Design for Electrical and Computer Engineers

Theory, Concepts, and Practice

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0.1 About the Authors

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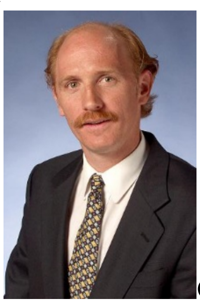

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Contents

0.2 Preface

This book is written for undergraduate students and teachers engaged in electrical and computer engineering (ECE) design projects, primarily in the senior year. The objective of the text is to provide a treatment of the design process in ECE with a sound academic basis that is integrated with practical application. This combination is necessary in design projects because students are expected to apply their theoretical knowledge to bring useful systems to reality. This topical integration is reflected in the subtitle of the book: Theory, Concepts, and Practice. Fundamental theories are developed whenever possible, such as in the chapters on functional design decomposition, system behavior, and design for reliability. Many aspects of the design process are based upon time-tested concepts that represent the generalization of successful practices and experience. These concepts are embodied in processes presented in the book, for example, in the chapters on needs identification and requirements development. Regardless of the topic, the goal is to apply the material to practical problems and design projects. Overall, we believe that this text is unique in providing a comprehensive design treatment for ECE, something that is sorely missing in the field. We hope that it will fill an important need as capstone design projects continue to grow in importance in engineering education.

We have found that there are three important pieces to completing a successful design project. The first is an understanding of the design process, the second is an understanding of how to apply technical design tools, and the third is successful application of professional skills. Design teams that effectively synthesize all three tend to be far more successful than those that don't. The book is organized into three parts that support each of these areas.

The first part of the book, the *Design Process*, embodies the steps required to take an idea from concept to successful design. At first, many students consider the design process to be obvious. Yet it is clear that failure to understand and follow a structured design process often leads to problems in development, if not outright failure. The design process is a theme that is woven throughout the text; however, its main emphasis is placed in the first four chapters. Chapter 1 is an introduction to design processes in different ECE application domains. Chapter 2 provides guidance on how to select projects and assess the needs of the customer or user. Depending upon how the design experience is structured, both students and faculty may be faced with the task of selecting the project concept. Further, one of the important issues in the engineering design is to understand that systems are developed for use by an end-user, and if not designed to properly meet that need, they will likely fail. Chapter 3 explains how to develop the Requirements Specification along with methods for developing and documenting the requirements. Practical examples are provided to illustrate these methods and techniques. Chapter 4 presents concept generation and evaluation. A hallmark of design is that there are many potential solutions to the problem. Designers need to creatively explore the space of possible solutions and apply judgment to select the best one from the competing alternatives.

The second part of the book, *Design Tools*, presents important technical tools that ECE designers often draw upon. Chapter 5 emphasizes system engineering concepts including the well known functional decomposition design technique and applications in a number of ECE problem domains. Chapter 6 provides methods for describing system behavior, such as flowcharts, state diagrams, data flow diagrams and a brief overview of the Unified Modeling Language (UML). Chapter 7 covers important issues in testing and provides different viewpoints on testing throughout the development cycle. Chapter 8 addresses reliability theory in design, and reliability at both the component and system level is considered.

The third part of the book focuses on *Professional Skills*. Designing, building, and testing a system is a process that challenges the best teams, and requires good communication and project management skills. Chapter 9 provides guidance for effective teamwork. It provides an overview of pertinent research on teaming and distills it into a set of heuristics. Chapter 10 presents traditional elements of project planning, such as the work breakdown structure, network diagrams, and critical path estimation. It also addresses how to estimate manpower needs for a design project. Chapter 11 addresses ethical considerations in both system design and professional practice. Case studies for ECE scenarios are examined and analyzed using the IEEE (Institute of Electrical and Electronics Engineers) Code of Ethics as a basis. The book concludes with Chapter 12, which contains guidance for students preparing for oral presentations, often a part of capstone design projects.

Features of the Book

This book aims to guide students and faculty through the steps necessary for the successful execution of design projects. Some of the features are listed below.

- Each chapter provides a brief motivation for the material in the chapter followed by specific learning objectives.

- There are many examples throughout the book that demonstrate the application of the material.
- Each end-of-chapter problem has a different intention. Review problems demonstrate comprehension of the material in the chapter. Application problems require the solution of problems based upon the material learned in the chapter. Design problems are directly applicable to design projects and are usually tied in with the Project Application section.
- Nearly all chapters contain a Project Application section that describes how to apply the material to a design project.
- Some chapters contain a Guidance section that represents the author's advice on application of the material to a design project.
- Checklists are provided for helping students assess their work.
- There are many terms used in design whose meaning needs to be understood. The text contains a glossary with definitions of design terminology. The terms defined in the glossary (Appendix A) are indicated by ***italicized-bold*** highlighting in the text.
- All chapters conclude with a Summary and Further Reading section. The aim of the Further Reading portion is to provide pointers for those who want to delve deeper into the material presented.
- The book is structured to help programs demonstrate that they are meeting the ABET (accreditation board for engineering programs) accreditation criteria. It provides examples of how to address constraints and standards that must be considered in design projects. Furthermore, many of the professional skills topics, such as teamwork, ethics, and oral presentation ability, are directly related to the ABET Educational Outcomes. The requirements development methods presented in Chapter 3 are valuable tools for helping students perform on cross-functional teams where they must communicate with non-engineers.
- An instructor's manual is available that contains not only solutions, but guidance from the authors on teaching the material and managing student design teams. It is particularly important to provide advice to instructors since teaching design has unique challenges that are different than teaching engineering science oriented courses that most faculty are familiar with.

- PowerPoint™ presentations are available for instructors through McGraw-Hill

- There are a number of complete case study student projects available in electronic form for download by both students and instructors and available at. These projects have been developed using the processes provided in this book.

