PART 1: HOW YOU CAN USE THIS BOOK

The main purpose of Mechanical Engineering Reference Manual (Reference Manual) is to get you ready for the NCEES PE mechanical exams. Use it along with the other PPI PE mechanical study tools to assess, review, and practice until you pass your exam.

Assess
To pinpoint the subject areas where you need more study, use the diagnostic exams on the PPI Learning Hub (ppi2pass.com). How you perform on these diagnostic exams will tell you which topics you need to spend more time on and which you can review more lightly.

Review
PPI offers a complete solution to help you prepare for exam day. Our mechanical engineering prep courses and Reference Manual offer a thorough review for the PE mechanical exams. Mechanical Engineering Practice Problems (Practice Problems), and the PPI Learning Hub quiz generator offer extensive practice in solving exam-like problems. Mechanical Engineering HVAC and Refrigeration Practice Exam, Mechanical Engineering Machine Design and Materials Practice Exam, and Mechanical Engineering Thermal and Fluid Systems Practice Exam provide practice exams that simulate the exam-day experience and let you hone your test-taking skills.

Practice
Learn to Use the NCEES PE Mechanical Reference Handbook

Download a PDF of the NCEES PE Mechanical Reference Handbook (NCEES Handbook) from the NCEES website. As you study, take the time to find out where important equations and tables are located in the NCEES Handbook. Although you could print out the NCEES Handbook and use it that way, it will be better for your preparations if you use it in PDF form on your computer. This is how you will be referring to it and searching in it during the actual exam.

A searchable electronic copy of the NCEES Handbook is the only reference you will be able to use during the exam, so it is critical that you get to know what it includes and how to find what you need efficiently. Even if you know how to find the equations and data you need more quickly in other references, take the time to search for them in NCEES Handbook. Get to know the terms and section titles used in the NCEES Handbook and use these as your search terms.

In this book, each equation from the NCEES Handbook is given in blue and annotated with the title of the section the equation is found in, also in blue. Whenever data are taken from a figure or table in the NCEES Handbook, the title of the figure or table is given in blue. Get to know these titles as you study; they will give you search terms you can use to quickly find the equations and data you need, saving valuable time during the exam.

Using steam tables, \( h_1 = 389.0 \text{ Btu/lbm} \), \( s_1 = 1.567 \text{ Btu/lbm}^{-\circ\text{R}} \), and \( p_2 = 4 \text{ psia} \). \( h_2 \) represents the enthalpy for a turbine that is 100% efficient. Since the turbine is isentropic, \( s_1 = s_2 \). Using steam tables, find the appropriate enthalpy and entropy values at state 2’ where \( 2' = 4 \text{ psia} \).

\[
\begin{align*}
\text{[Properties of Saturated Water and Steam (Temperature) - I-P Units]} \\
\hline
h_s & = 120.87 \text{ Btu/lbm} \\
(\text{at } 1006.4 \text{ Btu/lbm}) \\
s_f & = 0.2198 \text{ Btu/lbm}^{-\circ\text{R}} \\
(\text{at } 1.6424 \text{ Btu/lbm}) \\
f_g & = 1.567 \text{ Btu/lbm}^{-\circ\text{R}} \\
(\text{at } 0.82) \\
\text{The steam quality at the turbine exhaust (state 2) for a 100% efficient turbine is found from the entropy relationship.}
\end{align*}
\]

Some equations given in blue in this book may have a variable or two that is different from the equation as it appears in the NCEES Handbook. There are a small number of variables that are treated inconsistently in
the NCEES Handbook; to minimize possible confusion while studying, in this book these variables have been made consistent.

For example, pressure is represented by both p and P in different sections of the NCEES Handbook; in this book pressure is always represented by p. Similarly, in this book heat is always represented by Q; heat rate is \( \dot{Q} \) in reference to thermodynamic cycles and q otherwise; velocity is always v; and elevation is always z. All the variables and subscripts used in a chapter are defined in the nomenclature list at the end of each chapter.

Equations in blue may also differ from their presentation in the NCEES Handbook because of the presence of the gravitational constant, \( g \). The NCEES Handbook generally does not indicate whether an equation requires \( g \) when used with U.S. customary units. On the PE exam, then, you will need to know when and how to include \( g \) in a calculation without any help from the NCEES Handbook.

To show the correct use of \( g \), equations in this book are given in two versions where appropriate, one for use with SI units and one for use with U.S. customary units, with \( g \) correctly included in the U.S. version. When you solve practice problems, however, you should use the NCEES Handbook as your only reference, identifying when and how to use \( g \) on your own. This is more trouble than looking up the equations in this book, but it will better prepare you for the actual exam.

Access the PPI Learning Hub

Although the Reference Manual, Practice Problems, and the three mechanical engineering Practice Exams can be used on their own, they are designed to work with the PPI Learning Hub. At the PPI Learning Hub, you can access

- a personal study plan, keyed to your exam date, to help keep you on track
- diagnostic exams to help you identify the subject areas where you are strong and where you need more review
- a quiz generator containing hundreds of additional exam-like problems that cover all knowledge areas on the PE mechanical exams
- two full-length NCEES-like, computer-based practice exams for each of the PE mechanical engineering disciplines, to familiarize you with the exam day experience and let you hone your time management and test-taking skills

For more about the PPI Learning Hub, visit PPI’s website at ppi2pass.com.

Be Thorough

Really do the work.

Time and again, customers ask us for the easiest way to pass the exam. The short answer is pass it the first time you take it. Put the time in. Take advantage of the problems provided and practice, practice, practice! Take the practice exams and time yourself so you will feel comfortable during the exam. When you are prepared you will know it. Yes, the reports in the PPI Learning Hub will agree with your conclusion but, most importantly, if you have followed the PPI study plan and done the work, it is more likely than not that you will pass the exam.

Some people think they can read a problem statement, think about it for 10 seconds, read the solution, and then say, “Yes, that’s what I was thinking of, and that’s what I would have done.” Sadly, these people find out too late that the human brain makes many more mistakes under time pressure and that there are many ways to get messed up in solving a problem even if you understand the concepts. It may be in the use of your calculator, like using log instead of ln or forgetting to set the angle to radians instead of degrees. It may be rusty math, like forgetting exactly how to factor a polynomial. Maybe you can’t find the conversion factor you need, or don’t remember what joules per kilogram is in SI base units.

