The Proposal Playbook

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1 Overview

What makes a good proposal? What elements and structure are compelling? What makes the difference between success and not? As a graduate student (or perhaps a highly motivated undergraduate!), you may feel that proposal writing is a daunting task. This is not without reason – proposal writing is completely distinct from other writing assignments you have likely completed; writing laboratory reports and even scientific journal articles does not prepare you for constructing ideas and composing a compelling argument. Some of the prevailing challenge resides in teaching and experience: How do we teach someone to "have ideas"? How do we recognize if the scope of an idea is appropriate? How do I communicate this idea in a way that is persuasive? And, importantly, how do I deal with inevitable rejection?

I hate to say it ... but many of these questions are not easily answered by a simple document, and require a fair bit of effort and humility on behalf of the writer. In reality, the ability to answer these questions is constantly under (re)construction (much like the Denver Metro area). For many, grant writing does not come easily or naturally — it certainly doesn't come naturally to me! I would hazard that even seasoned veterans of the Proposal Meat Grinder still struggle with aspects of proposal writing.

Despite this somewhat unmotivating perspective, there is hope! Like most things in life, successful grant writing is a skill that can be learned, practiced, and improved. Unfortunately, this practice often comes in the throes of anxiety of writing your first graduate fellowship proposal. Although it is no substitute for beating your forehead against the proposal wall, the purpose of this document is to provide some guidance for best practices for proposal writing. As this document is intended for undergraduate and graduate students, it will focus primarily on graduate fellowship proposals that are typically $\leq$5 pages in length. These fellowship programs may include the National Science Foundation Graduate Research Fellowship Program (NSF GRFP), the National Defense Science and Engineering Graduate Fellowship (NDSEG), and the NASA graduate fellowship. For the most part, I attempt to keep this document as general as possible, so that the concepts and advice can presumably be translated to proposals of any length and scope. It is therefore up to the proposer to identify the necessary components of the proposals for their particular application.

Happy writing!

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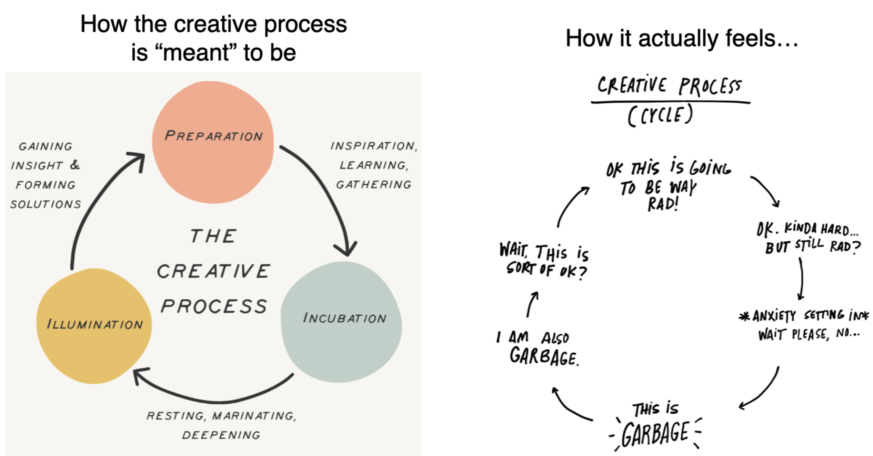
2 Iteration, Iteration, Iteration. . . and probably some more Iteration

Proposal writing is challenging for a multitude of reasons. Proposing scientific ideas fundamentally requires: (1) foundational knowledge of your discipline (e.g. chemistry, physics), (2) a healthy understanding of the state-of-the-art in your field *and* adjacent fields, (3) a fair bit of spite about the literature, (4) creativity to think outside the box and develop new ideas, and (5) the ability to craft a persuasive and well-written document. It also requires a non-trivial amount of *iteration*, including in idea generation and in the actual writing. Furthermore, a proposal has a distinct organization and purpose from other technical writing (e.g. lab reports, journal articles), and you (students) therefore have likely had very little practice in proposal writing in an academic setting. This last point is the reason this document exists!

2.1 How to have ideas

Having ideas is hard. Having good, *fundable* ideas is even harder. If you figure out a foolproof approach to having great ideas, please tell me. The creative process is often a bit painful, because it requires you to be reflective and self-critical of your own knowledge and ideas. It also requires a certain level of resilience, and an unwillingness to give in to the inevitable despair that will have you convinced that you should quit science altogether and open a bakery.