How to Use this Book

There are several common models for teaching capstone design, and this book has the flexibility to serve different needs. Particularly, chapters from the Professional Skills section can be inserted as appropriate throughout the course. Recommended usage of the book for three different models of teaching a capstone design course is presented.

- **Model I.** This is a two-semester course sequence. In the first semester, students learn about design principles and start their capstone projects. This is the model that we follow. In the first semester the material in the book is covered in its entirety. The order of coverage is typically Chapters 1–3, 9, 4–6, 10–11, and 7–8. Chapter 9 (Teams and Teamwork) is covered immediately after the projects are identified and the teams are formed. Chapters 10 (Project Management) and 11 (Ethical and Legal Issues) are covered after the system design techniques in Chapters 5 and 6 are presented. Students are in a good position to create a project plan and address ethical issues in their designs after learning the more technical aspects of design. Chapter 12 (Oral Presentations) is assigned to students to read before their first oral presentation to the faculty. The course concludes with principles of testing and system reliability (Chapter 7 and 8). We assign a good number of end-of-chapter problems and have quizzes throughout the semester. By the end of the first semester, design teams are expected to have completed development of the requirements, the high-level or architectural design, and developed a project plan. In the second semester, student teams implement and test their designs under the guidance of a faculty advisor.

- **Model II**. This two-semester course sequence is similar to Model I with the difference being that the first semester is a lower credit course (often one credit) taught in a seminar format. In this model chapters can be selected to support the projects. Some of the core chapters for consideration are Chapters 1–5, which take the student from project selection to functional design, and Chapters 9–11 on teamwork, project management, and ethical issues. Other chapters could be covered at the instructor's discretion. The use of end-of-chapter problems would be limited, but the project application sections and example problems in the text would be useful in guiding students through their projects.

- **Model III**. This is a one-semester design sequence. Here, the book would be used to guide students through the design process. Chapters for consideration are 1–5 and 9–10, which provide the basics of design, teamwork, and project management. The project application sections and problems could be used as guidance for the project teams.

Acknowledgements

Undertaking this work has been a challenging experience and could not have been done without the support of many others. First, we thank our families for their support and patience. They have endured many hours and late evenings that we spent researching and writing. Melanie Ford is to be thanked for her diligent proofreading efforts. Bob Simoneau, the former Director of the Penn State Behrend School of Engineering, has been a great supporter of the book and has also lent his time in reading and providing comments. Our school has a strong design culture, and this book would not have happened without that emphasis; our faculty colleagues need to be recognized for developing that culture. Jana Goodrich and Rob Weissbach are two faculty members with whom we have collaborated on other courses and projects. They have influenced our thinking in this book, particularly in regard to project selection, requirements development, cost estimation, and teamwork. We must also recognize the great collaborative working environment that exists at Penn State Behrend, which has allowed this work to flourish. Our students have been patient in allowing us to experiment with different material in the class and on the projects. Examples of their work are included in the book and are greatly appreciated. John Wallberg contributed the disk drive diagnostics case study in Chapter 11 that we have found very useful for in-class discussions. John developed this while he was a student at MIT. Thanks to Anne Maloney for her copyediting of the manuscript. The following individuals at McGraw-Hill have been very supportive and we thank them for their efforts to make this book a reality – Carlise Stembridge, Julie Kehrwald, Darlene Schueller, Craig Marty, Kris Tibbetts, and Mike Hackett.

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We hope that you find this book valuable, and that it motivates you to create great designs. We welcome your comments and input. Please feel free to email us.

Ralph M. Ford,

Chris S. Coulston,

Chapter 1

Oral Presentations

Nothing should be explained in a way that it cannot be understood by an intelligent 12 year old.—Albert Einstein

We can all probably remember the anticipation of our first oral presentation—the sweaty palms, butterflies in the stomach, and the pressure of trying to remember all the points to be made. Then there is the fear associated with standing up in front of peers or teachers and presenting ideas to have them openly criticized. According to a 1973 London Times survey, Americans are more afraid of speaking in front of groups than dying. Perhaps this is due to the fact that although people know they will die someday, the danger associated with giving a presentation is more imminent and a greater concern. Somewhere in the capstone design experience, it is likely that you will have to make an oral presentation. Examples are the project proposal, a mid-term design review, and the final presentation. The ability to communicate your ideas is important beyond your academic career, since practicing engineers are often required to make oral presentations. Further, your overall ability to communicate influences how others will accept your ideas and act upon them—those who communicate clearly are held in high regard by their peers and tend to advance more quickly. The good news is that there is help to overcome the fear of oral presentations. With practice and adherence to some basic principles, one can become a competent, if not excellent, communicator.

Learning Objectives

By the end of this chapter, the reader should:

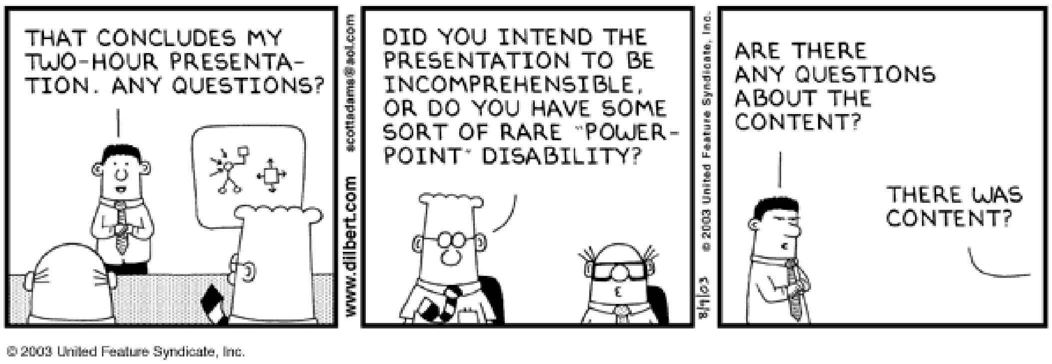

Figure 1.1: PowerPoint disability. (Dilbert © United Feature Syndicate. Reprinted by permission.)

