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Determining Where and How to Teach Engineering Communication Skills

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The authors of this paper co-teach a first-year "cornerstone" design experience that combines a first-year Computer Aided Design class with a Technical Report Writing class. This arrangement mirrors how the AE and ME engineering capstone courses are co-taught by a communication professor and an engineering professor, who guide student teams through a year-long design process.

In the cornerstone courses students carry out two design projects, one of which is a semester-long team assignment. For the team project, students write a System Specification document that outlines requirements, a Trade Studies Report, a Design Proposal, and a Final Report that is accompanied by a drawing package. They also give three presentations. The Conceptual Design Review, in which they present their selected concepts, is followed a Preliminary Design Review that introduces their chosen design. In the third presentation, the Critical Design Review, students show compliance with the design requirements. In this cornerstone experience the engineering professor guides students in applying engineering processes to solve real-world problems, while the communication professor instructs students on writing engineering design reports, giving presentations, project management, and teamwork in the context of engineering projects.

In a paper for the 2022 ASEE PSW conference two authors of this paper outlined the rational for developing the cornerstone courses: it aims to better prepare students for the design project they encounter in capstone. They also detailed how the course is structured to allow for the instruction by both professors.[1] This paper outlines the importance of developing engineering communication skills in a context that explicitly teaches engineering ways of thinking. These communication skills need to be taught in a setting in which the students develop proficiency in engineering design. We also address how these needed skills cannot be taught in stand-alone technical writing courses.

Inadequacies of Stand-alone Technical Writing Courses

At Embry-Riddle Aeronautical University nine to ten sections of a 200-level technical writing course are offered each semester. The four full-time instructors and one adjunct who teach the course all have Ph.D.s in the field of Technical Communication. The primary aim of this course is to equip students with the knowledge of writing professional documents and technical reports applicable across various disciplines and in their future professional endeavors. The course has students craft professional documents such as resumes, proposals, progress reports, and reflection essays. The students create presentations and submit digital portfolios.

In attempt to tailor the course to the needs of STEM students, course instructors design assignments that prompt students to select writing topics relevant to their majors. One recurring assignment found in four syllabi revolves around crafting instructional documents or manuals for products or processes. The following are brief descriptions of these assignments from the four syllabi:

> Instruction sets are common technical documents for many disciplines and occupations. Employees read instructions to learn how to assemble a product or complete a procedure. Supervisors write out company policies that oftentimes serve as instruction sets. Customers read instructions for using a product. You will develop a set of instructions advising users to perform a specific task.
>
> Choose a technological product that you know about and provide instructions on using the product for a specific task or set of related tasks. OR Select a complex process that requires a detailed technical explanation and specific instructions for someone to successfully complete.
>
> Communicating complex information clearly and usefully is a core practice in technical writing. For this project, you'll select a procedure you are knowledgeable about and compose clear and usable instructions or documentation for a specific audience or audiences in two unique modes, one text-based and one multi-media.
>
> Write an instructional document in the form of a manual on how to use a particular technical product/process from your field. Test the manual with two participants and write a User Experience report on your manual detailing the findings of your test and how you would improve the instructions.

The above assignments exemplify faculty efforts to teach students how to convey specialized information to diverse audiences. The attempt to link the assignment to the students' disciplines is limited to topic selection. The hope is that by allowing the students to choose a topic related to their field of study, the students will be more engaged in completing the task and develop the desired skills.

The problem with these assignments is that they do not parallel the communication tasks the students encounter in their engineering courses. And because the faculty teaching the Technical Writing course are unfamiliar with the engineering curriculum, they cannot explain to students the relevance of the assignment.

The challenge with these assignments is twofold: 1) can the assignments produce the sought-for skills and 2) whether students can apply these writing skills to industry-level design reports, which demand detailed explanations of system requirements, trade studies, mathematical and physical demonstrations, and CAD model explanations. The problem with the general technical writing class is that it aims to develop communication skills in a context divorced from the application of the skills.

While the general class serves as an introduction to specific technical writing skills, it falls short in providing industry-level engineering writing and communication skills. According to Donnell et al., "General skills technical communication courses—courses delivered outside of the student's major department—use a different approach to communication instruction and present different types of problems."[2] Cross-disciplinary efforts are necessary to teach engineering and communication in the same class to engineering students, ensuring a seamless transfer of communication skills to engineering writing assignments.

