A Guide to Writing a Senior Design Thesis in the Bioengineering Department

This thesis guide has been put together to help guide students who are writing a thesis in bioengineering department.

Use SoE guidelines for everything else that is not covered in this document: http://scu.edu/engineering/srdesign/student.cfm

It is expected that each student work most closely with their thesis advisors (e.g., weekly or biweekly meetings are typical). The faculty advisor provides scores for your performance during the senior design project and signs the thesis. The responsibilities of the faculty advisor typically include:

1. Guidance and Mentorship

- Helping students define project scope, objectives, and deliverables.
- Providing technical expertise and feedback on design approaches, methodologies, and solutions.
- Encouraging innovative thinking and problem-solving.

2. Project Oversight

- Monitoring progress to ensure students meet deadlines and maintain focus on the project goals.
- Assisting in breaking down complex tasks into manageable steps.
- Ensuring compliance with ethical, safety, and professional standards.

3. Technical and Professional Development

- Teaching students how to document their work through reports, presentations, and prototypes.
- Offering advice on using engineering tools, simulations, or experimental techniques.
- Introducing students to industry standards and practices relevant to their project.

4. Facilitation of Resources

- Connecting students with necessary resources, such as labs, equipment, and funding.
- Introducing students to subject matter experts or industry collaborators when needed.

5. Evaluation and Feedback

- Providing constructive feedback throughout the project lifecycle.
- Assessing final deliverables, including reports, presentations, and prototypes.
- Evaluating students' teamwork, problem-solving, and communication skills.

6. Motivation and Conflict Resolution

- Encouraging teamwork and resolving any group conflicts that may arise.
- Helping students stay motivated and focused, especially during challenges.

7. Career and Academic Advising

- Advising students on how to leverage their senior design experience for careers or further academic pursuits.
- Writing recommendation letters based on the students' project performance.

Contents

What are the goals of the senior design thesis?

Your senior design thesis is a formal report of the clinical need or the real-world problem you worked on, the product or strategies that you have developed to solve this problem, and the work you have conducted in the laboratory. Important goals of your thesis are: 1) to review the relevant background in your specific subfield field; 2) to describe how your work fits into the larger scientific context; 3) to clearly describe your experimental measurements and data 4) to demonstrate your independence and mastery of technical engineering depth; and 5) to fully quantify, analyze and criticize your results. It is also important to 6) discuss how future experiments should address particular issues or build upon your work.

As you write your thesis, you should keep in mind that *clarity is of the utmost importance*. In order to write very clearly, it is crucial that you always keep in mind the basic scientific question(s) and design goals that your work attempts to address. These questions should be introduced and explained well in your Introduction. You should return to these driving questions in subsequent sections throughout the thesis, regularly reminding the reader how each result fits into your overall scientific/engineering goal.

Learning objectives for the senior design course:

1) Communicating technical knowledge effectively to diverse audiences

2) Functioning effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives

3) Understanding and Applying Foundational Concepts
    - Students will be able to recall key scientific and engineering principles that underlie upper-level engineering courses.
    - Students will explain how research and design methodologies are employed in engineering fields, distinguishing between qualitative and quantitative approaches.
    - Students will apply skills acquired from previous engineering courses to solve basic technical problems with a moderate level of complexity.

4) Analyzing and Evaluating Research/Design Approaches
    - Students will analyze the technical depth of their projects to ensure they exceed the expectations of upper-level engineering courses, using statistical and analytical evaluations to assess performance.
    - Students will evaluate design solutions or research findings based on engineering principles, offering constructive critique on areas such as methodology, technical rigor, and the use of scientific reasoning.
    - Students will independently apply quantitative methods to analyze complex engineering systems, integrating knowledge from multiple areas of study.

5) Creating and Demonstrating Innovation in Research and Design
    - Students will design and conduct experiments that demonstrate independence of thought, using innovative approaches that extend beyond their prior coursework.
    - Students will defend the analytical evaluation methods used, ensuring that their designs or research outcomes are backed by rigorous statistical analysis and quantitative reasoning.
    - Students will synthesize their knowledge and skills to create solutions that contribute to the advancement of engineering research, demonstrating a mastery of both research and design processes.