For real exam preparation, you’ll have to spend some time with a stubby pencil. You have to make these mistakes during your exam prep so that you do not make them during the actual exam. So do the problems—all of them. Do not look at the solutions until you have sweated a little.

IF YOU ARE AN INSTRUCTOR

If you are teaching a prep course for the PE examination, you can use the material in this book as a guide to prepare your lectures. The first two editions of this book consisted of a series of handouts prepared for the benefit of my PE prep courses. These editions were intended to be compilations of all the long formulas, illustrations, and tables of data that I did not have time to put on the chalkboard. You can use this edition in the same way.

“Capacity assignment” is the goal in my prep courses. If you assign 20 hours of homework and a student is able to put in only 10 hours that week, that student will have worked to his or her capacity. After the PE examination, that student will honestly say that he or she could not have prepared any more than he or she did in your course. For that reason, you have to assign homework on the basis of what is required to become proficient in
the subjects of your lecture. You must resist assigning only the homework that you think can be completed in an arbitrary number of hours.

Homework assignments in my prep courses are not individually graded. Instead, students are permitted to make use of existing solutions to learn procedures and techniques to the problems in their homework set, such as those in the companion Practice Problems, which contains solutions to all practice problems. However, each student must turn in a completed set of problems for credit each week. Though I don’t correct the homework problems, I address comments or questions emailed to me, posted on the course forum, or noted on the assignments.

I believe that students should start preparing for the PE exam at least six months before the examination date. However, most wait until three or four months before getting serious. Because of that, I have found that a 13- or 14-week format works well for a live PE prep course. It’s a little rushed, but the course is over before everyone gets bored with my jokes. Each week, there is a three-hour meeting, which includes lecture and a short break. If you can add more course time, your students will appreciate it. However, I don’t think you can cover the full breadth of material in much less time or in many fewer weeks.

Lecture coverage of some examination subjects is necessarily brief; other subjects are not covered at all. These omissions are intentional; they are not the result of scheduling omissions. Why? First, time is not on our side in a prep course. Second, some subjects rarely contribute to the examination. For example, I have found that very few people study modeling and systems analysis, material handling, and manufacturing methods. Unless you have six months in which to teach your PE review, your students’ time can be better spent covering other subjects.

All the skipped chapters and any related practice problems are presented as floating assignments to be made up in the students’ “free time.”

I strongly believe in exposing my students to a realistic sample examination, but I no longer administer an in-class mock exam. Since the prep course usually ends only a few days before the real PE examination, I hesitate to make students sit for several hours in the late evening to take a “final exam.” Rather, I distribute and assign a sample exam at the first meeting of the prep course.

If the practice test is to be used as an indication of preparedness, caution your students not to even look at the sample exam prior to taking it. Looking at the sample examination, or otherwise using it to direct their review, will produce unwarranted specialization in subjects contained in the sample examination.

There are many ways to organize a PE prep course, depending on your available time, budget, intended audience, facilities, and enthusiasm. However, all good course formats have the same result: The students struggle with the workload during the course, and then they breeze through the examination after the course.

**PART 2: EVERYTHING YOU EVER WANTED TO KNOW ABOUT THE PE EXAM**

**WHAT IS THE FORMAT OF THE PE EXAM?**

The NCEES PE examination in mechanical engineering consists of two four-hour sessions separated by a one-hour lunch period. The examinee may choose one of three disciplines: HVAC and refrigeration, machine design and materials, or thermal and fluid systems. You must be approved by your state licensing board before you can register for the exam using the “My NCEES” system on the NCEES website. You select your discipline when you register for the exam. Switching disciplines is not possible at the exam appointment.

Both the morning and afternoon sessions contain 40 questions in multiple-choice (i.e., “objective”) or alternative-item-type (AIT) format. As this is a “no-choice” exam, you must answer all questions in each session correctly to receive full credit. There are no optional questions.

**WHAT SUBJECTS ARE ON THE PE EXAM?**

NCEES has published a description of subjects on the exams. Irrespective of the published examination structure, the exact number of questions that will appear in each subject area cannot be predicted reliably.

There is no guarantee that any single subject will occur in any quantity. One of the reasons for this is that some of the questions span several disciplines. You might categorize and solve a steam flow question as a fluids problem, while NCEES might categorize it as a thermodynamics (ideal gas or compressible flow) problem.

Table 1 describes the subjects in detail and gives the approximate number of problems for each topic. Most examinees find the list to be formidable in appearance. NCEES adds,

The examination is developed with questions that require a variety of approaches and methodologies including design, analysis, application, and operations. Some questions may require knowledge of engineering economics. These areas are examples of the kinds of knowledge that will be tested but are not exclusive or exhaustive categories.
WHAT IS THE TYPICAL PROBLEM FORMAT?

Almost all of the problems are stand-alone—that is, they are complete and independent. Problem types include traditional multiple-choice problems, as well as alternative item types (AITs). AITs include, but are not limited to

- **multiple correct**, which allows you to select multiple answers
- **point and click**, which requires you to click on a part of a graphic to answer
- **drag and drop**, which requires you to click on and drag items to match, sort, rank, or label
- **fill in the blank**, which provides a space for you to enter a response to the problem

Although AITs are a recent addition to the PE mechanical exams and may take some getting used to, they are not inherently difficult to master. For your reference, additional AIT resources are available on the PPI Learning Hub (ppl2pass.com).

Traditional multiple-choice problems will have four answer options, labeled A, B, C, and D. If the four answer options are numerical, they will be displayed in increasing value. One of the answer options is correct (or “most nearly correct”). The remaining answer options will consist of three “logical distractors,” the term used by NCEES to designate options that are incorrect but look plausibly correct.

HOW MUCH “LOOK-UP” IS REQUIRED ON THE EXAM?

Since most of the questions are multiple choice in design, all required data will appear in the situation statement. Since the examination would be unfair if it was possible to arrive at an incorrect answer after making valid assumptions or using plausible data, you will not generally be required to come up with numerical data that might affect your success on the problem. Friction factors and pipe roughness, thermal conductivities, \( U \) and \( R \)-heat transfer factors, most pipe sizes, material strengths and other properties, and relevant assumptions will be given in the question statement. There will also be superfluous information in the majority of questions.

