum, A. V. (1991). Total Quality Control, 3rd ed. McGraw-Hill.
6. Montgomery, D. C. Introduction to Statistical Quality Control, 8th ed. Wiley.

Review Questions — Chapter 1

Recall

1. List Garvin’s five classical definitions of quality.
2. State the four cost-of-quality categories in the PAF model.
3. Define quality assurance and quality control in one sentence each.

Application

1. For a domestic water pump, give one measurable characteristic under each of Garvin’s eight dimensions.
2. Place the following on the PDCA cycle: a pilot run, a control-chart review, a revised work instruction, an objective.
3. Classify each as prevention, appraisal, internal, or external failure: design review, final test, scrap, recall.

Analysis

1. A plant’s CoQ is 80% appraisal and failure, 20% prevention. Diagnose the system and predict its trajectory.
2. Explain why an organisation can pass an ISO 9001 audit yet still deliver poor quality to customers.

Design

1. Design a one-page monthly CoQ dashboard for a manufacturing line: what would you measure and why?

2. Propose a prevention programme to move a failure-dominated process toward a prevention-dominated one, and justify the sequence.

Multiple-Choice Questions

1. Crosby's definition of quality is best summarised as: (A) Innate excellence (B) Fitness for use (C) Conformance to requirements (D) Value for money **✓ Answer: C.** *Crosby framed quality as conformance to requirements; fitness for use is Juran's.*

2. Which cost category is usually the largest and most hidden? (A) Prevention (B) Appraisal (C) Internal failure (D) External failure **✓ Answer: D.** *External failure (warranty, recalls, lost reputation) is the submerged mass of the iceberg.*

3. Inspecting finished product to remove defects is an example of: (A) Quality assurance (B) Quality control (C) Quality planning (D) Prevention **✓ Answer: B.** *Detection on the output is QC; prevention upstream would be QA.*

4. The PDCA cycle is most directly associated with: (A) Garvin (B) Shewhart and Deming (C) Taguchi (D) Ishikawa **✓ Answer: B.** *Shewhart originated it and Deming popularised it.*

Short and Long Questions

Short Questions

1. Why is a single definition of quality insufficient for engineers?
2. Distinguish appraisal cost from prevention cost with one example of each.
3. What does it mean to say each era of quality 'absorbed' the previous one?

Long Questions

1. Trace the evolution of quality from inspection to Quality 4.0, explaining the limitation that drove each transition.
2. "Quality is free." Using the cost-of-quality model, argue for or against Crosby's claim with reference to the prevention–failure trade-off.

Problems, Labs, and Projects

Numerical Problems

1. A line of 60,000 units/yr at $90 unit cost reports prevention $70k, appraisal $210k, internal $300k, external $640k. Compute CoQ, CoPQ, and CoQ as % of production cost.
2. If a $120k prevention spend cuts failure costs by 40% and appraisal by 15%, recompute CoQ for Problem 1 and find the payback period.
3. A product scores (out of 10) on Garvin dimensions: 8,6,9,7,5,4,6,7. Compute a simple and a weighted quality index using weights that prioritise reliability and conformance, and comment.

Practical Assignment

Choose any engineered product you own. Write a one-page quality profile rating it on all eight Garvin dimensions, identify the two dimensions its maker competed on, and propose one improvement with the dimension it targets.

Laboratory Activity

Lab 1 — CoQ data hunt. Using a provided (or simulated) month of production records, classify every quality-related expense into the four PAF categories, build the cost-of-quality iceberg as a chart, and present the single change you would fund first. Deliverable: a labelled PAF table and a 5-minute recommendation.

Mini-Project

Build a reusable CoQ spreadsheet model: inputs for the four categories and production volume; outputs for CoQ, CoPQ, %-of-cost, and a what-if slider for prevention investment and its effect on failure cost. (This model is reused in Chapters 18 and 22.)

Capstone Project Idea

Across the course, develop a complete quality-management concept for a small real or fictional manufacturer: definition and acceptance criteria (Ch 4), a QMS skeleton (Ch 5), an SPC plan (Ch 11), an FMEA (Ch 16), and a CoQ-driven improvement roadmap (Ch 18, 22). Chapter 1 contributes the quality definition and the baseline CoQ model.

