The Pennsylvania State University One Year MS in Biomedical Engineering

Handbook

2020

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I. General Information

The Penn State M.S. in Biomedical Engineering is a one-year degree that includes faculty members with their primary appointment in the Biomedical Engineering Department.

Graduate Program Office

The Graduate Program Office for Biomedical Engineering is located in 122B Chemical and Biomedical Engineering Building (CBEB). The graduate programs coordinator, Stacy Smith (122B CBEB), is available to assist students between the hours of 8:00-4:30 Monday through Friday. If she is unavailable, you may contact Lisa Daub, Administrative Staff Coordinator in 122C CBEB.

The Graduate Program Office can help with the following:

- answer administrative questions and supply forms
- schedule controlled biomedical engineering/bioengineering classes
- submit final scholarly papers

Keys: Keys may be obtained by asking your adviser to send an email to Gary Meyers at gmeyers@engr.psu.edu detailing which lab keys are needed. Keys can then be picked up at his office in 124 CBEB. Before you leave the BME Program, all keys need to be returned to Gary.

Purchasing Equipment and Supplies: Graduate students may be responsible for purchasing supplies for their lab. Before ordering any supplies or equipment, please see Brooke Carrico for the correct procedures for ordering and completing the forms. In addition, be prepared and know what budget numbers to use. Consult your adviser for this information.

Mail: Inter-university mail and all outgoing mail is picked up at 1:00 Monday–Friday. Students may put personal mail in the outgoing wire basket as long as it has postage.

Sending UPS Packages: The office staff in CBEB can send out packages. Bring package to 122 CBEB along with shipping information, phone number of recipient, budget number to be charged, weight and whether or not the package needs insured.

Packages are delivered to the mailroom outside 122 CBEB by UPS. Each student is responsible for checking deliveries of their lab supplies. This room is used by the entire department for many functions, so please be diligent in retrieving your packages.

II. Registration and Tuition

Tuition Bills

After enrolling in classes, all students will receive an e-mail notification from the Penn State Bursar's Office requiring payment of tuition. Students should follow the instructions outlined in the e-mail to file the tuition bill electronically. Do not ignore this e-mail.

Full-time Academic Status

Full-time academic status is achieved by taking appropriate course loads as shown in the following pages. Most loan granting agencies and other organizations will consider a 9-12 credit course load to be full-time status, fulfilling their registration requirements. The U.S. Immigration and Customs Enforcement (ICE) requires that all international students on student visas must achieve "full-time academic status" during the Fall and Spring semesters. For ICE purposes, a course load of nine credits is considered full-time during Fall and Spring semesters. Students must request registration for BME 590 through the graduate staff assistant. For full details, see the Graduate Degree Programs Bulletin website at http://bulletins.psu.edu/bulletins/whitebook/index.cfm.

Course Load

Students will take 15 credits in the Fall, 13 credits in the Spring, and 2 credits for each Summer session for a total of 32 credits for the 1-year BME MS Program. The Graduate School requires that all students receive a cumulative grade point average of 3.0 or better to graduate. Only grades of C or better count toward MS course requirements.

Student Insurance

Health insurance is mandatory for all international students (and their dependents) who are supported on assistantships/fellowships or who are self-supported. US students on other health care plans may file a waiver on-line with the Student Insurance Office if they are covered under another health insurance plan. International students may file a declination form on-line but they must present evidence of being covered under another health care plan which is equivalent to the Penn State plan. Students on assistantships/fellowships are automatically enrolled in the medical, dental and vision plans. Insurance premiums are deducted monthly from the assistantship stipend. Penn State will pay 80% of insurance coverage and the student is responsible for 20%. Students who are not on assistantships/fellowships must pre-pay for health care coverage.

The insurance subsidy for eligible dependents is 75% of the annual premium expense for spouse, domestic partner OR children; 76% of the annual premium expense for family.

Detailed information on health insurance, including the health insurance booklet, enrollment deadlines and table of monthly payroll deductions is available at:
https://studentaffairs.psu.edu/health-wellness/health-insurance.

It is each student's responsibility to notify the department, payroll office, and the international office (if applicable) if there is a change of address during your stay at Penn State. Please change the information on LionPath also.