WHAT DOES “MOST NEARLY” REALLY MEAN?

One of the more disquieting aspects of these questions is that the available answer choices are seldom exact. Answer choices generally have only two or three significant digits. Exam questions ask, “Which answer choice is most nearly the correct value?” or they instruct you to complete the sentence, “The value is approximately . . .”

A lot of self-confidence is required to move on to the next question when you don’t find an exact match for the answer you calculated, or if you have had to split the difference because no available answer choice is close.

NCEES describes it like this:

Many of the questions on NCEES exams require calculations to arrive at a numerical answer. Depending on the method of calculation used, it is very possible that examinees working correctly will arrive at a range of answers. The phrase “most nearly” is used to accommodate answers that have been derived correctly but that may be slightly different from the correct answer choice given on the exam. You should use good engineering judgment when selecting your choice of answer. For example, if the question asks you to calculate an electrical current or determine the load on a beam, you should literally select the answer option that is most nearly what you calculated, regardless of whether it is more or less than your calculated value. However, if the question asks you to select a fuse or circuit breaker to protect against a calculated current or to size a beam to carry a load, you should select an answer option that will safely carry the current or load. Typically, this requires selecting a value that is closest to but larger than the current or load.

The difference is significant. Suppose you were asked to calculate “most nearly” the volumetric pure airflow required to dilute a contaminated air stream to an acceptable concentration. Suppose, also, that you calculated the answer to be 823 cfm. If the answer choices were (A) 600 cfm, (B) 800 cfm, (C) 1000 cfm, and (D) 1200 cfm, you would go with answer choice (B), because it is most nearly what you calculated. If, however, you were asked to select a fan or duct with the same rated capacities, you would have to go with choice (C), because an 800 cfm fan wouldn’t be sufficient. Got it?

HOW MUCH MATHEMATICS IS NEEDED FOR THE EXAM?

There are no pure mathematics questions (algebra, geometry, trigonometry, etc.) on the exam. However, you will need to apply your knowledge of these subjects to the exam questions.

Generally, only simple algebra, trigonometry, and geometry are needed on the PE exam. You will need to use the trigonometric, logarithm, square root, exponentiation, and similar buttons on your calculator. There is no need to use any other method for these functions.

Except for simple quadratic equations, you will probably not need to find the roots of polynomial equations. For second-order (quadratic) equations, the exam does not care if you find roots by factoring, completing the square, using the quadratic equation, graphing, or using
Table 1 Detailed Analysis of Tested Subjects\textsuperscript{a,b}

HVAC and Refrigeration

I. Principles (28–43 problems)

A. Basic engineering practice (units and conversions, economic analysis, electrical concepts)
B. Thermodynamics (cycles, properties, compression processes)
C. Psychrometrics (heating/cooling processes, humidification/dehumidification processes)
D. Heat transfer
E. Fluid mechanics
F. Energy/mass balances

II. Applications (42–64 problems)

A. Heating/cooling loads
B. Equipment and components (cooling towers and fluid coolers, boilers and furnaces, heat exchangers, condensers/evaporators, pumps/compressors/fans, cooling/heating coils, control systems components, refrigerants, refrigeration components)
C. Systems and components (air distribution, fluid distribution/piping, refrigeration, energy recovery, basic control concepts)
D. Supportive knowledge (codes and standards, air quality and ventilation, vibration control, acoustics)

Machine Design and Materials Exam

I. Principles (35–55 problems)

A. Basic engineering practice (engineering terms and symbols, interpretation of technical drawings, quality assurance/quality control, project management and economic analysis, units and conversions, design methodology)
B. Engineering science and mechanics (statics, kinematics, dynamics)
C. Material properties (physical, chemical, mechanical)
D. Strength of materials (stress/strain, shear, bending, buckling, torsion, fatigue, failure theories)
E. Vibration (natural frequencies, damping, forced vibrations)

II. Applications (35–55 problems)

A. Mechanical components (pressure vessels and piping; bearings; gears; springs; dampers; belt, pulley, and chain drives; clutches and brakes; power screws; shafts and keys; mechanisms; basic mechatronics; hydraulic and pneumatic components; motors and engines)
B. Joints and fasteners (welding and brazing; bolts, screws, and rivets; adhesives)
C. Supportive knowledge (manufacturing processes, fits and tolerances, codes and standards, computational methods and their limitations, testing and instrumentation)

Thermal and Fluid Systems Exam

I. Principles (28–44 problems)

A. Basic engineering practice (engineering terms, symbols, and technical drawings; economic analysis; units and conversions)
B. Fluid mechanics (fluid properties, compressible flow, incompressible flow)
C. Heat transfer principles
D. Mass balance principles
E. Thermodynamics (thermodynamic properties, thermodynamic cycles, energy balances, combustion)
F. Supportive knowledge (pipe system analysis, joints, psychrometrics, codes and standards)

II. Hydraulic and Fluid Applications (21–33 problems)

A. Hydraulic and fluid equipment (pumps and fans, compressors, pressure vessels, control valves, actuators, connections)
B. Distribution systems

III. Energy/Power System Applications (21–33 problems)

A. Energy/power equipment (turbines, boilers and steam generators, internal combustion engines, heat exchangers, cooling towers, condensers)
B. Cooling/heating
C. Energy recovery
D. Combined cycles

\textsuperscript{a} Considerable overlap, duplication, and flexibility exists in each topic.

\textsuperscript{b} NCEES may occasionally revise exam subjects somewhat. For the most current information, visit ppi2pass.com.
your calculator’s root finder. Occasionally, it will be convenient to use the equation-solving capability of your calculator. However, other solution methods will always exist.

There is essentially no use of calculus on the exam. Rarely, you may need to take a simple derivative to find a maximum or minimum of some simple algebraic function. Even rarer is the need to integrate to find an average, moment of inertia, statical moment, or shear flow.

There is essentially no need to solve differential equations. Questions involving radioactive decay, seismic vibrations, control systems, chemical reactions, and fluid mixing have appeared from time to time. However, these applications are extremely rare, have usually been first-order, and could usually be handled without having to solve differential equations.