- Understand how people evaluate oral presentations.
- Understand common elements of a technical presentation.
- Be able to assemble an effective presentation.

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1.1 How People Evaluate Presentations

It is informative to understand how your audience responds to and evaluates oral presentations. Listening to a presentation is strongly associated with what is referred to as right-brain activity. Right-brain activity is dominated by emotion and intuition, while left-brain activity is associated with logical thinking and reason. This is an oversimplified model of the brain, but the point is that emotion and intuition are important elements that people rely on when evaluating a presentation.

There are three elements, known as the "three V's," that constitute a presentation: the verbal, the vocal, and the visual. Verbal is what the speaker says—the actual words and content that come out of the speaker's mouth. Vocal is indicative of how it is said, and includes pitch, enthusiasm, inflection, and intonation. Visual is what the audience sees—the speaker's appearance, eye contact, posture, facial expressions, and gestures. All three factors go into the evaluation of speakers, but what is the relative importance of each? The results of a 1964 UCLA study by Dr. Albert Mehrabian (who has bachelors and masters degrees in engineering and a Ph.D. in psychology) indicates that the impact of the three elements is 7% verbal, 38% vocal, and 55% visual. That seems disappointing because we would like to think that the content of the presentation is most important. Realize that the numbers come from a simplified study and it is likely that that the percentages would be different for a highly technical audience. The point is that content is important, but the other elements can't be ignored. If the visual and vocal aspects of the presentation are poor, it will be perceived negatively and make it difficult for the audience to accept and pay attention to the information presented.

Here is another consideration to think about the next time you make a presentation or meet somebody. In the first seven seconds of meeting someone, people typically form a great number of subconscious opinions about the person they meet [Bai81]. This includes the person's income level, education level, competence, character, trustworthiness, personality, confidence, intelligence, work ethic, and dependability. Based on what factors are the opinions made? They include appearance, dress, posture, and speech patterns.

1.2 Preparing the Presentation

In order to make an effective presentation, the presenter must understand the subject matter (substance counts), understand the needs of the audience, and prepare the presentation. The remainder of this section provides guidance for preparing the presentation.

Analyze the Audience

An oral presentation is for the benefit of the audience, not the presenter. It is necessary to analyze and understand the audience's needs and prepare the presentation to meet them. For example, a presentation for engineering professors would likely be different from one for your family and friends. Analyzing the audience is no different than the process that one goes through when writing a document. Some questions to ask in this process are [Bai81]:

- What are they interested in?
- What do they want from your talk?
- What does the audience already know about my subject?

- What don't they know?
- What is the attitude of the audience towards me and my subject?
- What are the values of the audience?
- What do you want them to know or learn?

Understanding the needs of the audience and putting their interests first establishes credibility so that they are more willing to accept the content of the presentation.

Before creating the presentation, identify the main points that the audience should take away from it. A rule of thumb is to identify three main points for a talk, as people tend to forget more than that. Although it is not a strict rule, keep the number of points in that range, say two to five. Once the points are identified, organize the presentation to support them.

Organize the Presentation

Just like a story, a presentation has an introduction, a body, and a conclusion. This is encapsulated in the often-heard wisdom for presentations to "tell them what you are going to tell them" (the introduction), "tell it to them" (the body), and "tell them what you just told them" (the conclusion).

The introduction is absolutely critical—if the audience does not understand the presentation from the outset, they will tune out. Einstein's advice that nothing should be explained in such a way that it cannot be understood by an intelligent 12 year old is particularly relevant here. Take time to explain the problem in simple terms. Part of an effective introduction is obtaining the interest of the audience. There are many ways to accomplish this, and examples include the use of rhetorical questions or the narration of an experience that the audience can relate to. This should have to do in some way with the information being presented. Overall, the objective is to motivate the audience by describing what is being presented and why it is important. After giving motivation of the problem, an overview of the talk can be provided. The overview should be relevant to the problem at hand, not a generic one that can apply to virtually any presentation.

Structure the body of the presentation to support the main points. This is done by having a group of two to four related slides that support each of the main points. The first slide of the group provides some key ideas, followed by the remaining slides that go into more detail on the particular point. Don't make the talk unnecessarily technical or use a lot of jargon.

This does not mean that it should not have technical content, but that judgment should be exercised in presenting the right amount of detail. The level of technical detail depends upon the education and experience of the audience. If it is necessary to use jargon or acronyms, make sure that they are defined for the audience. Consider alternative ways of explaining things. The use of analogies is particularly powerful when explaining complex and abstract material. One strategy is to increase the level of complexity as the talk proceeds. That way, much of the early material will be understandable to the majority of the audience, while the latter more complex material may only be understood by a small fraction. Everybody will then leave the presentation with some understanding of the content.

In a typical engineering classroom lecture, the professor usually goes through many steps in defining and deriving equations. Realize that the goals of a classroom lecture are very different from that of an oral presentation. When working with equations, don't derive or give too many intermediate steps, unless that is the point of the presentation. Provide assumptions, selected intermediate equations, and the important results. Audiences generally assume you have done your homework and derived the equations properly. There is a tendency to present equations, vaguely refer to them, and then move on. Equations should be presented for a reason, so talk about them and describe their significance. Every equation has its own story; it is the presenter's job to tell it. The same is also true of graphs and plots.

The conclusion provides the opportunity to summarize and emphasize the main points of the presentation. Again, tell them what you told them by reviewing the important points and conclusions. That way if somebody was lost during the presentation, they can understand the importance of the work. If there are recommendations to be made for future action, address them here. The conclusion is also an opportunity to explain the next steps for the project.

Lay Out the Slides

Below are pointers for the layout of the slide content.

- *Use a large font.* This ensures that information on the slides can easily be seen by the audience. 24 point or greater font is typically sufficient.