Interview and Certification Practice

Interview Questions

- What is the difference between QA and QC, and why does it matter to a cost-conscious manager?
- Walk me through the cost-of-quality model and how you would use it to justify a budget.
- How would you respond to a manager who wants to ‘add more inspection’ to fix a quality problem?
- Which of Garvin’s dimensions would you prioritise for a safety-critical aerospace component, and why?

Certification Practice (CQE / ISO 9001 style)

1. In ISO 9000 terms, quality is defined as: (A) Excellence beyond requirements (B) Degree to which inherent characteristics fulfil requirements (C) Zero defects (D) Customer delight ✓ **B.** *ISO 9000:2015 uses ‘degree to which a set of inherent characteristics fulfils requirements.’*

2. Reducing process variation primarily reduces which cost category over time? (A) Prevention (B) Appraisal (C) Internal and external failure (D) Fixed overhead ✓ **C.** *Less variation means fewer nonconformities, cutting both failure categories.*

3. A documented procedure verifying that a process can meet requirements is best classified as: (A) Quality control (B) Quality assurance (C) Inspection (D) Rework ✓ **B.** *Verifying process capability to prevent defects is QA, not QC.*

See also — companion volume

Engineering Safety, Chapter 1 (Safety, Hazard, and Risk) develops the same prevention-over-detection logic for hazards, and Chapter 8 of that book shares this chapter's root-cause and cost-of-failure thinking. The cost-of-quality model here is the direct analogue of the cost-of-incidents argument used to justify safety investment.

PART I — FOUNDATIONS OF ENGINEERING QUALITY

Chapter 2 — Quality Philosophies and the Quality Gurus

Learning Objectives

Explain why the ideas of the quality gurus still shape every modern standard and method.

Describe Deming's System of Profound Knowledge and distinguish common-cause from special-cause variation.

Apply the Juran Trilogy to separate quality planning, control, and breakthrough improvement.

Summarise Crosby's Four Absolutes and critique the Zero Defects idea on engineering grounds.

Use Taguchi's quadratic loss function to quantify the cost of deviating from a target.

Compare the philosophies and select the right thinker's lens for a given engineering problem.

Key Concepts

- System thinking; common-cause vs special-cause variation; PDSA.
- The Quality Trilogy: planning, control, and improvement.
- Conformance to requirements; the price of nonconformance; Zero Defects.
- Robust design; the quality loss function; signal-to-noise ratio.
- Total Quality Control and the 'hidden plant'.

2.1 Why the Gurus Still Matter

It is tempting to treat the mid-twentieth-century quality thinkers as history — portraits on a training-room wall. That would be a mistake. The clauses of ISO 9001, the structure of Six Sigma, the logic of statistical process control, and the very idea that management (not the worker) owns quality all descend directly from a handful of people who argued these points when they were genuinely controversial. To understand why a modern quality system is built the way it is, you have to understand the arguments that built it.

This chapter introduces six figures whose ideas form the intellectual bedrock of the discipline. They did not always agree — Deming and Crosby would have disagreed sharply about Zero Defects — and the disagreements are themselves instructive. Read them not as a gallery of saints but as a set of competing, complementary engineering arguments you can deploy as the situation demands.

Figure 2.1 The quality gurus and their signature contributions.

2.2 W. Edwards Deming — The System Thinker

Deming is the towering figure of the field. An American statistician largely ignored at home until his methods helped rebuild post-war Japanese industry, he returned to Western attention in the 1980s with a message that was as much about management and psychology as about statistics. His central claim was radical: the overwhelming majority of quality problems — he put it as high as 94% — originate in the system that management controls, not in the workers who are blamed for them.

The System of Profound Knowledge

Late in life Deming distilled his thinking into four interacting lenses he called the System of Profound Knowledge. A manager, he argued, must look through all four at once; viewing an organisation through any single lens produces predictable errors.