Basic statistical analysis of observed data may be necessary. Statistical calculations are generally limited to finding means, medians, standard deviations, variances, percentiles, and confidence limits. Since the problems are multiple choice, you won’t have to draw a histogram, although you might have to interpret one. Usually, the only population distribution you need to be familiar with is the normal curve. Probability, reliability, hypothesis testing, and statistical quality control are not explicit exam subjects, though their concepts may appear peripherally in some problems. You will not have to use linear or nonlinear regression and other curve fitting techniques to correlate data.

Quantitative optimization methods, such as linear, dynamic, and integer programming, generally associated with the field of operations research are not exam subjects.

The PE exam is concerned with numerical answers, not with proofs or derivations. You will not be asked to prove or derive formulas, use deductive reasoning, or validate theorems, corollaries, or lemmas.

Inasmuch as first assumptions can significantly affect the rate of convergence, problems requiring trial-and-error solutions are unlikely. Rarely, a calculation may require an iterative solution method. Generally, there is no need to complete more than two iterations. You will not need to program your calculator to obtain an “exact” answer. Nor will you generally need to use complex numerical methods.

HOW ABOUT ENGINEERING ECONOMICS?

For most of the early years of engineering licensing, questions on engineering economics appeared frequently on the examinations. This is no longer the case. What this means is that engineering economics concepts might appear in several questions on the exam, or the subject might be totally absent. While the degree of engineering economics knowledge has decreased somewhat, the basic economic concepts (e.g., time value of money, present worth, non-annual compounding, comparison of alternatives, etc.) are still valid test subjects.

If engineering economics is incorporated into other questions, its “disguise” may be totally transparent. For example, you might need to compare the economics of buying and operating two blowers for remediation of a hydrocarbon spill—blowers whose annual costs must be calculated from airflow rates and heads. Also, you may need to use engineering economics concepts and tables in problems that don’t even mention “dollars” (e.g., when you need to predict future water demand, population, or traffic volume).

WHAT ABOUT FIRE PROTECTION ENGINEERING?

At one time, fire protection was a topic on the mechanical engineering PE exam. Numerical questions dealt with sprinkler capacity, sprinkler layout, fire pumps, hydrants, standpipes, hose and nozzle flow rate, and occupancy categories. This topic disappeared when the mechanical engineering PE exam adopted the breadth-and-depth format. However, piping, pumps, valve, and controls for fire protection are easily categorized into other exam topics. The fire protection chapter in this book covers basic material that might still be useful on the exam.

WHAT ABOUT NUCLEAR ENGINEERING?

At one time, nuclear engineering problems appeared regularly on the mechanical engineering PE exam. These problems dealt with shielding, health safety, core power development, decay, liquid metal flow and heat transfer, and core design. Such problems disappeared when the nuclear engineering PE exam became available. Problems involving nuclear reactor environments continue to appear, but these can always be solved with “traditional” heat transfer, thermodynamic, power cycle, and fluid machinery concepts.

WHAT ABOUT PROFESSIONALISM AND ETHICS?

For many decades, NCEES has considered adding professionalism and ethics questions to the PE exam. However, these subjects are not part of the test outline, and there has yet to be an ethics question in the exam. Professional practice questions dealing with obligations related to contracts, bidding, estimating, inspection, and regulations sometimes get pretty close. However, you won’t encounter the phrase “ethical obligation” in the exam.
WHAT ABOUT CODES AND STANDARDS?

NCEES does not specify “codes and standards” in its lists of exam topics. For that reason, at least for the mechanical engineering PE exams, “codes and standards” seems to imply “knowledge about codes and standards,” as opposed to “possession of and reference to the codes and standards” during the exam. The distinction is significant, because (without a specific list) it would be unreasonably expensive to purchase every code and standard affecting mechanical engineers. Among others, ASME, ASTM, ANSI, ASHRAE, SAE, NFPA, NEC, AGMA, EPA, OSHA, and other U.S. organizations publish numerous documents, as do Canada and the European Union (EU).

There are a few noteworthy exceptions: ASME Y14.5 (Dimensioning and Tolerancing); ASME Boiler and Pressure Vessel Code (BPVC) Sec. VIII, Div. 1; ASHRAE Standard 62.1 (Ventilation for Acceptable Indoor Air Quality); TEMA’s Standards of the Tubular Exchanger Manufacturers Association; and, OSHA CFR 29. Depending on your discipline, one or more of these publications could be valuable.

Inasmuch as fire protection is no longer a specific topic on the mechanical PE exams, none of the NFPA publications should be needed. A useful standard for non-fatigue applications, ASME’s Code for Design of Transmission Shafting (ASA-B17c), is obsolete and is unlikely to be needed during the exam.

IS THE EXAM TRICKY?

Other than providing superfluous data, the PE exam is not a “tricky exam.” The exam does not overtly try to get you to fail. Examinees manage to fail on a regular basis with perfectly straightforward questions. The exam questions are difficult in their own right. NCEES does not need to provide misleading or conflicting statements. However, you will find that commonly made mistakes are represented in the available answer choices. Thus, the alternative answers (known as distractors) will be logical.

Questions are generally practical, dealing with common and plausible situations that you might experience in your job. You will not be asked to determine the radiated heat transfer from the side of a spacecraft at night after it has landed on a Jovian moon with a methane atmosphere.

WHAT MAKES THE QUESTIONS DIFFICULT?

Some questions are difficult because the pertinent theory is not obvious. There may be only one acceptable procedure, and it may be heuristic (or defined by a code) such that nothing else will be acceptable. For example, if you don’t know the AGMA procedure for designing gears, no other knowledge of gear design is going to be helpful for an AGMA question.

Some questions are difficult because the data needed are hard to find. Solving some HVAC problems depends on having climatological data for a specific location and performance characteristics of specific construction types.

Some questions are difficult because they defy the imagination. Problems involving epicyclical gear trains can be like this. If you cannot visualize the operation of the mechanism, if you cannot get an intuitive feeling about what is going on, you probably cannot analyze it.

Some questions are difficult because the computational burden is high, and they just take a long time. Convective heat transfer, HVAC, and pipe networks analyzed with the Hardy-Cross method fall into this category.

Some questions are difficult because the terminology is obscure, and you just don’t know what the terms mean. This can happen in almost any subject.

DOES THE PE EXAM USE SI UNITS?

The PE mechanical machine design and materials exam and the PE mechanical thermal and fluid systems exam primarily use customary U.S. units (also known as “English units,” “inch-pound units,” and “British units”), although SI and a variety of other metric systems are also used. The PE mechanical HVAC and refrigeration exam only uses customary U.S. units.