Integrating Engineering and Communication in Courses

Donnell et al. argue for classrooms to simulate workplaces, defining goals for writing and audiences in ways that align with students' needs and professional activities beyond the classroom.[2] In this paper, we describe our approach to teaching engineering writing in combined courses, addressing the communication needs of these students, as traditional technical writing courses fall short in providing workplace-level writing instruction.

We acknowledge the existing body of research focusing on courses that underscore the importance of writing skills in specific engineering majors. For instance, Bodnar and Clark aimed to enhance written and oral communication skills by targeting sophomore chemical engineers enrolled in an Introduction to Chemical Product Design class.[3] This course required students to produce design reports and deliver elevator pitches, emphasizing practical communication skills in their field. Additionally, Harishchandra et al. integrated technical communication assignments across seven engineering and computer science undergraduate programs.[4] The engineering faculty underwent training in technical communication and subsequently incorporated diverse communication assignments into their courses, including writing technical memos, presenting data through tables and plots, creating oral and visual presentations, and effectively summarizing and presenting data persuasively. In alignment with these efforts, this paper contributes another facet to the development of engineering communication skills. Our approach is contextualized within an explicit teaching of engineering ways of thinking. We hope that by sharing our insights, we can assist other institutions in reconsidering and refining their pedagogical approaches to teaching engineering writing.

Focus on Engineering Design

At its core, engineering is the process of solving a problem or some societal need, and there is a well-established process, outlined in *Figure 1*, that engineers follow to achieve this.

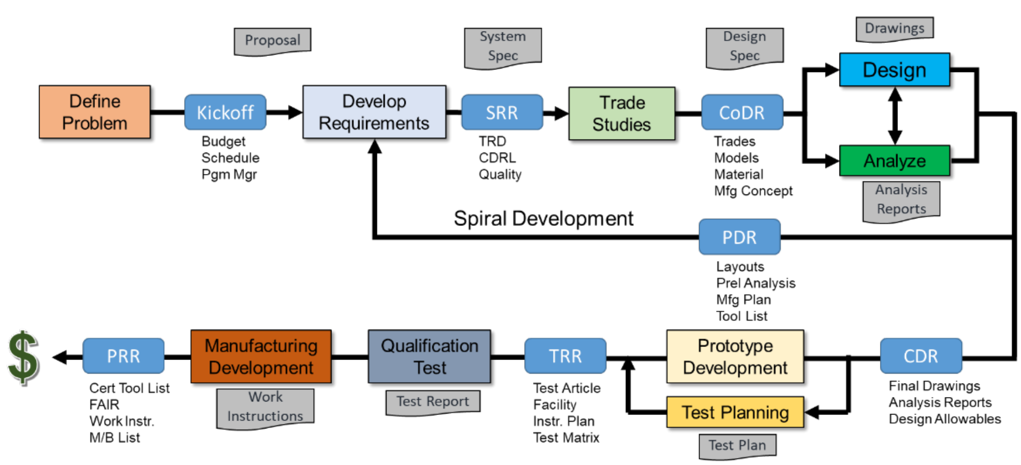

Figure 1: Engineering Design Process

The process begins by clearly defining the problem and developing clear, specific top-level requirements. Engineers then conduct trade studies to identify and objectively compare different conceptual solutions to the problem. Upon selecting the concept that promises to best satisfy the established requirements, lower-level requirements, specific to the selected concept, are derived from the top-level requirements. The concept is then further defined through an iterative design and analysis loop. The design establishes a complete definition of the solution, and the analysis verifies that the design satisfies all established requirements. A prototype of the design is then fabricated, and carefully planned tests are conducted to validate that the design meets all requirements. Finally, manufacturing processes, appropriate for the anticipated production rate, are developed and verified.

At each stage of the engineering process, there is typically a review where engineers present formal slide presentations to customers, superiors, or other stakeholders. Each step of the engineering process typically requires a significant increase in investment, so these reviews serve as a gate that must be passed before proceeding to the next step.