Training in the Responsible Conduct of Research (RCR)

During the first year of study, all graduate students studying for the M.S. in Biomedical Engineering are required to complete the free online Scholarship and Research Integrity (SARI) training provided by the Collaborative Institutional Training Initiative (CITI). This may be completed during BIOE 591. https://www.research.psu.edu/training/sari. Upon completing the training, participants are issued a certificate of completion. Email or photocopy the certificate and submit it to the Graduate Programs Coordinator prior to the end of the first semester of study.

Code of Conduct

The Penn State 1 year MS BME Program has adopted the same Code of Conduct as The Graduate School. Please refer to the links below regarding the code policies.

http://gradschool.psu.edu/graduate-education-policies/gcac/gcac-800/gcac-801-conduct/

Bioengineering/Biomedical Engineering Colloquium

The Bioengineering/Biomedical Engineering Colloquium (BME 590/BIOE 590) is held every week during the Fall and Spring semesters. All graduate students are required to register for BIOE/BME 590 (1 credit) each semester in attendance. **Attendance is mandatory**.

III. Master's Degree Requirements

Below are degree requirements for the BME M.S. degree in terms of general requirements as delineated by the Graduate School and specific requirements set by the Biomedical Engineering Department.

The policies described here apply to the M.S. degree in Biomedical Engineering. Official Graduate School policies covering all M.S. degrees at Penn State can be found at:
http://gradschool.psu.edu/graduate-education-policies/

Requirements:

Ethics and Professional Development (1 credit)
Foundations: 9 credits (3 courses)
Fundamentals and Applications: 12 credits (4 courses)
- A minimum of 3 credits in each category

Graduate Seminar: 2 credits
Mentored Projects: 8 credits (2 credits BME 429, 1 credit of Fall BME 594, 1 credit of Spring BME 594, 2 credits of summer BME 594
Total: 30 credits

List of existing courses that may be used to fulfill the requirements:

We will provide a matrix in which courses (existing and new) intersect technology areas. Students are required to take BIOE 590 (2 semesters) and BIOE 591. They are also required to take all 3 foundational courses including a new Numerical Methods course. Additional coursework includes BME 429, 12 credits of Fundamentals and Applications based courses of which 3 must be taken from each category, and 6 credits of BME 594 over the Fall, Spring, and Summer semester/sessions. The fundamental and applications courses are to be selected based on what is relevant to their careers. The courses are grouped here under options so that students can elect an emphasis if they desire. Other BIOE courses not listed can be used when they are offered.

Course	# Credits	Bio-imaging	Drug Delivery	Tissue engineering / Regenerative medicine	Bio-manufacturing	Biomaterials
Ethics and Professional Development	1					
BIOE 591 BIOENGINEERING ETHICS AND PROFESSIONAL DEVELOPMENT (Fall)	1					
Foundations (take all 3)	9					
BIOE 512 Cell and BioMolecular Engineering (Fall)	3					
BIOE 504 Numerical Methods in Biomedical Engineering (Fall)	3					
BIOL 472 Physiology (Fall) or PHSIO 571 (Fall)	3					

Course	# Credits	Bio-imaging	Drug Delivery	Tissue engineering / Regenerative medicine	Bio-manufacturing	Biomaterials
Fundamentals (take at least 3 credits)						
BIOE 501 Bioengineering Transport Phenomena	3		x	x	x	x
BIOE 503 Fluid Mechanics of Bioengineering Systems	3		x	x	x	x
BIOE 505 Bioengineering Mechanics	3			x	x	x
BIOE 506 Medical Imaging	3	x	x			
BIOE 508 Biomedical materials	3			x	x	x
BIOE 509 Mechanobiology	3					
Applications (take at least 3 credits)						
BIOE 510 Bio mems and Bionanotechnology	3		x	x	x	x
BIOE 514 Quantitative Microscopy	3	x	x		x	
BIOE 515 Cell Mechanics and Biophysics	3			x	x	
BIOE 517 Biomaterials Surface Science	3		x	x	x	x
BIOE 519 Artificial Organ Design	3				x	x
BIOE 518 Organic Nanobiomaterials	3		x	x	x	x
Mentored Projects	**8**					
BME 429 Biomedical Mechanics and Techniques Lab (Spring)	2					
BME 594 Research Projects (Fall/Spring/Summer)	4					

With respect to fundamental courses, students who have had identical courses at another institution before coming to Penn State may choose to substitute a higher level related course from BME or another department.