- *Have a goal of five-to-seven bullet points per page.* Avoid the tendency to cram as much information as possible on a page, which is often done so that the presenter does not neglect any material. Avoid this, and use five to seven bullet points to guide the discussion. Presentation software packages, such as Microsoft PowerPoint™, allow you to introduce bullet items one at a time, which help to keep the discussion on track.

- *Avoid fancy graphics and special effects that add no value.* Presentation packages allow the addition of fancy features, such as spiraling text and sound effects. They add little to the presentation and when overused distract from the content. The content and material are what matter the most, not fancy formatting and special effects. To quote Edward Tuft, professor emeritus at Yale,

  Power Corrupts, PowerPoint Corrupts Absolutely.

  His point is that fancy graphics and features are used far too much with PowerPoint presentation software, and that this overpowers both the content and the audience. [Tuf03].

- *Group slides together to make a major point.* Make the first slide the general one with key statements. The following ones should have more detailed information supporting the point.

- *Do not create a canned talk or speech.* That is acceptable in some fields, but not in engineering and science where a more extemporaneous style is the norm. Let the bullet points and other material on the slides serve as guides for what to say. Avoid the use of cue cards and do not just read directly from the slides for the presentation.

Meet the Time Constraints

Make sure that the presentation falls within the time constraints—the audience will be alienated if it is far too short or too long. The tendency is to exceed the time limit since there is so much information that the presenter wants to convey. You may be abruptly cut off and not be able to conclude the presentation if the time limit is exceeded. Think about this—how would you describe all that you know about electrical or computer engineering in ten minutes? It is challenging, but if you only had ten minutes you would probably give a brief overview of the major accomplishments made in the field. Accept that all of the information can't be conveyed in the given time and use it carefully to highlight the important material.

A heuristic is to take the length of the allotted time in minutes and divide it by two. That provides an estimate of the number of slides to prepare. Once the presentation is prepared, practice to see if it can be presented reasonably in the time allotted. Practice the talk in front of your teammates, boyfriend, girlfriend, mother, or pet rock. Be careful not to over-prepare to the point of sounded scripted. Practice the talk the night before the presentation and only do a brief review of the material right before the talk. Be sure to allow time for the question and answer session that usually occurs at the end of a presentation.

Prepare for the Question and Answer Session

One of the biggest fears of presenters is the dreaded question and answer session. This is where the audience gets to ask questions and possibly expose the presenter for what they don't know. For example, the questioner may ask "*Are you familiar with the work of Johnson and Smith from 1984 in which they proposed exactly the same idea as yours?*"

How do you prepare for this? You must be knowledgeable about the subject, but you don't need to have the answers to every possible question. It is good practice to rephrase questions that are asked for the benefit of you, the audience, and the questioner. Rephrasing the question ensures that you are answering the correct question (how many times have you been annoyed when a teacher answered the wrong question?) and provides time to think and formulate a response. It demonstrates to the questioner that you understand their question and are able to present it in a different format. If the questioner is hostile, make sure that you rephrase the question in a positive light. Rephrasing is also a courtesy for the other members of the audience who may have not heard or understood the question.

Most questions are made in good faith as the questioner is trying to clarify a point or learn more. Sometimes, questioning can become hostile or aggressive. If this happens, make sure not to respond in kind or put the questioner down. The presenter has the position of power and becomes a bully if they do this. Be sure to maintain eye contact with the questioner, smile, and remain relaxed in your responses. If you can't answer the question, admit it and don't try to come up with a phony answer. If the questioner is persistent, offer to discuss it in more detail with them after the presentation.

1.3 Project Application: Design Presentations

Examples of the three presentations that you may make during the design process are listed in Table 12.1. It is a guide of points to consider preparing presentations and should be adjusted to meet particular needs of the situation. The checklist in Table 12.2 is provided to aid in preparing for presentations.

1.4 Summary and Further Reading

During the design process and your professional career, you will need to communicate ideas effectively. One of the most common ways to do this is via an oral presentation. Visual, verbal, and vocal aspects impact the effectiveness of an oral presentation. Although the verbal aspect, or content, is important, the visual and vocal delivery aspects heavily influence the audience's perception and cannot be overlooked. In preparing the presentation, the needs and background of the audience should be taken into consideration and the main points to be conveyed identified. Creating the presentation is much like telling a story—there should be an introduction, a body, and a conclusion that are organized to support the main points. The slides should be grouped to support these points. Concepts should be explained as simply and clearly as possible. Increasing the complexity as the presentation proceeds will allow the presentation to reach all members of the audience to some extent. Practicing the presentation is especially important for novice presenters, and tips were provided for meeting the time constraints and preparing for question sessions.

There are many excellent resources and articles available regarding oral presentations. A concise and humorous article geared for new speakers in the technical fields is *Advice to Beginning Physics Speakers* by James Garland [Gar91]. The IEEE Transactions on Professional Communications journal addresses many aspects of communications including oral presentations. Mindtools (www.mindtools.com) has a section on communication skills that includes a preparation checklist on presentation, delivery, appearance, and visual aids. *A Good Speech is Worth a Thousand Words* by Bert Decker [Dec84] addresses right and left brain thinking as well as the three V's of giving a presentation. The article *How to Overcome Errors in Public Speaking* by John Baird [Bai81] addresses how to analyze the audience, the judgments that are made when meeting a person, the introduction, and conclusion. Other resources used in the preparation of this chapter include: *The Engineering Presentation—Some Ideas on How to Approach and Present It* [Ros93], *Handling a Hostile Audience—With Your Eyes* [Car89], and *How to Speak so that Facts Come Alive* [Ste89]. Many of the references are compiled in the book Writing and Speaking in the Technology Professions: A Practical Guide

Table 1.1: Guide for preparing design presentations. The chapters associated with the points are identified.