Questions use the units that correspond to commonly accepted industry standards. Metric units are used in chemical-related subjects, including electrical power (watts) and water concentration (mg/L) questions. Either system can be used for fluids, stress analysis, and thermodynamics.

Unlike this book, the exam does not differentiate between lbf and lbm (pounds-force and pounds-mass). Similarly, the exam does not follow this book’s practice of meticulously separating the concepts of mass and weight, density and specific weight, and gravity, g, and the gravitational constant, g_c.

WHY DOES NCEES REUSE SOME QUESTIONS?

NCEES reuses some of the more reliable questions from each exam. The percentage of repeat questions isn’t high—no more than 25% of the exam. NCEES repeats questions in order to equate the performance of one group of examinees with the performance of an earlier group. The repeated questions are known as equaters, and together, they are known as the equating subtest.
Occasionally, a new question appears on the exam that very few of the examinees do well on. Usually, the reason for this is that the subject is too obscure or the question is too difficult. Questions on control systems and some engineering management subjects (e.g., linear programming) fall into this category. Also, there have been cases where a low percentage of the examinees get the answer correct because the question was inadvertently stated in a poor or confusing manner. Questions that everyone gets correct are also considered defective.

NCEES tracks the usage and “success” of each of the exam questions. “Rogue” questions are not repeated without modification. This is one of the reasons historical analysis of question types shouldn’t be used as the basis of your review.

DOES NCEES USE THE EXAM TO PRE-TEST FUTURE QUESTIONS?........................................................................................................................

NCEES does not use the PE exam to “pre-test” or qualify future questions. (It does use this procedure on the FE exam, however.) All of the questions you work will contribute toward your final score.

ARE THE EXAMPLE PROBLEMS IN THIS BOOK REPRESENTATIVE OF THE EXAM?........................................................................................................................

The example problems in this book are intended to be instructional and informative. They were written to illustrate how their respective concepts can be implemented. Example problems are not intended to represent exam problems or provide guidance on what you should study.

ARE THE PRACTICE PROBLEMS REPRESENTATIVE OF THE EXAM?........................................................................................................................

The practice problems in the companion Practice Problems book were chosen to cover the most likely exam subjects. Some of the practice problems are multiple choice, and some are alternative item types. Some may be more comprehensive and complex than actual exam problems.

Practice problems in the companion book were selected to complement subjects in the Mechanical Engineering Reference Manual. Over the many editions of both books, the practice problems have developed into a comprehensive review of the most important mechanical engineering subjects covered on the exams.

All of the practice problems are original. Since NCEES does not release old exams, and since examinees are sworn to secrecy before taking the exam, none of the practice problems are actual exam problems.

WHAT REFERENCE MATERIAL IS PERMITTED IN THE EXAM?........................................................................................................................

The PE Mechanical exam is a closed-book exam. You will be provided with a searchable electronic copy of the NCEES Handbook. This is the only reference material you can use during the exam. The PPI Learning Hub (ppi2pass.com) simulates exam day experience by allowing you to upload your NCEES Handbook PDF to use as you prepare with its Practice Exams.

WHAT ABOUT CALCULATORS?........................................................................................................................

The exam requires use of a scientific calculator. However, it may not be obvious that you should bring a spare calculator with you and leave it in your locker during the examination. It is always unfortunate when an examinee is not able to finish because his or her calculator stopped working for some unknown reason.

To protect the integrity of its exams, NCEES has banned communicating and text-editing calculators from the exam site. NCEES provides a list of calculator models acceptable for use during the exam. Calculators not included in the list are not permitted. Check the current list of permissible devices at the PPI website (ppi2pass.com).

The exam has not been optimized for any particular brand or type of calculator. In fact, for most calculations, a $15 scientific calculator will produce results as satisfactory as those from a $200 calculator. There are definite benefits to having built-in statistical functions, graphing, unit-conversion, and equation-solving capabilities. However, these benefits are not so great as to give anyone an unfair advantage.

It is essential that a calculator used for the mechanical PE examination have the following functions.

- trigonometric and inverse trigonometric functions
- hyperbolic and inverse hyperbolic functions
- \( \pi \)
- \( \sqrt{x} \) and \( x^2 \)
- both common and natural logarithms
- \( y^x \) and \( e^x \)

For maximum speed and utility, your calculator should also have or be programmed for the following functions.

- interpolation
- extracting roots of quadratic and higher-order equations
- calculating factors for economic analysis questions

You may not share calculators with other examinees. Be sure to take your calculator with you whenever you leave the examination room for any length of time.
Laptop and tablet computers (including the iPad®), and electronic readers (e.g., Nook® and Kindle®), are not permitted in the examination.

**ARE CELL PHONES PERMITTED?**

You may not possess or use a walkie-talkie, cell phone, or other communications or text-messaging device during the exam, regardless of whether it is on.

**HOW YOU SHOULD GUESS**

There is no deduction for incorrect answers, so guessing is encouraged. However, since NCEES produces defensible licensing exams, there is no pattern to the placement of correct responses. Since the quantitative responses are sequenced according to increasing values, the placement of a correct answer among other numerical distractors is a function of the distractors, not of some statistical normalizing routine. Therefore, it is irrelevant whether you choose all “A,” “B,” “C,” or “D” when you get into guessing mode during the last minute or two of the exam period.

The proper way to guess is as an engineer. You should use your knowledge of the subject to eliminate illogical answer choices. Illogical answer choices are those that violate good engineering principles, that are outside normal operating ranges, or that require extraordinary assumptions. Of course, this requires you to have some basic understanding of the subject in the first place.

Otherwise, it’s back to random guessing. That’s the reason that the minimum passing score is higher than 25%.

You won’t get any points using the “test-taking skills” that helped you in college—the skills that helped with tests prepared by amateurs. You won’t be able to eliminate any [verb] answer choices from “Which [noun] . . .” questions. You won’t find problems with options of the “more than 50” and “less than 50” variety. You won’t find one answer choice among the four that has a different number of significant digits, or has a verb in a different tense, or has some singular/plural discrepancy with the stem. The distractors will always match the stem, and they will be logical.