The required BIOE 591 course, taken by all students in the program, will address biomedical ethics and responsible conduct of research through readings and class discussions.
Readings and discussions will cover both Penn State and NIH regulations regarding ethical treatment of animals, data management, conflict of interest, and intellectual property. At least 5 hours of class discussion time will be devoted to these topics. Additionally, all students in BIOE 591 will be required to complete the online PSU SARI training through the CITI program. These activities will ensure that students in the program meet the University's SARI@PSU requirements.

- Scholarly paper and presentation. Each student must follow the guidelines outlined below regarding their scholarly paper. A pdf copy of the final paper must be submitted to the Graduate Program Coordinator (Stacy Smith, sls60@psu.edu) via email. A presentation of the scholarly paper must be given during the second summer session after the paper has been submitted. The presentation will be 12 minutes with 3 minutes for Q&A.

Example Timeline for Biomedical Engineering M.S. Degree

Fall

- Take 14 credits of courses including BIOE 590 and BIOE 591
- Take 1 credit of BME 594
- Identify adviser
- Submit project summary

  The first month of the program during the fall is to identify the research adviser with the assistance of the M.S. Program Director and carry out a literature review for the proposed research while the rest of the first semester is working on the project. Students will identify their research interests and faculty will be contacted. If a large number of students are interested in working with a particular faculty member, we will make an effort to redirect the student to another faculty member in a similar field.

Spring

- Take 12 credits of courses including BIOE 590 and BME 429
- Take 1 credit of BME 594
- Submit title and one-page proposal on mentored research

Summer

- Take 2 credits of BME 594
- Submit first draft of scholarly paper by July 1st
- Submit final scholarly paper by August 1st

Through the fall offering of BME 594, students will be exposed to the faculty research labs via lab tours and brief faculty presentations covering their current research projects. Facilitated discussion by the MS program director will help guide students towards identifying their advisers.

Scholarly Paper Format

The format of the proposal will be similar in style to an NIH R21 proposal. Examples of NIH proposals can be found online at: http://www.niaid.nih.gov/researchfunding/grant/pages/appsamples.aspx. The proposal should contain the following sections:

I. Title Page (see Appendix)

II. Summary (1/2 page)

State the proposal's broad, long-term objectives and specific aims, making reference to the health or biology relatedness of the project. Describe concisely the research design and methods for achieving these goals. Avoid summaries of past accomplishments and the use of the first person.
This abstract is meant to serve as a succinct and accurate description of the proposed work when separated from the proposal. Do not exceed the ½ page limit. Make page separate from title page and specific aims.

III. Specific Aims (1 page limit)

State concisely the goals of the proposed research and summarize the expected outcome(s), including the impact that the results of the proposed research will exert on the research field(s) involved. List succinctly the specific objectives of the research proposed, e.g., to test a stated hypothesis, create a novel design, solve a specific problem, challenge an existing paradigm or clinical practice, address a critical barrier to progress in the field, or develop new technology. A figure on the specific aims page is allowed.

IV. Research Strategy (6 pages)

Significance (max. 2 pages):
Explain the importance of the problem or critical barrier to progress in the field that the proposed project addresses. Describe the scientific premise for the proposed project, including consideration of the strengths and weaknesses of published research or preliminary data crucial to the support of your application. Explain how the proposed project will improve scientific knowledge, technical capability, and/or clinical practice in one or more broad fields. Describe how the concepts, methods, technologies, treatments, services, or preventative interventions that drive this field will be changed if the proposed aims are achieved.

Innovation (max. ½ page):
Explain how the application challenges and seeks to shift current research or clinical practice paradigms. Describe any novel theoretical concepts, approaches or methodologies, instrumentation or interventions to be developed or used, and any advantage over existing methodologies, instrumentation, or interventions. Explain any refinements, improvements, or new applications of theoretical concepts, approaches or methodologies, instrumentation, or interventions.

Approach (the remainder of the 6 pages):
Describe the overall strategy, methodology, and analyses to be used to accomplish the specific aims of the project. Describe the experimental design and methods proposed and how they will achieve robust and unbiased results. Discuss potential problems, alternative strategies, and benchmarks for success anticipated to achieve the aims. If the project is in the early stages of development, describe any strategy to establish feasibility, and address the management of any high risk aspects of the proposed work. Provide a tentative sequence and time table for the investigation.