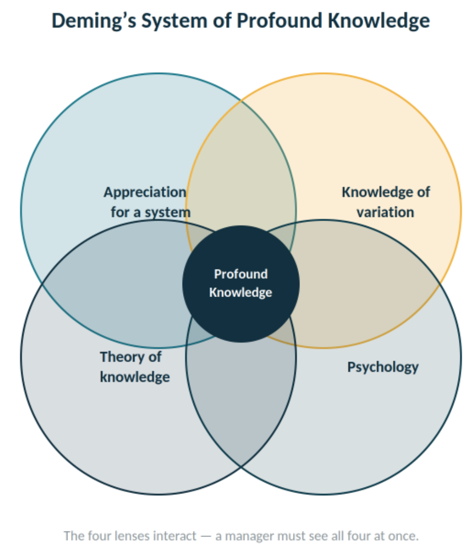

Figure 2.2 Deming's four interacting lenses of Profound Knowledge.

- Appreciation for a system: an organisation is a network of interdependent parts with a shared aim; optimising one part in isolation usually harms the whole.
- Knowledge about variation: every process varies; the skill is to distinguish routine common-cause variation from genuine special-cause signals.
- Theory of knowledge: management is prediction; you cannot improve what you cannot, in some form, theorise and test (hence PDSA).
- Psychology: people are motivated intrinsically as well as extrinsically; systems that rely on fear and ranking destroy the very cooperation quality needs.

Common-cause versus special-cause variation

This single distinction may be Deming's most practically important contribution, and it is the foundation of the control charts of Chapter 11. Common-cause (or chance) variation is the natural, ever-present noise of a stable process — the sum of many small influences. Special-cause (or assignable) variation is a signal: something specific and identifiable has changed. The cardinal error, which Deming called tampering, is to react to common-cause variation as if it were a special cause — adjusting a stable process in response to ordinary noise, which provably increases variation rather than reducing it.

Standards & Method Spotlight — from Deming to the standard

PDSA (Plan–Do–Study–Act), Deming's refinement of Shewhart's cycle, is the skeleton of ISO 9001's 'plan-do-check-act' structure (Chapter 5).

The common/special-cause distinction underlies all control-chart theory and the rules of Statistical Process Control (Chapter 11).

Deming's insistence that management owns the system anticipates ISO 9001's entire

> *'Leadership' clause.*

Deming summarised his prescription as Fourteen Points for management, ranging from 'create constancy of purpose' to 'drive out fear' and 'eliminate slogans and numerical quotas.' The specifics matter less than the through-line: build a stable, well-understood system and lead it with knowledge rather than exhortation.

2.3 Joseph M. Juran — Quality as Fitness for Use

If Deming was the statistician-philosopher, Juran was the engineer-manager. He gave the field two enduring gifts. The first is a definition that keeps the customer central: quality is fitness for use — a product is good if it does what the user needs, regardless of how neatly it meets an internal drawing. The second is a framework for managing quality as three distinct processes, the Quality Trilogy.