**HOW IS THE EXAM GRADED AND SCORED?**

The maximum number of points you can earn on the mechanical engineering PE exam is 80. The minimum number of points for passing (referred to by NCEES as the cut score) varies from exam to exam. The cut score is determined through a rational procedure, without the benefit of knowing examinees’ performance on the exam. That is, the exam is not graded on a curve. The cut score is selected based on what you are expected to know, not based on passing a certain percentage of engineers. Each of the questions is worth one point. Grading is straightforward—either you get the question right or you don’t. If you mark two or more answers for the same problem, no credit is given for the problem.

Your score is based on the number of correct answers you selected. It is converted to a scaled score which represents your ability compared to the minimum ability established for the exam. Within 7 to 10 days of taking the exam, you will receive an email from NCEES notifying you to view your results in your MyNCEES account.

If you fail, you will also receive a diagnostic report showing your performance in each subject area.

**HOW IS THE CUT SCORE ESTABLISHED?**

The raw cut score may be established by NCEES before or after the exam is administered. Final adjustments may be made following the exam date.

NCEES uses a process known as the modified Angoff procedure to establish the cut score. This procedure starts with a small group (the cut score panel) of professional engineers and educators selected by NCEES. Each individual in the group reviews each problem and makes an estimate of its difficulty. Specifically, each individual estimates the number of minimally qualified engineers out of a hundred examinees who should know the correct answer to the problem. (This is equivalent to predicting the percentage of minimally qualified engineers who will answer correctly.)

Next, the panel assembles, and the estimates for each problem are openly compared and discussed. Eventually, a consensus value is obtained for each. When the panel has established a consensus value for every problem, the values are summed and divided by 100 to establish the cut score.

Various minor adjustments can be made to account for examinee population (as characterized by the average performance on any equater questions) and any flawed problems. Rarely, security breaches result in compromised problems or examinations. How equater questions, examination flaws, and security issues affect examinee performance is not released by NCEES to the public.

**WHAT IS THE PASSING RATE?**

Within a few percentage points, 69–77% of first-time takers pass the mechanical engineering PE exams. The passing rate for repeat exam takers is two-thirds of the first-time taker passing rate.
CHEATING AND EXAM SUBVERSION

There aren’t very many ways to cheat on a computer-based test. You shouldn’t try to smuggle your cell phone, camera, or notebook into the exam, or anything else that could be used to capture a record of the exam problems.

NCEES regularly reuses good problems that have appeared on previous exams. Therefore, examination integrity is a serious issue with NCEES, which goes to great lengths to make sure nobody copies the questions. You may not keep your scratch paper or enter text of questions into your calculator.

NCEES has become increasingly unforgiving about loss of its intellectual property. NCEES routinely prosecutes violators and seeks financial redress for loss of its examination problems, as well as invalidating any engineering license you may have earned by taking one of its examinations while engaging in prohibited activities. Your state board may impose additional restrictions on your right to retake any examination if you are convicted of such activities. In addition to tracking down the sources of any examination problem compilations that it becomes aware of, NCEES is also aggressive in pursuing and prosecuting examinees who disclose the contents of the exam in internet forum and “chat” environments.

Your constitutional right to free speech and expression will not protect you from civil prosecution for violating the nondisclosure agreement that NCEES requires you to sign before taking the examination. If you wish to participate in a dialog about a particular exam subject, you must do so in such a manner that does not violate the essence of your nondisclosure agreement. This requires decoupling your discussion from the examination and reframing the question to avoid any examination particulars.

PART 3: HOW TO PREPARE FOR AND PASS THE PE EXAM IN MECHANICAL ENGINEERING

WHAT SHOULD YOU STUDY?

The exam covers many diverse subjects. Strictly speaking, you don’t have to study every subject on the exam in order to pass. However, the more subjects you study, the more you’ll improve your chances of passing. You should decide early in the preparation process which subjects you are going to study. The strategy you select will depend on your background. Following are the four most common strategies.

A broad approach is the key to success for examinees who have recently completed their academic studies. This strategy is to review the fundamentals in a broad range of undergraduate subjects (which means studying all or most of the chapters in this book). The examination includes enough fundamentals problems to make this strategy worthwhile. Overall, it’s the best approach.

Engineers who have little time for preparation tend to concentrate on the subject areas in which they hope to find the most problems. By studying the list of examination subjects, some have been able to focus on those subjects that will give them the highest probability of finding enough problems that they can answer. This strategy works as long as the examination cooperates and has enough of the types of questions they need. Too often, though, examinees who pick and choose subjects to review can’t find enough problems to complete the exam. The PPI Mechanical Learning Hub offers diagnostic exams, hundreds of exam-like practice problems, and realistic practice exams to help you to assess, review, and practice.

Engineers who have been away from classroom work for a long time tend to concentrate on the subjects in which they have had extensive experience, in the hope that the exam will feature lots of problems in those subjects. This method is seldom successful.

Some engineers plan on modeling their solutions from similar problems they have found in textbooks, collections of solutions, and old exams. These engineers often spend a lot of time compiling and indexing the example and sample problem types in all of their books. This is not a legitimate preparation method, and it is almost never successful.

DO YOU NEED A CLASSROOM PREP COURSE?

Approximately 60% of first-time PE examinees take an instructor-led prep course of some form. Live online courses, as well as previously recorded lessons of various types, are available for some or all of the exam topics. Live courses and instructor-moderated courses provide several significant advantages over self-directed study, some of which may apply to you.

- A course structures and paces your review. It ensures that you keep going forward without getting bogged down in one subject.
- A course focuses you on a limited amount of material. Without a course, you might not know which subjects to study.
- A course provides you with the questions you need to solve. You won’t have to spend time looking for them.
- A course spoon-feeds you the material. You may not need to read the book!
- The course instructor can answer your questions when you are stuck.
You probably already know if any of these advantages apply to you. A prep course will be less valuable if you are thorough, self-motivated, and highly disciplined.

**HOW LONG SHOULD YOU STUDY?**

We’ve all heard stories of the person who didn’t crack a book until the week before the exam and still passed it with flying colors. Yes, these people really exist. However, I’m not one of them, and you probably aren’t either. In fact, after having taught thousands of engineers in my own classes, I’m convinced that these people are as rare as the ones who have taken the exam five times and still can’t pass it.