What constitutes a bioengineering senior design thesis?

It is highly recommended that students review past theses to better understand the expectations for technical depth and project scope expected in a thesis.

A senior design thesis in bioengineering <u>should</u>

- Contain a level of technical depth beyond upper level engineering courses
- Be research, design, or a combination of the two
- Extend from skills acquired in one or more engineering courses
- Be quantitative and based on scientific and engineering principles
- Contain statistical or other analytical evaluation
- Show independence of thought and experimentation

[Note: It is ultimately up to your thesis advisor and senior design conference judges to determine if your project and written thesis are sufficient for a senior design thesis to fulfill the requirements for a degree in Bioengineering.]

A bioengineering thesis <u>is not</u>

- a literature review of a topic (although this can form an introductory chapter to a thesis)
- a project whose scope can ordinarily be completed in a single quarter
- a lab report or a final project in a course

Contents and formatting of the thesis

As a bioengineer, your thesis must integrate your knowledge of physics, math, engineering, and biology with your research topic. You should consider how your previous coursework relates to your thesis. A good rule of thumb is that at least two of your upper- level concentration courses are related to your thesis project. While your lab mentor(s) will be able to help you, the onus is on you to find the appropriate literature/background materials and think about how they relate to your work.

THESIS STRUCTURE

In terms of how it is written and its structure (but not necessarily in terms of the quality of data), the thesis should read like a typical journal article from your subfield of engineering (e.g. cardiovascular tissue engineering), but with more detailed (longer) introduction, analysis and discussion sections.

Your thesis should have a clear point and there should be no doubt to the reader (or to you) what that point is. You should be able to complete the following sentence: "The goal of this thesis is to ______." To develop your goal(s), you must first clearly identify the overall and specific scientific questions or engineering design goals that your experiments attempt to address. *Explicitly* explain these to the reader (in your Introduction or in one of your introductory chapters). You should also explain clearly things that may seem obvious to you (e.g., Poiseuielle flow or connexins that form gap junctions). Your readers may not know as much about your specific topic as you do. Even if they do, what you don't explain in your writing may seem like a lack of understanding on your part. Take the time to explain things in concrete sentences. In addition, try to frame your thesis like a good story, arranging the material so that the reader will follow enthusiastically from beginning to end.

Different sub-fields within engineering have different traditions and styles of presentation. However, here are some general guidelines. Some flexibility is allowed for your thesis format so please consult with your thesis advisor before writing and formatting your thesis..

Title page
Acknowledgements
List of Contributions
Abstract
Table of Contents
Table of Figures

Introduction
Technical specifications/Design
Materials and Methods
Results
Figures (each placed where appropriate within Results)
Analysis and Discussion
Professional Issues
References

Abstract. The Abstract should be a single paragraph and should not exceed 250 words. It should be designed to define clearly what is dealt with in the thesis and should (1) state the principal objectives and scope of the investigation,
(2) describe the methods employed, (3) summarize the results, and (4) state the principal conclusions. Most of the abstract should be written in the past tense, because it refers to completed work. The abstract should never give any information or conclusion that is not stated in the thesis. References to the literature should not be cited in the abstract.

Table of Contents. The table of contents should list every subsequent section of the thesis, as well as the abstract and other pages that precede it.

Introduction. The Introduction should present an overall framework for your project by reviewing the literature, discussing what is currently known about the particular subject (as well as perhaps how this knowledge may have evolved historically), identifying relevant questions or debates that exist in the field, and detailing the specific questions that you investigate in the thesis. The Introduction often reads like a mini review article on your topic. It should be obvious to the reader what specific scientific questions you aim to address with your work. If you introduce the background well, the reader should also understand why your specific experiments are an important and obvious next step for your particular field or laboratory.

You should end your introduction by clearly stating (or perhaps restating) your objectives and rationale for the thesis. This provides a starting point for the thesis and tells the reader what to expect in the forthcoming sections. Try your best to list the steps of your project in a logical order that walks the reader through your ‘story’. Also, include here any significant components of your work that it might be important to highlight, for example if your research involves a detailed statistical analysis.