Although the reviews often go by different names depending on the industry or the organization, the content is similar. There is a Kickoff meeting where it is agreed that the problem is worth pursuing, a System Requirements Review (SRR) to confirm that the problem is fully and accurately defined, a Concept Design Review (CoDR) to review the trade studies and confirm the selected concept will likely best meet requirements, a Preliminary Design Review (PDR) to confirm that the developing design will meet key requirements, and a Critical Design Review (CDR) to verify that the design is complete and meets all requirements. After a prototype is fabricated, there is a Test Readiness Review (TRR) to confirm that the planned tests will safely achieve their objectives. After the tests validate that the design meets requirements and the manufacturing process is fully developed, a Production Readiness Review (PRR) is conducted to approve the start of production.

The formal written documents vary significantly in content and tone. Technical proposals are a sales pitch, but they are addressed to other engineers who require data to support every claim. Requirements documents and specifications are legally binding and require very precise language. Analysis reports are rife with tables of data, graphs, and equations. They must provide sufficient detail on the inputs, assumptions, and methods so that another engineer could repeat the analysis. Test reports must similarly provide sufficient detail that another engineer could repeat the tests, and they must fully document and interpret the resulting data. They are rife with photographs and tables of data. Test plans have elements of both analysis reports and test reports. They include uncertainty analyses to ensure the accuracy of the data will support the test objectives, and they include detailed descriptions of the test hardware and equipment. Work instructions provide detailed instructions to the shop personnel who will manufacture the hardware. They are divided into discrete manufacturing operations and are written in precise simplified language.

Deliverables in Capstone Courses and Cornerstone Courses

The Mechanical Engineering senior capstone design sequence at Embry-Riddle Aeronautical University mimics the engineering process over two semesters.

In the first semester, student teams define a problem, write requirements, conduct trade studies, and develop a preliminary design. System requirements are documented in a System Specification, and subsystem requirements are documented in a Design Specification. Trade studies and the selected concept, along with supporting analyses, are presented in a Concept Design Review. At the conclusion of the first semester, teams present a Preliminary Design Review and submit a Final Report and Verification Plan. Both the presentation and the report describe the design and the supporting analyses with an emphasis on compliance with specified requirements.

In the second semester, teams complete their designs, including formal drawings. They present the design and the supporting analyses in a Critical Design Review that emphasizes compliance with requirements. They then fabricate a prototype and plan tests to validate compliance with requirements. They submit a formal test plan and present a Test Readiness Review prior to any testing. Finally, at the conclusion of the second semester, they present their test results in a Final Technical Presentation, and they submit a final report that summarizes their project and the test results that demonstrate their design meets the requirements and thereby solves the problem defined in the beginning of the course.

Like the senior capstone design sequence, the first-year cornerstone classes mimic the engineering process. Whereas the senior capstone class spans two semesters and culminates in the fabrication and testing of the design, the first-year cornerstone classes last only one semester and culminates in a finished design with formal drawings and a Critical Design Review. On one hand, the compressed schedule limits the complexity of the projects in the cornerstone class, but on the other hand, the projects can be more complex because they do not face the time and budget constraints required to build and test their designs. For example, one team designed a mobile rocket launch platform that included an erectable 80-foot launch rail. Although the finished design was workable, it could not possibly be built within the timeframe or budget of a capstone project.

Another obvious factor affecting the scope of the cornerstone projects is the fact that first-year students have not completed any engineering coursework. They lack the analysis skills required to verify their designs meet requirements. Although they could not be expected to independently perform every necessary analysis as we expect of seniors, we found that with limited instruction specific to their projects, first-year students are remarkably receptive to and capable of applying advanced engineering concepts. They did not analytically verify every requirement, but they did apply engineering analysis to a real-world problem. For example, the team that developed the mobile launch platform performed a transient thermal analysis of the blast deflector to show it could survive the hot rocket exhaust.

Because any mechanical design must not fail under applied loads, there was one lecture on solid mechanics. The concept of stress and strain were introduced, and the behavior of materials was explained with stress-strain curves. Without derivation, equations for stress and deflection under tension and bending were presented, illustrating the importance of short and straight load paths in their designs. Acknowledging that bending is often unavoidable, the concept of area moment of inertia and the advantage of moving material away from the neutral axis was explained. The concept of stress concentration was also explained to caution them to avoid sharp corners in their designs.

Students found the solid mechanics lecture overwhelming, but it enticed them to apply the concepts to their designs. With one-on-one follow-up instruction on the material as it related to their designs, students quickly grasped and applied the concepts effectively. Most teams performed at least one structural analysis, and one team that designed a robot for painting houses expanded on the static formulations to analyze the dynamic behavior of their boom.