V. Bibliography

Provide a list of all references cited in the above sections that is in the format of articles written for major journals, such as the American Journal of Physiology or Journal of Biomechanics. Citations within the text may be made by either author (year) or by number. Provide the full citation in the bibliography, i.e. authors, title, journal, volume, page numbers and year (do not use “et. al.” or give download information for standard references). The student is expected to have critically read and understood the publications that provide the foundation of their proposal. There is no limit to the number of references for the thesis proposal. The use of EndNote, Mendeley, or equivalent bibliographic software is strongly recommended.

VI. Appendix

The student should include as an appendix any code, design drawings and/or manuscripts on which he/she is first or middle author and which have been published, accepted, or submitted to date as part of their graduate studies. There is no page limit or format requirements for the appendix.

All text in the proposal (not including the appendix) should be typed single space and a minimum font size of 11 points should be used. A minimum 3/4 inch margin should be maintained on the top, bottom and sides of each page. Each page should be numbered at the bottom. Figures should all have legends, and images taken from the literature should be properly referenced.

Students submit a pdf file of the completed proposal by noon on August 1st of that year to the Graduate Programs Coordinator, Stacy Smith (sls60@psu.edu).

Final Grade

The final 2 credits of BME 594 will be based on the final scholarly paper and the presentation.

Intent to Graduate

You must activate the intent to graduate on LionPath during the semester in which you plan to graduate. This will put your name on the graduation list so that a diploma is printed for you. If you fail to meet the completion deadline, your intent to graduate will be removed. It does not carry over to the next semester.

Biomedical Engineering Graduate Faculty

Igor Aronson,* Ph.D., Huck Chair Professor of Biomedical Engineering, Chemistry, and Mathematics. Biophysics, materials science, and applied mathematics and chemistry.

Justin Brown, ***** Ph.D., Associate Professor of Biomedical Engineering. Musculoskeletal regenerative engineering.

Peter Butler,* Ph.D., Associate Dean for Education and Professor of Biomedical Engineering. Membrane biophysics, cell mechanotransduction, vascular physiology; use of quantitative light microscopy to investigate the molecular bases of vascular function.

Cheng Dong, * Ph.D., Distinguished Professor of Biomedical Engineering, and engineering science and mechanics; Department Head of Biomedical Engineering. Biomechanics, cellular mechanics, cell motility, cell deformation and cell adhesion in the microcirculation, computer modeling.

William Hancock, * Ph.D., Professor of Biomedical Engineering Motor proteins, cytoskeletal mechanics, quantitative cell biology.

Daniel Hayes, * Ph.D., Associate Professor of Biomedical Engineering and Chair of Graduate Programs in Biomedical Engineering. Biomaterials engineering for applications ranging from regenerative medicine to lab-on-a-chip technologies.

**Deb Kelly, ***Ph D, Professor of Biomedical Engineering and Director of Center for Structural Oncology. Cryo-EM, structural biology, In situ TEM, breast cancer, glioblastoma, pancreatic cancer.

Sri-Rajasekhar Kothapalli, * Ph.D., Assistant Professor of Biomedical Engineering. Focuses on developing novel optical, ultrasound and photoacoustic imaging/sensing technologies for both pre-clinical and clinical applications in cancer and neurological diseases

Xiaojun (Lance) Lian, * Ph.D., Assistant Professor of Biomedical Engineering. Directed Differentiation of human pluripotent stem cells to cardiovascular, blood, brain, and pancreatic cell lineages.

Xiao Liu, * Ph.D., Assistant Professor of Biomedical Engineering. Developing and integrating multimodal neuroimaging techniques and computational methods.

Keefe Manning,* Ph.D., Associate Dean for Academic Affairs, Associate Professor of Biomedical Engineering. Hemodynamics, pediatric heart defects, blood rheology and cardiovascular prosthetics.

Scott Medina, * Ph.D., Assistant Professor of Biomedical Engineering. Cell Signaling and Cancer, Nanomedicine and Drug Delivery, Tissue Engineering and Regenerative Medicine.

Justin Pritchard, * Ph.D., Assistant Professor of Biomedical Engineering. Cell and Molecular Bioengineering, Cell Signaling and Cancer.