Presentation	**Points to Consider in Preparing the Presentation**
Project Proposal	*Introduction.* Provide an overview of the project and address the need, motivation, goals, and objectives. The audience is probably not familiar with the concept and it is important to describe the problem in simple and concise terms (Chapter 2). *Problem Analysis.* Indicate what the current state-of-the-art in the field is regarding the technology. If it is a new product concept, identify similar products that are available and what is unique about this one. If it is a research-oriented project, include the basic theory and address current status of work in this area (Chapter 2). *Requirements Specifications.* Address the engineering requirements and provide a justification for their selection. Describe the standards and constraints that apply to the problem (Chapter 3). *Preliminary Design Options.* Depending upon progress, some preliminary options for the design may have been developed and can be presented here (Chapter 4).
Design Review	*Introduction.* Provide a brief overview of the motivation for the project. *Requirements.* Recap the critical requirements that have to be met. *The Proposed Design.* Present the high-level design. Explain how it works and how the pieces fit together. Include design details of the sub-components and systems. Address how the proposed design meets the engineering requirements. Identify the alternatives investigated (Chapters 4, 5, and 6). *Preliminary Test Results.* Include test and prototype results (Chapter 7). *Project Plan.* By this point (if not earlier), a project plan should be in place, so consider presenting a summary of the plan (schedule, responsibilities, and cost) (Chapter 10).
Final Presentation	*Introduction.* Provide an overview or motivation for the project. *The Final Design.* Describe the final design implementation. A good way to organize is to provide a high-level overview of the design and describe how it operates. Then, provide detail and a description for each of the successive hardware/software subsystems (Chapters 5 and 6). *Testing & Results.* Describe/demonstrate the key tests and results that show the functionality of the design. Provide demonstrations if appropriate. Indicate how the final realization did or did not meet the requirements (Chapter 7). *Conclusions.* Summarize conclusions about the project and provide recommendations for further work. Indicate lessons learned.

Table 1.2: Checklist and self-assessment for oral presentation preparation. Score the elements as 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4= Agree, 5 = Strongly Agree.

Organization	**Score**
The background and needs of the audience were analyzed.	
The main points of the presentation are identified.	
The motivation is clear and would be understandable to an intelligent 12 year old.	
An overview of the presentation is provided. It is relevant to the presentation, not a generic one that can be used in any presentation.	
The body is organized to support the main points.	
The conclusion summarizes the main points and future work.	
Visual Aids	
The fonts and graphics are large enough to be seen by the audience.	
The equations are of the right number and level. The presenters are prepared to discuss any equations presented.	
The slides are arranged to support the main points.	
The presentation does not contain unnecessary graphics and special effects.	
Presentation Delivery	
The presentation has been rehearsed. It meets the time constraints and there is sufficient time for questions and answers.	
Voice projection is loud enough so that the audience can hear the presenters.	
All members participate in the presentation and have reasonably equal responsibilities. (If one team member always presents the introduction and another the technical material, it is a sign that not all members are participating equally on the project).	
The presenters do not rely on cue cards.	
The presenters are comfortable in front of an audience (Do they make good eye contact with the audience? Do the presenters move around the room or do they stand stiffly behind a podium?)	
All presenters are knowledgeable on the subject and prepared to answer questions.	
The presentation software was tested on the platform to make sure it works.	
The presenters are dressed properly for the occasion.	

edited by David Beer [Bee03].

Appendix A Glossary

Term	Definition
acceptance test	An acceptance test verifies that the system meets the ***Requirements Specification*** and stipulates the conditions under which the customer will accept the system (Chapter 7).
activity on node	A form of a ***network diagram*** used in a project plan. In the Activity on Node (AON) form, activities are represented by nodes and the dependencies by arrows (Chapter 10).
activity	An activity is a combination of a ***task*** and its associated ***deliverables*** that is part of a project plan (Chapter 10).
activity view	The activity view is part of the ***Unified Modeling Language***. It is characterized by an activity diagram; its ***intention*** is to describe the sequencing of processes required to complete a task (Chapter 6).
Analytical Hierarchy Process (AHP)	A decision-making process that combines both quantitative and qualitative inputs. It is characterized by weighted criteria against which the decision is made, a numeric ranking of alternatives, and computation of a numerical score for each alternative (Appendix B and Chapters 2 and 4).
artifact	System, component, or process that is the end-result of a design (Chapter 2).
automated script test	An automated script test is a sequence of commands given to a unit under test. For example, a test may consist of a sequence of inputs that are provided to the unit, where the outputs for each input are then verified against pre-specified values (Chapter 7).
baseline requirements	The original set of requirements that are developed for a system (Chapter 3).
black box test	A test that is performed without any knowledge of internal workings of the unit under test (Chapter 7).

Term	Definition
bottom-up design	An approach to system design where the designer starts with basic components and synthesizes them to achieve the design objectives. This is contrasted to ***top-down*** design (Chapter 5).
Bohrbug	Bohrbugs are reliable ***bugs***, in which the error is always in the same place. This is analogous to the electrons in the Bohr atomic model which assume a definite orbit (Chapter 7).
brainstorming	A freeform approach to concept generation that is often done in groups. This process employs five basic rules: 1) no criticism of ideas, 2) wild ideas are encouraged, 3) quantity is stressed over quality, 4) build upon the ideas of others, and 5) all ideas are recorded (Chapter 4).
Brainwriting	A variation of ***brainstorming*** where a group of people systematically generate ideas and write them down. Ideas are then passed to other team members who must build upon them.
break-even point	The break-even point is the point where the number of units sold is such that there is no profit or loss. It is determined from the total costs and revenue (Chapter 10).
bug	A problem or error in a system that causes it to operate incorrectly (Chapter 7).
cardinality ratio	The cardinality ratio describes the multiplicity of the entities in a relationship. It is applied to ***entity relationship diagrams*** and Unified Modeling Language ***static view diagrams*** (Chapter 6).
class	Classes are used in object-oriented system design. A class defines the attributes and methods (functions) of an ***object*** (Chapter 6).
cohesion	Refers to how focused a module is—highly cohesive systems do one or a few things very well. Also see ***coupling*** (Chapter 5).
component design specification	See ***subsystem design specification*** (Chapter 3).
concept fan	A graphical tree representation of design decisions and potential solutions to a problem. Also see ***concept table*** (Chapters 1 and 4).
concept generation	A phase in the ***design process*** where many potential solutions to solve the problem are identified (Chapter 1).
concept table	A tool for generating concepts to solve a problem. It allows systematic examination of different combinations, arrangements, and substitutions of different elements for a system. Also see ***concept fan*** (Chapter 4).