In addition to solid mechanics, each team required instruction on project-specific topics. Several designs included electric motors, so those teams were taught to calculate applied torques and interpret motor performance curves. Other projects involved high temperatures, so those teams were taught heat transfer concepts and equations directed at their specific problems.

Students were also taught to effectively communicate their analyses. For both their presentations and reports, they were prescribed the following guidelines for describing any analysis: 1) explain the purpose of the analysis, 2) describe what is known, 3) explain and justify all assumptions, 4) explain the methodology including relevant equations, 5) present the results, and 6) interpret the results as they relate to the purpose of the analysis. By following this outline, students were not only able to effectively communicate their analyses, but they also gained a deeper understanding of the analyses. For example, after drafting their initial slides to explain the dynamic analysis of the boom on the house-painting robot, the team recognized a deficiency in their design and changed the configuration of the boom to resolve the issue.

Summary of the Instruction on the Engineering Design Process

The following lists highlight the instruction provided by the engineering professor in the cornerstone courses.

1. Document what is Done at Each Stage of the Design Process
    - Define the problem
    - Specify requirements
    - Conduct trades studies and select options
    - Allocate requirements
    - Develop the design: conceptual design, preliminary design, final design with drawings
    - Conduct needed analyses to verify the design
    - Provide updates

2. Explain what is Required for Each Deliverable
    - Individual Water Rocket Proposal
    - Team Requirements Document
    - Team Trade Study Report
    - Team Proposal
    - Team Final Design Report
    - Conceptual Design Review
    - Preliminary Design Review
    - Critical Design Review

3. Additional Topics in Engineering
   - Design for manufacturing
   - Properties of metals
   - Project-specific topics

4. Calculating and Presenting Results
   - How to use Excel to calculate analyses
   - How to present the results of analyses

Engineering Communication Curriculum

The goal since the authors began the cornerstone courses has been to develop a "complete" engineering communication curriculum. The starting point for this curriculum was the eight presentations the communication instructor had developed for capstone courses. In the capstone courses most of the communication instruction has been provided in the form of feedback on written documents and design briefings.

Introduction to Engineering Communication

One of the main challenges in developing the curriculum has been to identify the instructional needs of first-semester engineering students. All the years of teaching senior capstone students has taught the authors what we want first-year students to accomplish, but in developing this curriculum we have had to determine what instruction first-year students need and how best to deliver the instruction.

In order to introduce engineering communication practices we developed the following presentations:

1. Defining Characteristics of Engineering Writing

2. Identifying Keys to Engineering Arguments

3. Writing Technical Descriptions for an Engineering Audience

4. Identifying Requirements for Design Briefings

The first presentation introduces key characteristics of engineering reports and how these are similar to and different than types of writing students have done in other settings. The presentation provides an explicit framework for subsequent engineering-specific communication instruction. We highlight what engineers value and how this informs what and how they write. We introduce how documents are produced collaboratively, the need to follow a style manual, and the need to present information visually.

The second presentation discusses the types of arguments that engineers make. The focus is on making arguments related to presenting the team's design. We highlight the need to 1) present requirements, 2) document the design in text and figures, 3) provide justification of the design and/or the results of analyses, and 4) document compliance with requirements. We stress the importance of explaining the implications of the results for the design. In particular we drive home the need to make arguments to justify their design rather than simply report the work they have done.

The third presentation highlights the need to write detailed design descriptions that are clear and precise. This past semester it became evident how this single presentation needs to be expanded into multiple lessons. For example, it was apparent that we need to cover how to introduce a design to an outside audience. This is a topic that capstone students might scoff at, but it is essential for engineering novices. We will use student examples to highlight the need to start with the "big picture" and then describe smaller components. We will emphasize planning design descriptions rather than simply starting with the first thing that comes to mind, as is often the case.

The last introductory presentation identifies what engineering audiences expect to encounter in a design briefing. We highlight what the audience wants to know about the team's design.