A thorough review takes approximately 300 hours. Most of this time is spent solving problems. Some of it may be spent in class; some is spent at home. Some examinees spread this time over a year. Others try to cram it all into two months. Most classroom prep courses last for three or four months. The best time to start studying will depend on how much time you can spend per week.

**ADDITIONAL REVIEW MATERIAL**

In addition to this book and its accompanying *Mechanical Engineering Practice Problems*, PPI can provide you with many targeted references and study aids, some of which are listed here. All of the books have stood the test of time, which means that examinees continually report their usefulness and that PPI keeps them up-to-date.

- *Mechanical Engineering HVAC and Refrigeration Practice Exam*
- *Mechanical Engineering Machine Design and Materials Practice Exam*
- *Mechanical Engineering Thermal and Fluid Systems Practice Exam*
- *PPI Learning Hub, ppi2pass.com*
- *Engineering Unit Conversions*
- *Thermal and Fluids Systems Reference Manual for the Mechanical PE Exam*

**SHOULD YOU LOOK FOR OLD EXAMS?**

The traditional approach to preparing for standardized tests includes working sample tests. However, NCEES does not release old tests or questions after they are used. Therefore, there are no official questions or tests available from legitimate sources. NCEES publishes booklets of sample questions and solutions to illustrate the format of the exam. However, these questions have been compiled from various previous exams, and the resulting publication is not a true “old exam.” Furthermore, NCEES sometimes constructs its sample questions books from questions that have been pulled from active use for various reasons, including poor performance. Such marginal questions, while accurately reflecting the format of the examination, are not always representative of actual exam subjects.

**WHAT SHOULD YOU MEMORIZE?**

In theory, everything you need will be provided in the *NCEES Handbook*, so you can get by without memorizing anything.

In practice, you may find there are some very common, basic equations, such as the formula for the area of a circle, that are not given anywhere in the *NCEES Handbook*. You can recognize these equations in this book because they are not given in blue. You probably already have these memorized, but if you don’t, make a note to know them by exam day.

You can speed up your problem solving significantly if you don’t have to look up the conversion from ft-lbf/sec to horsepower, the definition of the sine of an angle, and the chemical formula for carbon dioxide. But you don’t really have to memorize these simple things. As you work practice problems, you will automatically memorize the things that you come across more than a few times.

**DO YOU NEED A STUDY PLAN?**

The PPI Mechanical Learning Hub allows you to create a personalized study plan to plan your time and topics. It takes the guesswork out of what to study and for how long. PPI also offers a prep course for each of the three PE mechanical exams, which paces the review and practice of the important exam topics.

It is important that you develop and adhere to a study outline and schedule. Once you have decided which subjects you are going to study, you can allocate the available time to those subjects in a manner that makes sense to you. If you are not taking a classroom prep course (where the order of preparation is determined by the lectures), you should make an outline of subjects for self-study to use for scheduling your preparation.

**HOW YOU CAN MAKE YOUR REVIEW REALISTIC**

In the exam, you must be able to quickly recall solution procedures, formulas, and important data. You must remain sharp for eight hours or more. When you played a sport back in school, your coach tried to put you in game-related situations. Preparing for the PE exam isn’t much different from preparing for a big game. Some part of your preparation should be realistic and representative of the examination environment.
There are several things you can do to make your review more representative. The most important is to refer to the NCEES Handbook frequently as you study and use it as your sole reference as you solve practice problems. Being able to find what you need quickly in the NCEES Handbook is crucial to performing well on the exam.

Learning to use your time wisely is one of the most important lessons you can learn during your review. You will undoubtedly encounter questions that end up taking much longer than you expected. In some instances, you will cause your own delays by spending too much time looking through books for things you need (or just by looking for the books themselves!). Other times, the questions will entail too much work. Learn to recognize these situations so that you can make an intelligent decision about skipping such questions in the exam.

WHAT TO DO A FEW DAYS BEFORE THE EXAM

There are a few things you should do a week or so before the examination. You should arrange for childcare and transportation. Since the examination does not always start or end at the designated time, make sure that your childcare and transportation arrangements are flexible.

If it’s convenient, visit the exam location in order to find the building, parking areas, examination room, and restrooms. If it’s not convenient, you may find driving directions and/or site maps on the web.

Take the battery cover off your calculator and check to make sure you are bringing the correct size replacement batteries. Some calculators require a different kind of battery for their “permanent” memories. Put the cover back on and secure it with a piece of masking tape. Write your name on the tape to identify your calculator.

If your spare calculator is not the same as your primary calculator, spend a few minutes familiarizing yourself with how it works. In particular, you should verify that your spare calculator is functional.

WHAT TO DO THE DAY BEFORE THE EXAM

Take the day before the examination off from work to relax. Do not cram the last night. A good night’s sleep is the best way to start the examination. If you live a considerable distance from the examination site, consider getting a hotel room in which to spend the night.

Calculate your wake-up time and set the alarms on two bedroom clocks. Select and lay out your clothing items. (Dress in layers.) Select and lay out your breakfast items.

If it’s going to be hot on exam day, put your (plastic) bottles of water in the freezer.

Make sure you have gas in your car and money in your wallet.

WHAT TO DO THE DAY OF THE EXAM

You should arrive at least 30 minutes before the examination starts. This will allow time for finding a convenient parking place, making room and seating changes, and calming down. Be prepared, though, to find that the examination room is not open or ready at the designated time.

You also will need to check in and verify your identity. Any items that you bring that are not approved for the testing room, including cell phone, watch, wallet, food, or drink, will need to be stored in a test center locker.

WHAT TO DO DURING THE EXAM

All of the procedures typically associated with timed, proctored, computer-graded assessment tests will be in effect when you take the PE examination.

Listen carefully to everything the proctors say. Do not ask your proctors any engineering questions. Even if they are knowledgeable in engineering, they will not be permitted to answer your questions.

If there are any questions that you think were flawed, in error, or unsolvable, ask a proctor for a “reporting form” on which you can submit your comments. Follow your proctor’s advice in preparing this document.

WHAT ABOUT EATING AND DRINKING IN THE EXAM ROOM?

No food or beverages are allowed in the exam room. You may, however, leave them in your locker to have during the break in the middle of the exam.

You may also take an unscheduled break during the exam by raising your hand to notify a proctor. You’ll be allowed to visit your locker and consume any food or beverage you stored there. However, any break time you take during the exam is lost; you won’t get to stop the clock until you get back to the computer.