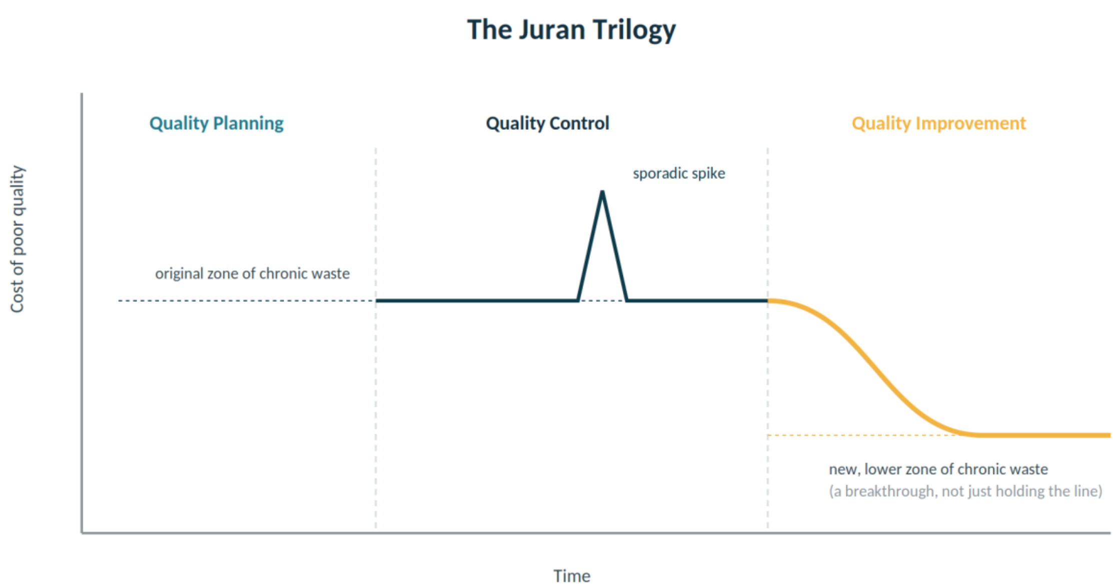

Figure 2.3 The Juran Trilogy: planning sets the level, control holds it, improvement breaks through to a new level.

- Quality Planning establishes the processes and targets needed to meet customer requirements — it sets the baseline.
- Quality Control operates the process and holds it at the planned level, reacting to sporadic spikes (special causes) to restore the status quo.
- Quality Improvement attacks the chronic waste that control merely maintains, driving a breakthrough to a new, permanently lower level of poor quality.

The trilogy's power is in separating two things organisations constantly confuse. Control asks, 'are we holding the line?' Improvement asks, 'why is the line where it is, and how do we move it?' A firm that only does control is condemned to pay for its chronic waste forever. Juran also popularised the Pareto principle in quality — the 'vital few' causes that account for most defects (Chapter 14) — and the idea that improvement happens 'project by project and in no other way.'

2.4 Philip B. Crosby — Quality Is Free

Crosby brought the quality message to the boardroom in plain commercial language. His provocative slogan, Quality Is Free, makes a precise economic claim: quality costs nothing because the savings from preventing defects always exceed the cost of prevention — what is expensive is nonconformance. His thinking is captured in four 'Absolutes.'

1. The definition of quality is conformance to requirements — not goodness or elegance.
2. The system for causing quality is prevention, not appraisal.
3. The performance standard is Zero Defects — not 'acceptable' quality levels.
4. The measurement of quality is the Price of Nonconformance (PONC), in money, not indices.

Zero Defects is best understood as a cultural standard rather than a statistical guarantee: a refusal to plan for failure, and a rejection of the idea that some defect rate is 'good enough.' Engineers rightly note its limits — with real tolerances and finite process capability, defects have a non-zero probability (Chapters 11 and 13) — but as a management posture it productively raises the bar. Crosby's lasting tool is the DIRTFT principle: Do It Right The First Time.

2.5 Kaoru Ishikawa — Tools for Everyone

Ishikawa's genius was democratisation. He believed quality improvement should not be the preserve of statisticians but a company-wide activity in which every employee participates, and he built the tools and structures to make that possible. He created the cause-and-effect diagram — the fishbone or Ishikawa diagram — which organises the possible causes of a problem into categories so a team can reason about them visually (developed fully in Chapters 14 and 15). He championed quality circles, small groups of workers who study and solve quality problems in their own area, and he assembled the Seven Basic Tools of quality — the histogram, Pareto chart, cause-and-effect diagram, check sheet, scatter diagram, control chart, and stratification — deliberately chosen because, he argued, they could solve the large majority of workplace quality problems without advanced mathematics.

2.6 Genichi Taguchi — Designing Quality In

Taguchi shifted the focus upstream, from the factory floor to the design office. His core insight is that quality is decided largely in design, and that the goal is robustness — a product whose performance is insensitive to the inevitable variation in manufacturing, materials, and use environment. Two ideas from his work are essential for any engineer.

The quality loss function

Taguchi rejected the conventional 'goalpost' view of tolerances, in which any part inside the specification limits is equally good and any part outside is equally bad. He argued instead that loss begins to accrue the moment a characteristic departs from its target, even within spec, and that this loss grows quadratically with the deviation.