I have no magic solution, but here are some pieces of advice that I have found helpful:

- Start simple: Write a balanced chemical equation. Draw a simple cartoon sketch of a physical phenomenon. Ask simple questions: “Why/how does that happen?” Pretend to be a precocious toddler and ask “Why” about everything!
- A slightly cynical approach: What ticks you off about your scientific field/area? If that problem went away, how much better off would the world be? Once you’re thoroughly miffed, think creatively about possible ways to solve it.
- Your first idea will most likely not be your last: Commit to iterating on your ideas. Take care not to get stuck in your first ideas, and instead allow them to evolve. Go back to the drawing board often and don’t be afraid of the Delete button. I believe novelists say “Kill your darlings”.*

* “Kill your darlings” is a piece of writing advice that encourages writers to ruthlessly cut or revise any part of their work, even if it’s something they love or are particularly proud of, if it’s not serving the overall story effectively.

- Dig deeper: As your ideas coalesce, ask yourself: "How could I push this even further?" or "How can I break this?"
- Identify risks: What if your core idea doesn't work? How can you reframe your ideas such that the proposal will be a success, even if your original hypothesis is wrong? This is key! Funding agencies ideally like to fund successful projects, so the ability to think about how to mitigate risks can help your ideas evolve.
- Do not take anything for granted – just because Dr. So-and-So said something in a paper does not mean it is true. *Think critically* about the literature and the potential for alternative hypotheses.
- Rubber Duck your ideas: "Rubber ducking" is a term coined in software engineering, in which talking to a literal rubber ducky about code helps to identify the underlying causes of problems. In this vein, find a friend and force yourself to talk about your ideas out loud. Blather away at your friends and colleagues, and ask knowledgeable people about your ideas.
- Turn your ideas upside down: It is easy to copy well-known approaches and ideas in the literature and to do something "incremental". But that is *boring*. If you find yourself in the Boredom Rut, try turning your idea on its head or try looking at the problem from a different angle. Take inspiration from unrelated fields (see bullet point about reading literature, below).
- Be okay with some insanity (at first): Think big, and be inspired! If you had infinite resources, what would you do and what crazy ideas do you think you could come up with? Then, create realistic boundaries on your Infinite Insanity.
- Read literature: Read across disciplines and decades. Older literature is ripe with unanswered questions that may have become answerable with new techniques/approaches available today. Don't skip the Introduction section – if it is well-written, it will likely highlight "white space" in the field. Use that to fuel and refine your ideas and to find other connected literature.
- Find inspiration everywhere: Similar to the prior bullet point, try to learn a lot about a lot, especially outside your area of study. Connections between seemingly separate disciplines can enable you to see creative ideas that others may not.
- Turn sad faces into opportunities: Is there a way you can turn a perceived challenge for one field into a benefit for another? For example: Ion conduction in semiconductors is bad for photovoltaics, but is good for applications in neuromorphic computing.
- Relax your brain: Let your brain incubate on ideas. Meditate and let your brain churn for a bit. Warning: take care that this does not turn into procrastination!

2.1.1 The Heilmeier Catechism

As you are developing your ideas, it is good to continuously reflect on your idea in the context of (*i*) the scientific field, (*ii*) the benefits and impacts to society, and (*iii*) the needs/interests of the funding agency. The *Heilmeier Catechism*, created by former DARPA director George H. Heilmeier, provides a framework of eight questions for researchers to fully understand the context, costs, and effort required to execute a given project.

1. What are you trying to do? Articulate your objectives using absolutely no jargon.
2. How is it done today, and what are the limits of current practice?
3. What is new in your approach and why do you think it will be successful?
4. Who cares? If you are successful, what difference will it make?
5. What are the risks?
6. How much will it cost?
7. How long will it take?
8. What are the mid-term and final "exams" to check for success?

These questions address both the scientific/technical validity as well as the scope and financial feasibility of a proposal. However, as graduate fellowships don't rely on the financial details, I've modified the Heilmeier Catechism below to align better with the focus of graduate fellowships.