Spencer Szczesny, * Ph.D., Assistant Professor of Biomedical Engineering. Tendon/ligament, multiscale mechanics, computational modeling, mechanobiology.

Meghan Vidt, * Ph.D., Assistant Professor of Biomedical Engineering. Musculoskeletal, Shoulder, Upper Limb, Medical Imaging, Orthopaedic.

Yong Wang, * Ph.D., Professor of Biomedical Engineering. Using synthetic oligonucleotides and polymers to develop antibody-like nanomaterials, programmable protein delivery systems, and tissue-like nanostructured biomaterials.

Pak Kin Wong, Ph.D., * Professor of Biomedical Engineering. Advanced biomanufacturing and microfluidics to study collective cell migration, and cancer metastasis. BioMEMS for clinical diagnostics.

Jian Yang, * Ph.D., Professor of Biomedical Engineering. Development of novel biodegradable elastomers. Tissue engineering small diameter blood vessels, cardiac tissues and nerve tissue. Cancer imaging, drug delivery and regulation of stem cells via functional polymers.

Nanyin Zhang,* Ph.D., Professor of Biomedical Engineering. Translational Neuroimaging and Systems Neuroscience.

Biomedical Engineering Graduate Course:

594 RESEARCH TOPICS (1-2 cr.) Supervised student activities on research projects identified on an individual or small-group basis.

Bioengineering Graduate Courses:

501 BIOENGINEERING TRANSPORT PHENOMENA (3 cr.) Application of the equations of mass, energy, and momentum conservation to physiological phenomena and to the design of artificial organs.

503 FLUID MECHANICS OF BIOENGINEERING SYSTEMS (3 cr.) Cardiovascular system and blood flow, non-Newtonian fluid description, vessel flows, unsteady flows and wave motion, wind-kessel theory, **TRANSMISSION** line theory.

504 RESEARCH TOPICS (3 cr.) Numerical methods and computational techniques for modeling physiological systems and medical devices. Topics include differentiation equations, finite difference methods and finite element methods. Programming and finite element modeling software will be covered. Examples include physiological systems at the organ and cellular levels, physicochemical analysis of biological systems, and transport phenomena in engineered devices. Computing programming experience is required to be successful in this course.

505 BIOENGINEERING MECHANICS (3 cr.) Application of the principles of continuum mechanics to characterization of the passive and active mechanical properties of soft and hard tissues and their constituent cells. Fundamentals of the description of stress and strain and advanced topics in visco-elasticity are considered to describe the normal and diseased state at the tissue, cellular and molecular level. Prerequisites: EMCH 210, ME 033 or equivalent.

506 MEDICAL IMAGING (3 cr.) Medical diagnostic imaging techniques, including generation and detection of ultrasound, X-ray, and nuclear radiation; instrumentation and biological effects. Prerequisite: PHYS 202.

507 TECHNICAL FOUNDATIONS IN FUNCTIONAL MAGNETIC RESONANCE IMAGING (3 cr.) Theory and applications of functional magnetic resonance imaging.

508 (MATSE 508) BIOMEDICAL MATERIALS (3 cr.) Properties and methods of producing metallic, ceramic, and polymeric materials used for biomedical applications. Prerequisites: None

509 MECHANOBIOLOGY (3 cr) Explore the molecular bases of cell mechanics and the role of mechanics in cell biology.

510 BIO MEMS AND BIONANOTECHNOLOGY (3 cr.) Build basic foundations for understanding electrical, mechanical and chemical transducers in biomedical applications through learning BioMEMS fabrication, design and analysis.

512 CELL AND BIOMOLECULAR ENGINEERING (3 cr.) Graduate level cell and molecular biology course for engineers emphasizing molecular mechanisms.

513 BIOENGINEERING LABORATORY TECHNIQUES (3 cr.) Laboratory techniques in cell molecular biology, protein biochemistry and cell culture with an emphasis on engineering analysis and quantification.

514 QUANTITATIVE MICROSCOPY (3 cr.) Application of advanced microscopy to quantification of cellular and molecular function.

517 (MATSE 517) BIOMATERIALS SURFACE SCIENCE (3 cr.) Special properties of surfaces as an important causative and mediating agent in the biological response to materials. Prerequisite: None.