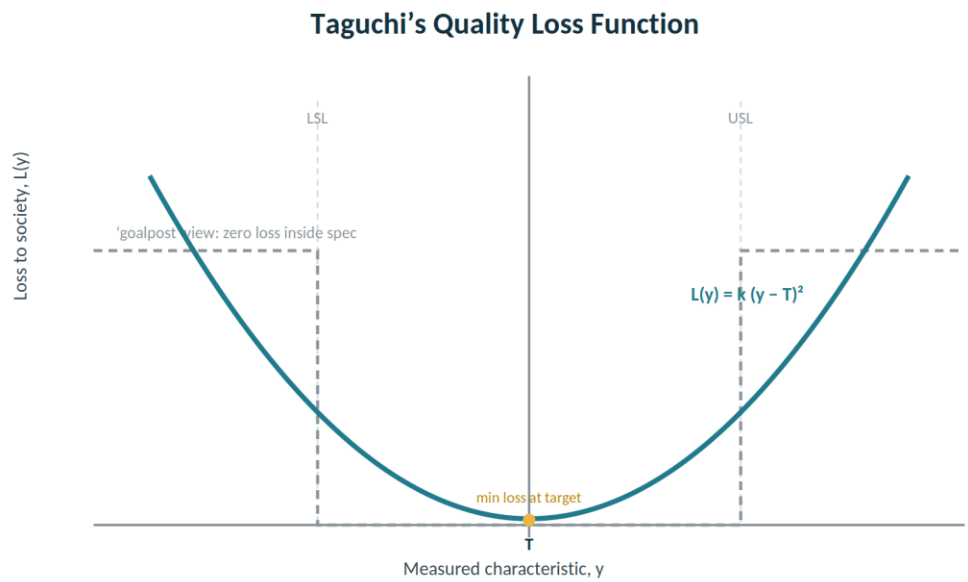

Figure 2.4 The quadratic loss function (teal) versus the traditional goalpost view (grey).

For a characteristic y with target T, the loss is modelled as $L(y) = k (y - T)^2$, where the constant k is found from a known reference point: if a deviation Δ at the spec limit causes a loss A (for example, the cost of scrap or warranty), then $k = A / \Delta^2$. The practical force of this model is that centring a process on target is worth money even when everything is 'in spec' — a conclusion the goalpost view completely misses.

Signal-to-noise and parameter design

Taguchi expressed robustness through a signal-to-noise (S/N) ratio that rewards being on target while penalising variation, and he used efficient designed experiments (orthogonal arrays) to find the control-factor settings that maximise it — the technique of parameter design, revisited in Chapter 12. The philosophy: first make the design insensitive to noise, then tighten tolerances only where it still matters.

Worked Example 2.1 — Taguchi loss in practice

Problem

A power-supply output is specified at 5.00 V with tolerance ±0.20 V. Field data show that a unit at the spec limit (0.20 V off target) generates an average warranty-plus-rework loss of $8.00. (a) Find the loss coefficient k. (b) A process is centred on target with a standard deviation of 0.08 V; estimate the average loss per unit. (c) A cheaper supplier runs off-centre at *a mean of 5.10 V with the same 0.08 V spread; estimate its average loss and decide whether a $1.50 unit saving justifies switching.*

Part (a) — $k = A / \Delta^2 = 8.00 / (0.20)^2 = 8.00 / 0.04 = \$200$ per V^2.

Part (b) — For a process with mean on target, the expected loss is $E[L] = k\cdot(\sigma^2 + (\mu-T)^2)$. With $\mu = T$, the bias term is zero, so $E[L] = 200 \times (0.08)^2 = 200 \times 0.0064 = \$1.28$ per unit. Even though every unit is well inside spec, the variation still costs about $1.28 each — invisible to the goalpost view.

Part (c) — Off-centre by $(5.10 - 5.00) = 0.10$ V: $E[L] = 200 \times (0.08^2 + 0.10^2) = 200 \times (0.0064 + 0.0100) = 200 \times 0.0164 = \$3.28$ per unit. The quality loss rises by $\$3.28 - \$1.28 = \$2.00$ per unit, which exceeds the $1.50 unit saving. The 'cheaper' supplier is more expensive once the loss of being off-target is counted — exactly the trade Taguchi's model is built to expose.