Throughout the introduction you should supply sufficient information to allow the reader to understand the forthcoming results without their needing to read previous publications. Assume that your audience has the background of a general undergraduate engineer but not necessarily one that knows your field well. (I.e., this means that you don't have to describe what MATLAB is, but you should explain things like "IHC", "iPS cells", or "MEMs".) When in doubt, explain briefly. Include schematic figures or diagrams in your Introduction that illustrate the details you are introducing, e.g., important cell types/electrical system/prior art you are discussing or a complex biochemical pathway/system diagram. If it is something crucial for the reader to understand, a figure is always a good idea. It improves your overall presentation and also helps the reader to focus on the important points they must understand for the remainder of the thesis. Many authors feel that one figure should be included for every main point in a scientific paper.

Throughout the Introduction and all subsequent sections, you should include in-text citations of all relevant published work. References serve multiple purposes. Beyond their most important role in giving credit to previous work, references also serve as resources for the reader to learn where they might find further reading on a particular subject. Be sure to include relevant reviews or even textbook chapters that you found helpful as you learned about your topic. (See "References" section below for citation format.)

Technical (Product) Specifications Describes the needs of the end user (e.g., patient, physician, etc.) and translates those needs into technical requirements for the solution to the engineering problem adequate for the solution's realization. These requirements are expressed as measurable specifications using explicit metrics and values adequate for testing. The specification discussion must address the standards and applied constraints applicable to the problem domain and proposed solution. The section shall also explain how each specification and its value was determined.

Technical (Product) Design Describes the technical design of the solution to the engineering problem, including the identification of systems and subsystems, and interfaces between subsystems. All specifications shall be assigned to the system, one or more of the subsystems and/or interfaces. This process ensures that all specifications are addressed and tested in an appropriate manner. A discussion of alternative solutions and their rejection must be included.

Materials and Methods (Project Plan and Procedure) Describes in detail the development of the proposed engineering solution and provides details of the development process and relevant testing procedures in adequate detail to allow duplication by others (e.g., include all concentrations, final dilution amounts, incubation times, etc.), but don't include the excruciating details of full step-by-step protocols (if desired and relevant, these can be placed in an Appendix).. This discussion must identify standards applicable to lab and testing procedures and any deviations from the relevant standards due to cost, equipment availability, schedule or other issues. Use subheadings to help guide the reader through the Material and Methods section (e.g., “Tissue preparation”; “Imaging & Analysis”; etc.).

Results. This section comprises the body of the thesis. The Results section should be presented in an explicit, logical order, so that the reader will understand the purpose of each experiment. This section summarizes the data obtained from the experiments and should describe the results in a matter-of-fact manner but not overly interpret them (which will be done in the Discussion). Rather than simply listing one experiment monotonously after another, walk us through your logic using key transition sentences that remind us of your underlying scientific questions. For example, instead of saying “Next, we used antibodies against Protein X at three different time points”, you might say “Next, in order to determine whether autism-associated proteins are indeed localized in the striatum throughout development, we used antibodies against Protein X at various postnatal ages.” If you completed two unrelated projects, you may consider separate sections or chapters within the Results section. You may also include relevant experiments with negative or no results

Figures. The visual elements in your thesis should be a mirror of the written elements such that either the figures or the text may stand alone to tell your story. In other words, you should ideally have a figure to visually represent each main result described in your text. Your figures, diagrams, and tables should be properly labeled, with descriptive figure legends and any sources acknowledged. (See below.) Clear, well-labeled figures help significantly to impress readers with the overall professional presentation of your thesis. Figures and tables should be numbered in the order that they are cited in the text (for example, Figures 1-2 in the Introduction, Figure 3 in the Methods, Figures 4-11 in the Results, etc). Ordinarily, figures should be presented in portrait orientation with the figure legends accompanying the appropriate figures. You can place the figure and caption immediately following the paragraph in which it was introduced or, for very large figures, you can dedicate an entire page, placed just after the page where the figure is first mentioned in the text. The figures should be numbered in sequence with the text.