519 ARTIFICIAL ORGAN DESIGN (3 cr.) Basic techniques and principles of a multidiscipline approach to artificial organs design. Prerequisites: None.

552 (**EMCH 552, IE 552) MECHANICS OF THE MUSCULOSKELETAL SYSTEM** (3 cr.) Structure and Biomechanics of bone, cartilage, and skeletal muscle; dynamics and control of musculoskeletal system models. Prerequisite: consent of program. Prerequisite or concurrent: BIOL 472

553 (**IE 553**) **ENGINEERING OF HUMAN WORK** (3 cr.) Physics and physiology of humans at work; models of muscle strength; dynamic movements; neural control; physical work capacity; rest allocation. Prerequisite: BIOL 041 or 472.

590 BIOENGINEERING COLLOQUIUM (1 cr.) Weekly series of seminars by speakers from outside and within Penn State University on new and developing research areas in Bioengineering, and presentations by registered students on their thesis research. All students are required to attend; M.S. degree students must register for four semesters and Ph.D. students must register every semester until comprehensive exam is passed.

591 BIOENGINEERING ETHICS AND PROFESSIONAL DEVELOPMENT (1 cr) Discussions focused on issues related to medical device development and marketing, responsible conduct of research, and meeting oversight requirements by Institutional review Boards for human studies and IACUC oversight of animal experiments.

596 INDIVIDUAL STUDIES (1-9 cr.) Opportunity for advanced graduate students to study independently in consultation with a faculty adviser.

597 SPECIAL TOPICS (1-9 cr.) This designation is assigned to new or developing graduate courses covering specialized areas of interest in Bioengineering. Past offerings have focused on topics such as advanced studies of cardiovascular function, advanced topics in artificial organ design and cellular biomechanics.

Some 400-level biomedical engineering courses may be used towards your degree in consultation with your adviser and/or advisory committee. Biomedical engineering courses are denoted by BME and can be found on the Schedule of Courses page at the following: http://soc.our.psu.edu/

Tips on writing papers, proposals and theses

Below are some words of wisdom about how to be efficient and effective in your scientific writing. One eternal truth is that writing is hard and to become a better writer, you must work at it and allocate sufficient time for both writing and revising. These tips refer to papers, theses, and dissertations, and are suitable for MS students, PhD students, and others.

Dissertation structure

A dissertation typically consists of an introduction chapter, some number of chapters that make up the various projects carried out and/or papers written during graduate studies, and a concluding chapter that ties everything together. If you have published papers, these can be included as chapters, there is no need to rewrite work that has been published or submitted. The peer-reviewed papers that come out of your work are the most important product of your research.

Getting started:

To start writing a paper or thesis, make an outline. Then fill in the outline with figures and tables that make up the results. Build your outline with successively more detail, and then replace these details with sentences and paragraphs and your written document will take shape. As you develop an outline go through it with your adviser to make sure you are on track.

To write a paper, write the Results first. Then write the Discussion in relation to the Results. Then write the Introduction and link it to the Discussion.

General writing tips:

- Generally getting a first draft is the hardest step. However, good writing requires multiple rounds of revisions. Don't underestimate the time required for revising and tightening text to focus ideas and clarify the presentation.
- Strive for clarity and brevity in your writing. Use first person ("we carried out the experiment" rather than "the experiment was carried out"). Put key action in verbs rather than nouns. Use active verbs. Avoid long introductory phrases or clauses and make subjects of sentences short and concrete.
- Minimize use of acronyms (if you use it 3 times or less, don't use acronym). Minimize use of jargon, and avoid lab jargon – consider renaming reagents, procedures, protocols, etc. for the purpose of writing (which is a different process than the day to day work in the lab).
- In revising text, distill your ideas, distill your sentences, and remove redundant text. Consider that adding more details can dilute your central message and most important points – readers can only take so much in so keep your focus.
- Throughout the thesis help guide your reader by using introductory sentences to paragraphs and transitions between paragraphs. You should strive for flow, and also give your reader signposts along the way to help guide them.
- In the age of spellcheck, there is no excuse for misspelled words and obvious grammar errors. Any thesis given to a committee must be free of spelling and grammar errors. If you feel writing clearly and using correct wording and grammar might be a problem, please have someone else look through the thesis first.
- In a paper, thesis or dissertation, the wording must be your own. No sentences can be derived form anyone else's work; this is plagiarism and any evidence of plagiarism will result in an unacceptable thesis, as well as other consequences.