2.7 Armand V. Feigenbaum — Total Quality Control

Feigenbaum coined Total Quality Control and argued, well ahead of his time, that quality is everyone's job across the whole product cycle — from marketing and design through production to service — not the responsibility of an inspection department at the end. He introduced the idea of the hidden plant: the proportion of capacity (he estimated up to a third in some operations) consumed entirely by finding and fixing defects. Making that hidden plant visible, through the cost-of-quality accounting of Chapter 1, turns a vague call for 'better quality' into a hard financial argument that reaches the boardroom.

2.8 Comparing the Philosophies

The thinkers overlap more than they conflict, but their centres of gravity differ, and choosing the right lens for a problem is itself an engineering skill.

Guru	Defines quality as	Greatest leverage point	Best deployed when…
Deming	Predictable conformance via a stable system	Management of the system & variation	Culture and variation are the real problem
Juran	Fitness for use	Project-by-project improvement	You must separate control from breakthrough
Crosby	Conformance to requirements	Prevention & a Zero-Defects culture	You need executive buy-in and a money case
Ishikawa	Satisfying the customer, company-wide	Broad participation & simple tools	Frontline teams must own improvement
Taguchi	On-target performance, minimal loss	Robust design upstream	Quality must be designed in, not inspected
Feigenbaum	Total, organisation-wide control	Visibility of the cost of quality	Quality is siloed in an inspection function

2.9 Multi-disciplinary Applications and a Case Study

These philosophies are not manufacturing-only. Deming's common/special-cause distinction governs how a power utility should (and should not) react to daily fluctuations in network losses. Juran's trilogy maps cleanly onto software: planning is requirements and architecture, control is regression testing, and improvement is refactoring that removes a class of bug for good. Taguchi's robustness is the heart of civil-structural design for variable loads and the calibration of control systems against sensor noise. The lenses are universal; only the examples change.

> **Case Study 2.1 — Tampering on a calibration line**
>
> *An instruments manufacturer calibrated pressure transducers on an automated line. Operators, trying to be diligent, nudged the trim setting after every unit that read slightly high or slightly low — chasing the ordinary scatter of a stable process. Output variation steadily worsened and yield fell, the textbook result of what Deming called tampering.*
>
> *A quality engineer plotted the trim adjustments on a control chart and showed the team that the process had been in a state of common-cause variation all along: there was no signal to react to. The fix was counter-intuitive but decisive — stop adjusting. Operators were retrained to change the setting only when a control rule actually flagged a special cause. Variation fell by roughly 60% within a month, with no new equipment.*
>
> *The lesson is pure Deming: reacting to noise as though it were signal makes things worse. Knowing the difference is the whole game, and it is why Chapter 11 exists.*

2.10 Best Practices, Common Mistakes, and Troubleshooting

Best Practices

- Before reacting to a number, ask whether it reflects common-cause or special-cause variation.
- Run quality as three explicit processes — planning, control, improvement — and resource improvement separately.
- Express quality problems in money (price of nonconformance, Taguchi loss) to win management support.
- Centre processes on target, not merely inside tolerance; the loss function rewards it.

Common Mistakes

- Tampering: adjusting a stable process in response to ordinary variation.
- Treating 'in spec' as 'no loss' and ignoring deviation from target.
- Doing only control and wondering why chronic waste never falls.
- Blaming operators for what are, statistically, system faults owned by management.

Troubleshooting

Symptom	Likely root cause	First action
Variation rises after 'corrections'	Tampering with a stable process	Chart it; adjust only on a real signal (Ch 11)
Improvement stalls despite tight control	No separate improvement process	Launch Juran-style breakthrough projects (Ch 18)
'In-spec' product still draws complaints	Off-target mean, goalpost thinking	Centre on target; apply the loss function

Frequently Asked Questions

Q: Is Zero Defects realistic for engineers? **A:** As a cultural standard and a design ambition, yes. As a literal statistical guarantee it depends on tolerances and capability (Ch 11, 13). Crosby's target and Taguchi's mathematics are complementary, not contradictory.