HOW TO SOLVE MULTIPLE-CHOICE QUESTIONS

When you begin each session of the exam, observe the following suggestions:

- Do not spend an inordinate amount of time on any single question. If you have not answered a question in a reasonable amount of time, make a note of it and move on.
- Five minutes before the end of each four-hour session, use the remaining time to guess at all of the remaining questions. Odds are that you will be successful with about 25% of your guesses, and these points will more than make up for the few points
that you might earn by working during the last five minutes.

- Make mental notes about any questions for which you cannot find a correct response, that appears to have two correct responses, or that you believe have some technical flaw. Errors in the exam are rare, but they do occur. Such errors are usually discovered during the scoring process and discounted from the examination, so it is not necessary to tell your proctor, but be sure to mark the one best answer before moving on.

**SOLVE QUESTIONS CAREFULLY**

Many points are lost to carelessness. Keep the following items in mind when you are solving the end-of-chapter questions. Hopefully, these suggestions will be automatic in the exam.

- Did you recheck your mathematical equations?
- Did the units cancel out in your calculations?
- Did you convert between radius and diameter?
- Did you convert between feet and inches?
- Did you convert from gage to absolute pressures?
- Did you convert between pounds and kips, or kPa and Pa?
- Did you use the universal gas constant that corresponds to the set of units used in the calculation?
- Did you recheck all data obtained from other sources, tables, and figures? (In finding the friction factor, did you enter the Moody diagram at the correct Reynolds number?)

**SHOULD YOU TALK TO OTHER EXAMINEES AFTER THE EXAM?**

The jury is out on this question. People react quite differently to the examination experience. Some people are energized. Most are exhausted. Some people need to unwind by talking with other examinees, describing every detail of their experience, and dissecting every examination question. Other people need lots of quiet space, and prefer to just get into a hot tub to soak and sulk. Most engineers, apparently, are in this latter category.

Since everyone who took the exam has seen it, you will not be violating your “oath of silence” if you talk about the details with other examinees immediately after the exam. It’s difficult not to ask how someone else approached a question that had you completely stumped. However, keep in mind that it is very disquieting to think you answered a question correctly, only to have someone tell you where you went wrong.

To ensure you do not violate the nondisclosure agreement you signed before taking the exam, make sure you do not discuss any exam particulars with people who have not also taken the exam.

**AFTER THE EXAM**

Yes, there is something to do after the exam. Most people return home, throw their exam “kits” into the corner, and collapse. A week later, when they can bear to think about the experience again, they start integrating their exam kits back into their normal lives and all of the miscellaneous stuff you brought with you to the exam is put back wherever it came from.

Here’s what I suggest you do as soon as you get home, before you collapse.

- Thank your family for helping you during your preparation.
- Take any paperwork you received on exam day out of your pocket, purse, or wallet. Put this inside your Mechanical Engineering Reference Manual.
- Reflect on any statements regarding exam secrecy to which you signed your agreement in the exam.
- Call your employer and tell him/her that you need to take a mental health day off on Monday.

A few days later, when you can face the world again, do the following.

- Make notes about anything you would do differently if you had to take the exam over again.
- Consolidate all of your application paperwork, correspondence to/from your state, and any paperwork that you received on exam day.
- If you took a live prep course, call or email the instructor (or write a note) to say “Thanks.”
- Return any books you borrowed.
- Write thank-you notes to all of the people who wrote letters of recommendation or reference for you.
- Find and read the chapter in this book that covers ethics. There were no ethics questions on your PE exam, but it doesn’t make any difference. Ethical behavior is expected of a PE in any case. Spend a few minutes reflecting on how your performance (obligations, attitude, presentation, behavior, appearance, etc.) might be about to change once you are licensed. Consider how you are going to be a role model for others around you.
- Put all of your review books, binders, and notes someplace where they will be out of sight.
FINALLY

By the time you’ve “undone” all of your preparations, you might have thought of a few things that could help future examinees. If you have any sage comments about how to prepare, any suggestions about what to do in or bring to the exam, any comments on how to improve this book, or any funny anecdotes about your experience, I hope you will share these with me. By this time, you’ll be the “expert,” and I’ll be your biggest fan.

AND THEN, THERE’S THE WAIT...

Waiting for the exam results is its own form of mental torture.

Yes, I know the exam grading should be almost instantaneous. But, you are going to wait, nevertheless. There are many reasons for the delay.

Although the actual machine grading “only takes seconds,” consider the following facts: (a) NCEES prepares multiple exams for each administration, in case one becomes unusable (i.e., is inappropriately released) before the exam date. (b) Since the actual version of the exam used is not known until after it is finally given, the cut-score determination occurs after the exam date.

I wouldn’t be surprised to hear that NCEES receives dozens, if not hundreds, of claims from well-meaning examinees who were 100% certain that the exams they took were seriously flawed to some degree—that there wasn’t a correct answer for such-and-such question—that there were two answers for such-and-such question—or even, perhaps, that such-and-such question was missing from their exam booklet altogether. Each of these claims must be considered as a potential adjustment to the cut score.

After the individual exams are scored, the results are analyzed in a variety of ways. Some of the analysis looks at passing rates by such delineators as degree, major, university, site, and state. Part of the analysis looks for similarities between physically adjacent examinees (to look for cheating). Part of the analysis looks for exam sites that have statistically abnormal group performance. And, some of the analysis looks for exam questions that have a disproportionate fraction of successful or unsuccessful examinees. All of these steps have to be completed for 100% of the examinees before any results can go out.

NCEES releases the results electronically 7 to 10 days after the exam.

There is no pattern to the public release of results. None. The exam results are not released to all states simultaneously. (The states with the fewest examinees often receive their results soonest.) They are not released by discipline. They are not released alphabetically by state or examinee name. The people who failed are not notified first (or last). Your coworker might receive his or her notification today, and you might be waiting another three weeks for yours.

Some states post the names of the successful examinees, or unsuccessful examinees, or both on their official state websites before the results go out. Others update their websites after the results go out. Some states don’t list much of anything on their websites.

AND WHEN YOU PASS...

[ ] Celebrate.
[ ] Notify the people who wrote letters of recommendation or reference for you.
[ ] Ask your employer for a raise.
[ ] Tell the folks at PPI (who have been rootin’ for you all along) the good news.