If a figure is a multi-panel plate, individual panels within the figure should be consecutively lettered, and for all images, a scale bar should be included in the figure and defined within the figure legend. Figures should be presented in a plain and unadorned style as much as possible. All text within the figure should be large enough to be read easily. Panels should not be set off by boxes or other edging, and lettering and images should not have gratuitous effects such as highlighting, three-dimensional edging, shading, etc. Where possible, figures should consist of black lines and lettering against a white background. Color should be used to differentiate or emphasize specific features of a drawing, but only if scientifically necessary (i.e., needed to differentiate the different parts of the image, such as different lines in a graph or different labels mapped against a brain section). Any data that was collected from replicate measurements (i.e., an average value on a plot) should be shown with an appropriate error bar (e.g., standard error or standard deviation). The figure caption should state what value the error bar represents and the number of replicates (e.g., n = 3).

In order to present a complete story, it is sometimes appropriate to include some minimal data conducted by another individual in the lab. Work done in collaboration with others or even by someone else may be included in your thesis, but *this must be acknowledged in the figure legend even if the appropriate researcher is also given credit elsewhere*. The reader assumes that all figure data presented are yours unless it is explicitly stated in the figure legend. Be sure that you do not make this ambiguous to the reader; their frustration/confusion may be reflected in your thesis recommendation.

Although Microsoft office (i.e., PowerPoint and Excel) serves well for figure creation, some alternative online resources to consider are; 1) for data visualization; plotly.com 2) for vector graphics; biorender.com, lucidchart.com 3) for 3D models; tinkercad.com etc. More exist as well.

Discussion. The discussion section should first of all summarize and analyze the results that you have presented. For example: "We demonstrated in Figure 8 that cell proliferation was decreased in the presence of ATP receptor antagonists. This result could be interpreted in a number of ways…" then go on to explain that one likely interpretation would support your overall hypothesis, but a caveat might be that the pharmacological agents could have caused cell damage. (Ideally you have done a control experiment to rule that out – explain how that control supports your hypothesis here.) In addition to this type of discussion, recapitulate your overall argument(s) presented in the Introduction as well as strengths and weaknesses and address the theoretical issues that were used in approaching and analyzing the problem. You should also explain how you may have modified your view of the issues in the course of conducting the analysis. If your experiments did not produce significant or meaningful results, explain here your thoughts on why this might have occurred, and suggest how things could be done differently. Convince the reader that you have fully thought through and understand the implications of your work, no matter how individual experiments may have turned out. The discussion is an important aspect of your thesis and should place your findings into the larger perspective. It is the best section to demonstrate to the reader how carefully you have thought about your work and how sophisticated your thinking might be regarding its nuances and implications. Be sure to compare your findings to previously published results – are your data consistent with findings from other studies? Why or why not?

Importantly, end with a section detailing further questions to be asked and directions for future study. Faculty readers will look specifically for a discussion of how future experiments may build upon or improve your work. If this is missing, they may feel that you have not adequately thought things through.

Professional issues and constraints Please follow the SoE guidelines here: https://www.scu.edu/media/school-of-engineering/pdfs/current-student-resources/undergraduate/Professional-Issues-and-Constraints.pdf

References. Factual statements and claims that you make throughout your Introduction, Methods, Results, and Discussion sections should be backed up by providing citations to relevant published work. For example, even a basic statement such as the following should include a citation using only bracketed numbers in IEEE format (to a review article or textbook chapter, for example):

The feasibility of imaging structures less a millimeter wide with dual-frequency ultrasound has been previously shown [1].

For references, you should use the **bibliographic notation style of the IEEE** journals. For example:

[1] R. Gessner, M. Lukacs, M. Lee, E. Cherin, F. S. Foster, and P. A. Dayton, "High-Resolution, High-Contrast Ultrasound Imaging Using a Prototype Dual-Frequency Transducer: In Vitro and In Vivo Studies," *Ieee Transactions on Ultrasonics Ferroelectrics and Frequency Control,* vol. 57, no. 8, pp. 1772-1781, Aug 2010, doi: 10.1109/tuffc.2010.1615.

Regarding in-text citation, please use only bracketed numbers as shown in the first sample above unless your lab explicitly uses another format. Do not use footnotes or “author, year” format.

To simplify the citation process, you are urged to use an in-text citation program such as Endnote (or Endnote Online), Mendeley, and Zotero. More exist as well.