Q: Deming or Six Sigma — which is right? **A:** Both. Six Sigma is, in large part, Juran's project-by-project improvement and Deming's variation thinking, industrialised into the DMAIC roadmap of Chapter 18.

Q: Why learn 1950s ideas for a Quality 4.0 world? **A:** Because the algorithms of Quality 4.0 still have to decide what is signal and what is noise — Deming's question — and still have to be aimed at customer fitness for use — Juran's. The tools are new; the questions are not.

Chapter Summary

The modern discipline rests on a handful of arguments made when they were radical. Deming taught system thinking and the decisive distinction between common- and special-cause variation, insisting that management owns the system. Juran separated quality planning, control, and breakthrough improvement, and kept the customer central through fitness for use. Crosby made the boardroom case — conformance, prevention, Zero Defects, and the price of nonconformance. Ishikawa democratised quality with simple tools and quality circles. Taguchi moved quality upstream into robust design and quantified the cost of missing target through the quadratic loss function. Feigenbaum made the whole organisation responsible and exposed the hidden plant. Together they supply the lenses every later chapter applies.

Glossary

Common-cause variation — Natural, ever-present variation of a stable process; not a signal.

Special-cause variation — Variation from a specific, identifiable change; a signal to act on.

Tampering — Adjusting a stable process in response to common-cause variation, which increases variation.

Quality Trilogy — Juran's division of quality into planning, control, and improvement.

Quality loss function — Taguchi's model $L(y)=k(y-T)^2$ of loss from deviating off target.

Price of nonconformance — Crosby's money measure of the cost of not doing it right the first time.

References and Suggested Reading

1. Deming, W. E. (1986/2018). Out of the Crisis. MIT Press.
2. Deming, W. E. (1993). The New Economics for Industry, Government, Education. MIT CAES.
3. Juran, J. M. (1989). Juran on Leadership for Quality. Free Press.
4. Crosby, P. B. (1979). Quality Is Free. McGraw-Hill.
5. Ishikawa, K. (1985). What Is Total Quality Control? The Japanese Way. Prentice Hall.
6. Taguchi, G., Chowdhury, S., & Wu, Y. (2005). Taguchi's Quality Engineering Handbook. Wiley.
7. Feigenbaum, A. V. (1991). Total Quality Control, 3rd ed. McGraw-Hill.

Review Questions — Chapter 2

Recall

1. Name Deming's four lenses of Profound Knowledge.
2. State the three elements of the Juran Trilogy.
3. Write Taguchi's quality loss function and define each symbol.

Application

1. A machine's output drifts within its usual range; an operator re-zeros it each time. Identify the error and its consequence.
2. Map the Juran Trilogy onto a software-development team's activities.
3. Given $k = \$150/\text{mm}^2$ and a process at $\mu = T$ with $\sigma = 0.05$ mm, compute the expected Taguchi loss per part.

Analysis

1. Crosby demands Zero Defects; Taguchi quantifies non-zero loss even in spec. Reconcile the two positions for a design engineer.
2. Explain, using Deming, why ranking employees by defect counts can degrade overall quality.

Design

1. Design a one-page decision aid that helps an operator decide whether an out-of-usual reading is common- or special-cause.
2. Propose how you would introduce quality circles into a department that currently relies on end-of-line inspection.

Multiple-Choice Questions

1. Adjusting a stable process in response to ordinary variation is called: (A) Control (B) Tampering (C) Improvement (D) Calibration ✓ **Answer: B.** *Deming's term for over-adjustment; it increases variation.*

2. The Juran Trilogy consists of planning, control, and: (A) Inspection (B) Conformance (C) Improvement (D) Appraisal ✓ **Answer: C.** *Planning, control, and improvement.*

3. Taguchi's loss function implies that loss is minimised when the characteristic is: (A) Anywhere in spec (B) At the upper limit (C) On target (D) Below nominal ✓ **Answer: C.** *$L(y)=k(y-T)^2$ is minimum at $y=T$.*

4. 'Quality is free' is most associated with: (A) Deming (B) Crosby (C) Ishikawa (D) Taguchi ✓ **Answer: B.** *Crosby's thesis: prevention pays for itself.*

Short and Long Questions

Short Questions

1. Distinguish common-cause from special-cause variation with one example of each.
2. Why did Feigenbaum call wasted rework capacity the 'hidden plant'?
3. What does 'fitness for use' add that 'conformance to spec' can miss?