Tasking Required to Complete the Final Design Report & Critical Design Review

Key to developing the communication curriculum is identifying all of the engineering tasks required to complete the Final Design Report and Critical Design Review. In *Table 1* we outline the ten engineering tasks required to complete the two deliverables. The list is nearly identical to the list of what is required of capstone students. The only difference is that in cornerstone we do not ask students to identify project risks and develop mitigation plans. This list enables us to highlight for the cornerstone students how this assignment directly mirrors what is required in capstone.

Table 1: Breakdown of Engineering Tasks

Cornerstone Design Tasks	**Capstone Design Tasks**
• Write for an engineering audience and establish credibility	• Write for an engineering audience and establish credibility
• State the problem / need	• State the problem / need
• Write requirements	• Write requirements
• Introduce the design solution	• Introduce the design solution
• Explain how the design functions	• Explain how the design functions
• Document the complete design	• Document the complete design
• Present costs	• Present costs

Cornerstone Design Tasks	Capstone Design Tasks
• Document compliance with system-level requirements	• Document compliance with system-level requirements
• Not required for cornerstone	• Identify project risks and develop mitigation plans
• Evaluate progress towards project completion	• Evaluate progress towards project completion
• Report trade studies	• Report trade studies

For each of the ten tasks cornerstone students must complete we have identified what instruction needs to be provided to first-semester students.

1. Write for an Outside Audience and Establish Credibility

Required Instruction
- How to develop a research plan that 1) documents the team's existing knowledge, and 2) identifies what research needs to be completed so the team can provide the needed background information and have credible sources
- Ways to present background information so the reader understands the project / design
- How to evaluate similar systems or existing products

2. State the Problem / Need

Required Instruction
- How to define an engineering problem
- How to write the problem statement

3. Write Requirements

Required Instruction
- Purpose of requirements
- How to develop system-level requirements
- How to write SMART requirements: requirements that are Specific, Measurable, Achievable, Relevant, and Technical
- How to allocate requirements by identifying design drivers, creating subsystem- and component-level requirements, revising requirements as needed, and tracking requirements

4. Introduce the Design Solution

Required Instruction
- How to plan out design descriptions
- Keys to presenting figures

5. Explain How the Design Functions

<u>Required Instruction</u>
- Ways to use visuals and text to present how the design functions

6. Document the Complete Design

<u>Required Instruction</u>
- How to determine which key features need to be described
- How to determine which figures are needed to introduce / show the design
- How to describe how each subsystem functions
- How to explain how subsystems integrate with one another
- How to determine which analyses and figures are needed to show compliance with requirements

7. Present Costs

<u>Required Instruction</u>
- Design for cost, cost estimating, itemizing costs including labor
- Ways to visually present costs
- Differences in presenting costs in presentations and reports

8. Document Compliance with System-level Requirements

<u>Required Instruction</u>
- What it means to verify a requirement
- Methods of verifying requirements: design, analysis, and test
- How to use a verification matrix to plan verification efforts and demonstrate compliance with requirements

9. Evaluate Progress towards Project Completion

<u>Required Instruction</u>
- How to identify future work
- How to present conclusions and recommendations

10. Conduct and Report Trade Studies

<u>Required Instruction</u>
- Purpose for conducting trade studies
- How to conduct a trade study: steps to completing a trade study and how to use a Pugh matrix
- How to present the results of trade studies in a separate report and in the design report appendix

Additional Content Areas

There are four additional areas that comprise the communication curriculum. These areas include Teamwork, Project Management, Writing Processes, and Oral Presentations.

Teamwork

In providing instruction regarding teamwork, the authors work with an expanded notion of what constitutes writing instruction. Any task required to complete a written document is included as part of the required writing instruction. Too often students are asked to complete team assignments / projects without being provided instruction on teamwork.

To address this problem the communication instructor previously developed five research-based presentations on teamwork for the capstone courses, which have been modified for the cornerstone students. The five presentations cover the following topics:

1. Creating a Positive Culture

2. Organizing the Team

3. Conducting Team Assessments and Making Improvements

4. Refining Communication Skills

5. Identifying and Addressing Conflicts

The first two presentations culminate in each team creating a contract that documents goals, rules, and roles. They are asked to identify specific actions to create and maintain a positive team culture, and they are required to update the contract.

The second presentation highlights the need to assign tasks to team members by building on the strengths of individuals and by building in redundancy in terms of assigned tasks. Ways of holding team members accountable are covered along with ways of conducting team meetings and the need to keep meeting minutes that document team decisions.