Figures and legends

- Use figures and diagrams to help your readers navigate the key points.
- Take the time and care to make excellent figures. Think about the best way to plot the data to emphasize the point you are making. Do not use fancy Excel colors and shading. Make axes and labels large and readable. Images should not be pixelated.
- If images are taken from published work say that clearly and include reference number, e.g. "Image adapted from Jones et al (19)" . For theses you do not need permissions from journals to use figures.
- All figures should have a legend that includes figure number, figure title, and a description of every panel in the figure. It is OK if there is redundancy between the text and the figure legends – ideally a reader should be able to go through the document and look at the figures and read the figure legends and get the main points that way.

Abstract

- Write a good abstract. This is the first thing that everyone reads and the only thing that many read. It is important to make a good impression and summarize your work clearly and succinctly. ABSTRACT SHOULD BE NO MORE THAN ONE DOUBLE SPACED PAGE FOR MS AND UP TO 2 FOR PHD DISSERTATION.

Introduction Chapter

What to include:

- An overview of your field of study that sets up your key questions and hypotheses
- Transitions between sections to help make the introduction a logical whole
- Clear statement of key questions and hypotheses
- Figures and diagrams to help explain the points you are making.
- A paragraph at the end of the introduction that previews the rest of the thesis for the reader, describes chapters and how they relate to published work, and lays out collaborations involved in the work.

What not to include:

- A list of everything you can think of that might touch on your project

Middle Chapters (and Papers)

- Each chapter can (and ideally should) be a published or planned paper. If it is published make sure you clearly describe how the chapter relates to the published work (Is it the paper word for word? Is it the paper plus some additional data? Is it part of the paper? Be specific).
- At the beginning of each chapter you should set up the question you will be asking. You need to make your audience excited about the hypothesis or design goal - this means they need to understand what the hypothesis or goal is and why it is important.
- In writing a paper, make sure that the first paragraph of the Introduction and the last paragraph of the Discussion are conceptually linked. Conclude the Introduction with a paragraph that previews the results and sets up the rest of the paper.
- Organize the Results section as a series of sub-sections, with each referring to a particular figure or table. Describe fully in the text everything that is contained in the figures. Think of the Results section as describing a logical sequence of experiments, with each sub-section starting with a description of the experimental design, followed by a description of the resulting findings written in the past tense. Stating the question being addressed in each sub-section is a good organizational tool. Remember that the sequence of presentation need not (and generally should not) follow the timeline of the experiments; instead build the best story you can with the data that you have.

- Discussion
- The first paragraph is an important setup of the discussion. Make it a summary of the key results and a roadmap of the rest of the discussion.
- In the Discussion, be sure to describe how the results answer the question(s) you posed in the Introduction.
- Acknowledge limitations and how work agrees or conflicts with other studies.
- Discuss the implication of the work for the field and how it may impact other fields.
- At the end of each chapter you should have some sort of conclusion or wrap up section. What was the answer to your question? Why is it important?
- If you include work of others, make sure to clearly acknowledge their specific contributions in the figure legends.
- Materials and Methods can be included within each chapter (either before Results or after Discussion) or it can make up a separate chapter in the thesis.

Conclusion/Future Directions Chapter

- The goal of the last chapter is to position your work in the field. You should say what you have learned, how this has advanced the general understanding in the field. Include some models to summarize your work. Tie this text into points you raised in your Introduction Chapter 1.
- Point toward the next questions or design iterations and larger questions. Don't just focus on what you would do over the next months if you continued; instead, think in a larger perspective of the field and discipline.

Other writing resources

K.L. Turabian. A manual for writers of research papers, theses and dissertations. Chicago style for students and researchers. 8th edition. University of Chicago Press. – Has sections on research to writing, proper citations, and style.

K. Kelner. Tips for publishing in scientific journals. *Science Careers* (2007). DOI: 10.1126/science.caredit.a0700046

J. M. Samet. Dear Author – advice from a retiring editor. *Am J Epidemiol* **150**:433–436 (1999)

W.A. Wells. Me write pretty one day: how to write a good scientific paper. *J. Cell Biol.* **165**:157-58 (2004)

https://careers.ucsc.edu/grad/resources/index.html