Long Questions

1. Compare Deming's and Crosby's philosophies, identifying where they reinforce and where they tension each other.
2. Explain Taguchi's robust-design philosophy and why designing quality in is cheaper than inspecting it out.

Problems, Labs, and Projects

Numerical Problems

1. A shaft diameter targets 25.000 mm; a deviation of 0.050 mm at the spec limit costs $12. Find k, then the expected loss for a centred process with $\sigma = 0.020$ mm.
2. Repeat the previous problem for a process running off-centre at 25.030 mm with the same spread, and state the cost of the off-centring.
3. Two suppliers offer the same part: A is on target with $\sigma = 0.03$ mm; B is $0.40 cheaper but off-target by 0.04 mm with $\sigma = 0.03$ mm. Using $k = \$90/\text{mm}^2$, decide which is truly cheaper.

Practical Assignment

Pick one of Deming's Fourteen Points and write a one-page argument applying it to an organisation you know, with a concrete change you would make and the variation or psychology principle behind it.

Laboratory Activity

Lab 2 — The funnel (tampering) experiment. Using a physical funnel-and-marble setup or a short simulation, drop a marble aiming at a target under two rules: (i) never adjust, and (ii) adjust the funnel to compensate for each miss. Record the spread of outcomes under each rule and explain, with reference to Deming, why rule (ii) is worse.

Mini-Project

Build a small spreadsheet that takes a target, a tolerance, a reference loss at the limit, and a process mean and standard deviation, and returns k and the expected Taguchi loss per unit, with a chart of loss versus mean shift. (Reused for tolerance decisions in Chapter 12.)

Capstone Project Idea

For your running course project, write the 'quality philosophy' section of the company's quality manual: which guru's lens dominates each process (design, production, service) and why, and how the System of Profound Knowledge will shape its management. This becomes the cultural preamble to the QMS you build in Chapter 5.

Interview and Certification Practice

Interview Questions

- Explain common- versus special-cause variation and why the distinction matters operationally.
- How would you use the Juran Trilogy to structure a quality department's annual plan?
- A manager wants to rank operators by defect count. Using Deming, how do you respond?
- Why might an 'in-spec' part still represent a quality loss?

Certification Practice (CQE / CMQ-OE style)

1. The principle that ~85–94% of quality problems are system-caused is attributed to: (A) Crosby (B) Deming (C) Ishikawa (D) Taguchi ✓ **B.** *Deming attributed the majority of problems to the system, owned by management.*

2. Quality circles and the cause-and-effect diagram are most associated with: (A) Juran (B) Feigenbaum (C) Ishikawa (D) Crosby ✓ **C.** *Both are Ishikawa's contributions.*

3. In $L(y)=k(y-T)^2$, doubling the deviation from target changes the loss by a factor of: (A) 2 (B) 3 (C) 4 (D) $\sqrt{2}$ ✓ **C.** *Loss is quadratic, so $2^2 = 4\times$.*

> **See also — companion volume**
>
> *Engineering Safety, Chapter 2 (Safety Culture, Leadership & Ethics) draws on the same Deming insight that culture and system, not individual blame, drive outcomes. The common/special-cause distinction here reappears as the difference between a systemic hazard and a one-off failure in that book's incident-investigation chapter (Safety Ch 8).*

END OF FREE PREVIEW

Continue reading — Chapters 3 to 22

Engineering Quality Assurance • Engineering Excellence Series, Book 1

You have just finished Chapters 1 and 2. The complete book carries you through the remaining twenty chapters — the four pillars and the cost of quality, ISO 9001 and the sector standards, metrology and gauge R&R, statistical process control and capability, acceptance sampling, root-cause analysis and CAPA, FMEA and fault trees, Lean and Six Sigma, reliability and risk, Industry 4.0, AI and digital twins, and the professional certification pathway — with worked examples, industrial case studies, four-tier review questions, and certification practice throughout.