Term	Definition
conditional rule-based ethics	An ethics system in which there are certain conditions under which an individual can break a rule. This is generally because it is believed that the moral good of the situation outweighs the rule. Also see ***rule-based ethics*** (Chapter 11).
constraint	A special type of requirement that encapsulates a design decision imposed by the environment or a stakeholder. Constraints often violate the abstractness property of engineering requirements (Chapter 3).
controllability	A principle that applies to testing. Controllability is the ability to set any node of the system to a prescribed value (Chapter 7).
copyright	Copyrights protect published works such as books, articles, music, and software. A copyright means that others cannot distribute copyrighted material without permission of the owner (Chapter 11).
coupling	Modules are coupled if they depend upon each other in some way to operate properly. Coupling is the extent to which modules or subsystems are connected. See also ***cohesion*** (Chapter 5).
creative design	A formal categorization of design projects. Creative designs represent new and innovative designs (Chapter 2).
critical path	The path with the longest duration in a project plan. It represents the minimum time required to complete the project (Chapter 10).
cross-functional team	Cross-functional teams are those that are composed of people from different organizational functions, such as engineering, marketing, and manufacturing. Also see ***multi-disciplinary team*** (Chapter 9).
data dictionary	A dictionary of data contained in a ***data flow diagram***. It contains specific information on the data flows and is defined using a formal language (Chapter 6).
data flow diagram	The ***intention*** of a data flow diagram (DFD) is to model the processing and flow of data inside a system (Chapter 6).
decision matrix	A matrix that is used to evaluate and rank concepts. It integrates both the user-needs and the technical merits of different concepts (Chapter 4).
derating	A decrease in the maximum amount of power that can be dissipated by a device. The amount of derating is based upon operating conditions, notably increases in temperature (Chapter 8).
deliverable	Deliverables are entities that are delivered to the project based upon completion of ***tasks.*** Also see ***activity*** (Chapter 10).

Term	Definition
descriptive design process	Describes typical activities involved in realizing designs with less emphasis on exact sequencing than a ***prescriptive design process*** (Chapter 1).
design architecture	The main (Level 1) organization and interconnection of modules in a system (Chapter 5).
design phase	Phase in the ***design process*** where the technical solution is developed, ultimately producing a detailed system design. Upon its completion, all major systems and subsystems are identified and described using an appropriate model (Chapter 1).
design process	The steps required to take an idea from concept to realization of the final system. It is a problem-solving methodology that aims to develop a system that best meets the customer's need within given constraints (Chapter 1).
design space	The space, or collection, of all possible solutions to a design problem (Chapter 2).
detailed design	A phase in the technical design where the problem can be decomposed no further and the identification of elements such as circuit components, logic gates, or software code takes place (Chapter 5).
engineering requirement	A requirement of the system that applies to the technical aspects of the design. An engineering requirement should be abstract, unambiguous, verifiable, traceable, and realistic (Chapter 3).
entity relationship diagram (ERD)	An ERD is used to model database systems. The ***intention*** of an ERD is to catalog a set of related objects (entities), their attributes, and the relationships between them (Chapter 6).
entity relationship matrix	A matrix that is used to identify relationships between entities in a database system (Chapter 6).
ethics	Philosophy that studies ***morality***, the nature of good and bad, and choices to be made (Chapter 11).
event	An event is an occurrence at a specific time and place that needs to be remembered and taken into consideration in the system design (Chapter 6).
event table	A table that is used to store information about ***events*** in the system. It includes information regarding the event trigger, the source of the event, and process triggered by the event (Chapter 6).
failure function	The failure function, $F(t)$, is a mathematical function that provides the probability that a device has failed at time t (Chapter 8).

Term	Definition
failure rate	The failure rate, $\lambda(t)$, for a device is the expected number of device failures that will occur per unit time (Chapter 8).
fixed costs	Fixed costs are those that are constant regardless of the number of units produced and cannot be directly charged to a process or activity (Chapter 10).
float	The amount of ***slippage*** that an activity in a project plan can experience without it becoming part of a new ***critical path*** (Chapter 10).
flowchart	A modeling diagram whose intention is to visually describe a process or algorithm, including its steps and control (Chapter 6).
functional decomposition	A design technique in which a system is designed by determining its overall functionality and then iteratively decomposing it into component subsystems, each with its own functionality (Chapter 5).
functional requirement	A ***subsystem design specification*** that describes the inputs, outputs, and functionality of a system or component (Chapters 3 and 5).
Gantt chart	Gantt charts are a bar graph representation of a project plan where the activities are shown on a timeline (Chapter 10).
Heisenbugs	Heisenbugs are ***bugs*** that are not always reproducible with the same input. This is analogous to the Heisenberg Uncertainty Principle, in which the position of an electron is uncertain (Chapter 7).
high-performance team	A team that significantly outperforms all similar teams. Part of the Katzenbach and Smith team model (Chapter 9).
integration test	An integration test is performed after the units of a system have been constructed and tested. The integration test verifies the operation of the integrated system behavior (Chapter 7).
intention	The intention of a model is the target behavior that it aims to describe (Chapter 6).
interaction view	The interaction view is part of the ***Unified Modeling Language***. Its ***intention*** is to show the interaction between objects. It is characterized by collaboration and sequence diagrams (Chapter 6).
key attribute	An attribute for an entity in a database system that uniquely identifies an instance of the entity (Chapter 6).