The third presentation outlines the need to conduct regular team evaluations. They are required to use assessment tools provided to them so they can make informed decisions regarding needed improvements.

The fourth presentation addresses the need to assess and improve team communication practices. The communication practices of effective teams are covered along with guidelines for giving and receiving feedback in a team setting.

The fifth presentation aims to help students anticipate team conflicts, identify the causes of the conflicts / problems, and develop solutions that address conflicts in a way that maintain relationships.

Project Management

In the previous iterations of the course, the authors have provided insufficient instruction regarding project management. For example, we highlighted for students the need to create a Sharepoint Site or Google Drive folder to keep track of all their design work and team documents, but we did not provide direct instruction on the matter. It became evident during the last semester that the students need more explicit instruction on how to organize these collaborative spaces. In the coming fall semester we will require them to have an Administration Folder that includes their updated schedule, meeting minutes, progress reports, and team assessments. A Design Folder will include subfolders for their initial design sketches, CAD work, and results of analyses, and a Deliverables Folder will include subfolders for all documents and slide decks. While this approach might seem overly prescriptive, first-semester engineering students need this overt guidance on how to organize the work and documents they produce during the course of the project.

In the fall 2024 semester the three project management presentations will be as follows:

1. Identifying and Scheduling Project Tasks

   With this presentation students will be taught to plan backwards starting with the end deliverable. In creating a schedule they need to account for the unexpected, and they have to build in time to practice presentations and revise documents.

2. Using a Scheduling Tool to Track Progress

   This presentation will introduce teams to project management software they can use to track their progress.

3. Keeping Track of Team Records using Google Drive or Sharepoint

Writing Processes

The four writing presentation are ones that could be found in a stand-alone technical writing course. They represent four tasks required of the teams to complete the design project and submit the written deliverable: writing as a team, revising documents, editing documents, and formatting documents.

In previous iterations of the course, the communication instructor identified the need to go beyond the teamwork instruction that is provided and focus on specific strategies for writing as a team. This instruction highlights the challenges teams face in writing coherent documents, and teams are required to identify procedures for writing their documents.

The editing instruction focuses on specific strategies for addressing sentence-level concerns while the instruction on formatting introduces students to the style manual they will use in their engineering courses. The later instruction covers how to use MS styles; the use of enumerated headings, white space, headers, figures and tables; and the need to include front and back matter in a document.

1. Writing as a Team

2. Revising Documents

3. Editing Documents

4. Formatting Documents

Oral Presentations

There are three lessons related to giving oral presentations that focus on the following topics:

1. Creating Audience-focused Presentations

2. Creating Effective PowerPoint Slides

3. Improving Delivery

Future Iteration of the Course

As stated earlier, the first-year cornerstone classes and the senior capstone design sequence mimic the engineering development process. For the capstone sequence, this structure permits students to demonstrate mastery of each of the ABET learning outcomes. By inference, the cornerstone classes introduce first-year students to these same outcomes.

The current Mechanical Engineering curriculum includes an Introduction to Engineering course, EGR 101, that aims to introduce the ABET outcomes to first-year students. Each week, the class includes a 1-hour lecture period where a variety of soft skills are taught and a 3-hour lab period where students work in teams to design and build Lego robots to compete on a course. Although teams present their designs in design reviews, there is no formal communication instruction and no instruction on engineering design principles.

Recognizing that the cornerstone classes provide a more rigorous and relevant introduction to the ABET learning outcomes, beginning next academic year, the authors will replace the current EGR 101 content with the cornerstone content. The technical communication course, COM 221, will be combined with EGR 101 instead of the CAD class, EGR 201. Aside from the CAD instruction, the content of the combined EGR 101/COM 221 course will be identical to the cornerstone content described herein. To ensure students have the CAD skills needed to support their projects, EGR 201 will be a co-requisite to EGR 101/COM 221.

This restructuring offers the opportunity to expand the cornerstone experience because it affords an additional four hours per week for lectures and mentoring of teams. This added time will enable us to provide additional lectures on engineering concepts like the solid mechanics lecture discussed earlier. It will also enable expanded instruction of engineering skills, such as problem-solving strategies, engineering calculations in Excel, literature searches, and interpretation of charts and graphs. More emphasis on engineering ethics will also be possible.

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