Term	Definition
lateral thinking	A thought process that attempts to identify creative solutions to a problem. It is not concerned with developing the solution for the problem, or right or wrong solutions. It encourages jumping around between ideas. It is contrasted to ***vertical thinking*** (Chapter 4).
liable	Required to pay monetary damages according to law (Chapter 11).
marketing requirement (specifications)	A statement that describe the needs of the customer or end-user of a system. They are typically stated in language that the customer would use (Chapters 2 and 3).
maintenance phase	Phase in the ***design process*** where the system is maintained, upgraded to add new functionality, or design problems are corrected (Chapter 1).
matrix test	A matrix test is a test that is suited to cases where the inputs submitted are structurally the same and differ only in their values (Chapter 7).
mean time to failure	The mean time to failure (MTTF) is a mathematical quantity which answers the question, "*On average how long does it take for a device to fail?*" (Chapter 8).
module	A block, or subsystem, in a design that performs a function (Chapter 5).
morals	The ***principles*** of right and wrong and the decisions that derive from those principles (Chapter 11).
multi-disciplinary team	In general, a multi-disciplinary team is one in which the members have complementary skills and the team may have representation from multiple technical disciplines. Also see ***cross-functional team*** (Chapter 9).
negligence	Failure to exercise caution, which in the case of design could be in not following reasonable standards and rules that apply to the situation (Chapter 11).
network diagram	A network diagram is a directed graph representation of the activities and dependencies between them for a project (Chapter 10).
Nominal Group Technique (NGT)	A formal approach to brainstorming and meeting facilitation. In NGT, each team member silently generates ideas that are reported out in a round-robin fashion so that all members have an opportunity to present their ideas. Concepts are selected by a multi-voting scheme with each member casting a predetermined number of votes for the ideas. The ideas are then ranked and discussed (Chapters 4 and 9).

Term	Definition
non-disclosure agreement	An agreement that prevents the signer from disseminating information about a company's products, services, and trade secrets (Chapter 11).
object	Objects represent both data (attributes) and the methods (functions) that can act upon data. An object represents a particular instance of a ***class***, which defines the attributes and methods (Chapter 6).
object type	Characteristic of a model used in design. The object type is capable of encapsulating the actual components used to construct the system (Chapter 6).
objective tree	A hierarchical tree representation of the customer's needs. The branches of the tree are organized based upon functional similarity of the needs (Chapter 2).
observability	This principle applies to testing. Observability is the ability to observe any node of a system (Chapter 7).
over-specificity	This refers to applying targets for ***engineering requirements*** that go beyond what is necessary for the system. Over-specificity limits the size of the ***design space*** (Chapter 3).
pairwise comparison	A method of systematically comparing all customer needs against each other. A comparison matrix is used for the comparison and the output is a scoring of each of the needs (Appendix B, Chapter 2, and Chapter 4).
parallel system	A system that contains multiple modules performing the same function where a single module would suffice. The overall system functions correctly when any one of the submodules is functioning (Chapter 8).
patent	A patent is a legal device for protecting a design or invention. If a patent is held for a technology, others cannot use it without permission of the owner (Chapter 11).
path-complete coverage	Path-complete coverage is where every possible ***processing path*** is tested (Chapter 7).
performance requirement	A particular type of ***engineering requirement*** that specifies performance related measures (Chapter 3).
physical view	The physical view is part of the ***Unified Modeling Language***. Its ***intention*** is to demonstrate the physical components of a system and how the logical views map to them. It is characterized by a component and deployment diagram (Chapter 6).

Term	Definition
potential team	A team where the sum effort of the team equals that of the individuals working in isolation. Part of the Katzenbach and Smith team model (Chapter 9).
prescriptive design process	An exact process, or systematic recipe, for realizing a system. Prescriptive design processes are often algorithmic in nature and expressed using flowcharts with decision logic (Chapter 1).
principle	Fundamental rules or beliefs that govern behavior, such as the Golden Rule (Chapter 11).
problem identification	The first phase in the design process where the problem is identified, the customer needs identified, and the project feasibility determined (Chapter 1).
processing path	A processing path is a sequence of consecutive instructions or states encountered while performing a computation. They are used to develop test cases (Chapter 7).
prototyping and construction phase	Phase in the ***design process*** in which different elements of the system are constructed and tested. The objective is to model some aspect of the system, demonstrating functionality to be employed in the final realization (Chapter 1).
pseudo-team	An under-performing team where the sum effort of the team is below that of the individuals working in isolation. Part of the Katzenbach and Smith team model (Chapter 9).
Pugh Concept Selection	A technique for comparing design concepts to the user needs. It is an iterative process where concepts are scored relative to the needs. Each concept is combined, improved, or removed from consideration in each iteration of the process (Chapter 4).
real team	A team where the sum effort of the team exceeds that of the individuals working in isolation. Part of the Katzenbach and Smith team model (Chapter 9).
redundancy	A design has redundancy if it contains multiple modules performing the same function where a single module would suffice. Redundancy is used to increase ***reliability*** (Chapter 8).
reliability	Reliability, $R(t)$, is the probability that a device is functioning properly (has not failed) at time t (Chapter 8).
research phase	Phase in the ***design process*** where research on the basic engineering and scientific principles, related technologies, and existing solutions for the problem are explored (Chapter 1).

Term	Definition
Requirements Specification	A collection of engineering and marketing requirements that a system must satisfy in order for it to meet the needs of the customer or end-user. Alternate terms that are used for the Requirements Specification are the *Product Design Specification* and the *Systems Requirements Specification* (Chapter 1 and 3).
reverse-engineering	Process where a device or process is taken apart to understand how it works (Chapter 11).
routine design	A formal categorization of design projects. They represent the design of artifacts for which theory and practice are well-developed (Chapter 2).
rule-based ethics	Rule-based ethics are based upon a set of rules that can be applied to make decisions. In the strictest form, they are considered to be absolute in terms of governing behavior (Chapter 11).
satisfice	Satisfice means that a solution may meet the design requirements, but not be the optimal solution (Chapter 11).
series system	A system in which the failure of a single component (or subsystem) leads to failure of the overall system (Chapter 8).
situational ethics	Situational ethics are where decisions are made based on whether they produce the highest good for the person (Chapter 11).
slippage	Refers to an activity in a project plan taking longer than its planned time to complete. See also ***critical path*** and ***float*** (Chapter 10).
standards	A standard or established way of doing things. Standards ensure that products work together, from home plumbing fixtures to the modules in a modern computer. They ensure the health and safety of products (Chapter 3).
state	The state of a system represents the net effect of all the previous inputs to the system. Since the state characterizes the history of previous inputs, it is often synonymous with the word memory (Chapter 6).
state diagram (machine)	Diagram used to describe systems with memory. It consists of states and transitions between states (Chapter 6).
static view	The static view is part of the ***Unified Modeling Language***. The ***intention*** of the static view is to show the classes in a system and their relationships. The static view is characterized by a class diagram (Chapter 6).
step-by-step test	A step-by-step test case is a prescription for generating a test and checking the results. It is most effective when the test consists of a complex sequence of steps (Chapter 7).

Term	Definition
strengths and weakness analysis	A technique for the evaluation of potential solutions to a design problem where the strengths and weaknesses are identified (Chapter 4).
structure charts	Specialized block diagrams for visualizing functional software designs. They employ input, output, transform, coordinate, and composite modules (Chapter 5).
strict liability	A form of ***liability*** that focuses only on the product itself—if the product contains a defect that caused harm, the manufacturer is liable (Chapter 11).
stub	A stub is a device that is used to simulate a subcomponent of a system during testing. Stubs simulate inputs or monitor outputs from the unit under test (Chapter 7).
subsystem design specification	Engineering requirements for subsystems that are constituents of a larger, more complex system (Chapter 3).
system integration	Phase in the ***design process*** where all of the subsystems are brought together to produce a complete working system (Chapter 1).
task	Tasks are actions that accomplish a job as part of a project plan. Also see ***activity*** and ***deliverable*** (Chapter 10).
Team Process Guidelines	Guidelines developed by a team that govern their behavior and identify expectations for performance (Chapter 9).
technical specification	A list of the technical details for a given system, such as operating voltages, processor architecture, and types of memory. The technical specification is fundamentally different from a requirement in that it indicates what was achieved in the end versus what a system needs to achieve from the outset. (Chapter 3).
test coverage	Test coverage is the extent to which the test cases cover all possible ***processing paths*** (Chapter 7).
test phase	Phase in the design process where the system is tested to demonstrate that it meets the requirements (Chapters 1 and 7).
testable	A design is testable when a failure of a component or subsystem can be quickly located. A testable design is easier to debug, manufacture, and service in the field (Chapter 7).
top-down design	An approach to design in which the designer has an overall vision of what the final system must do, and the problem is partitioned into components, or subsystems that work together to achieve the overall goal. Then each subsystem is successively refined and partitioned as necessary. This is contrasted to ***bottom-up*** design (Chapter 5).

Term	Definition
tort	The basis for which a lawsuit is brought forth (Chapter 11).
trade secret	An approach to protecting intellectual property where the information is held secretly, without ***patent*** protection, so that a competitor cannot access it (Chapter 11).
under-specificity	This refers to a state of the ***Requirements Specification***. When it is under-specified, requirements do not meet the needs of the user and/or embody all of the requirements needed to implement the system (Chapter 3).
Unified Modeling Language (UML)	A modeling language that captures the best practices of object-oriented system design. It encompasses six different system views that can be used to model electrical and computer systems (Chapter 6).
unit test	A unit test is a test of the functionality of a system module in isolation. It establishes that a subsystem performs a single unit of functionality to some specification (Chapter 7).
use-case view	The use-case view is part of the ***Unified Modeling Language***. Its ***intention*** is to capture the overall behavior of the system from the user's point of view and to describe cases in which the system will be used (Chapter 6).
utilitarian ethics	In utilitarian ethics, decisions are made based upon the decision that brings about the highest good for all, relative to all other decisions (Chapter 11).
validation	The process of determining whether the requirements meet the needs of the user (Chapter 3).
value	A value is something that a person or group believes to be valuable or worthwhile. Also see ***principles*** and ***morals*** (Chapter 11).
variable costs	Variable costs vary depending upon the process or items being produced, and fluctuate directly with the number of units produced (Chapter 10).
variant design	A formal categorization of design projects. They represent the design of existing systems, where the intent is to improve performance or add features (Chapter 2).
verifiable	Refers to a property of an engineering requirement. It means that there should be a way to measure or demonstrate that the requirement is met in the final system realization (Chapter 3).
vertical thinking	A linear, or sequential, thought process that proceeds logically towards the solution of a problem. It seeks to eliminate incorrect solutions. It is contrasted to ***lateral thinking*** (Chapter 4).

Term	Definition
whistleblower	A person who goes outside of their company or organization to report an ethical or safety problem (Chapter 11).
white box test	White box tests are those that are conducted with knowledge of the internal working of the unit under test (Chapter 7).
work breakdown structure	The work breakdown structure (WBS) is a hierarchical breakdown of the tasks and deliverables that need to be completed in order to accomplish a project (Chapter 10).
working group	A group of individuals working in isolation, who come together occasionally to share information. Part of the Katzenbach and Smith team model (Chapter 9).