Modified Heilmeier Catechism

1. What are you trying to do? What rad science are you trying to demonstrate, and what challenge/problem are you trying to solve? Articulate using absolutely no jargon.
2. How is it done today, and what are the limits of current practice?
3. What is new in your approach and why do you think it will be successful? (Logos Alert! 🧠)
4. Why is this idea timely? Why now? What has limited researchers' ability to address the challenge in the past? What advancements have occurred recently that now allow you to solve this problem?
5. Why you? What makes you the best person to carry out the work? (Ethos Alert! 💎)
6. Who cares? If you are successful, what difference will it make? (Pathos Alert! 💗)

Answering these questions will allow you to evaluate if: (a) your proposed ideas are actually solving a problem that is important and urgent (💗), (b) your proposed work is technically feasible (🧠), and (c) you are credible to execute the proposed work (💎).

2.1.2 Scientific Scope of Graduate Proposals

A common challenge that arises when "having ideas" is scope. My guess is that your initial idea generation will be very very broad and high level, and will thus lack depth. For example: "My proposal will develop a technology at the laboratory scale in year 1 and then scale up in year 2." My dude, that is a multimillion dollar effort. Graduate fellowships are "three years of one you's worth of work", and therefore must be much more specific and narrow in scope. What *specific* scientific question and hypothesis could you address in one year? Remember that everything takes a LOT longer than you expect — be ambitious but realistic.

One way to ensure your scope is appropriate is to have each Aim be approximately one year's worth of work. Note that this doesn't mean they are done chronologically! Rather, focus on three specific questions and hypotheses that each will take you about a year of work. Each question forms the foundation of your Aim. See Sections 4.4 and 5 for more details.

In similar vein, reading your PI's funded proposal on your project is a double-edged sword. On one hand, they likely have provided an excellent framework for thinking about your project. Your PI has probably done extensive work to identify/mitigate risks and develop deep scientific questions/hypotheses. However, PI proposals are often substantially broader in scope. They may leverage collaborations with other PIs or fund multiple graduate students/post docs. Additionally, these proposals are often 15+ pages and are therefore not a good example to follow for the shorter format of graduate fellowships.

2.2 Reviewing, Editing, Rewriting

Writing is an inherently iterative process. Every novel you have read has been through self-editing by the author, peer-editing from trusted friends and colleagues, and *then* rigorous feedback from an editor before it became published.

I'll take a bet that your academic writing career thus far has probably involved energy drink- and deadline-fueled mania to write a lab report or an essay that is due the next day. I'll bet that you have spent very little time reflecting on the quality, organization, and word choice. I bet even more money that you have not done a good deal of rigorous editing or even completely rewritten these assignments. While these first drafts may have been "good enough" to pass your undergraduate lab courses, I'm sorry to say that it will not cut it in the landscape of competitive proposal writing.

Fear not! This is yet **Another Opportunity for Growth** (I call them "**AFOGs**" – I'll let you guess what the 'F' stands for). You will need to learn the art of critical self-reflection. You will need to see your work and have the humility to recognize when it needs to be better and the courage to delete it and start over. I will not pretend that this is trivial – letting go of hard work you have put in is always challenging. (I have PAGES AND PAGES of rejected writing that I save in a separate document! Saving it helps me feel that it is not "gone", but simply saved elsewhere in case I ever want it again). Recognize that this is part of the process of idea generation *and* of writing, and be at peace with that.

My hope in writing this section was not to make you feel like this is all an impossible, horrible task. Rather, the goal of this section is to empathize with you – proposal writing *is* challenging. You are probably here because, you (like me) are a Try Hard™. Although the act of writing words on paper becomes faster and easier with practice, the act of generating and refining ideas, codifying them into a document, and then editing that document is uniquely challenging for every proposal I have ever written. However, these challenges are not insurmountable, and the purpose of this document is to help alleviate some of the common pain points that students (and professionals) face.

3 Ethos, Pathos, Logos

Let's abstract away from "writing a proposal" for a moment and consider its purpose, in general. If you said "The purpose is to get money!", you are absolutely right! But how do you convince someone with limited time, money, and energy to make it rain sweet dolla billz on you and your idea? In this light, we have to consider the three core tenets of successful *persuasive rhetoric*: **Ethos, Pathos, and Logos**. I will describe these concepts here in the context of a scientific proposal. Throughout the document, I will also include notes that reference Ethos (💎) / Pathos (❤) / Logos (🧠) where they arise.

💎 **Ethos.** *Ethos* (Greek for "character") is concerned with *credibility and trust* in the abilities and character of the writer. Successful use of ethos will address the question: "Why you?" In the context of a scientific proposal, the writer must convince the reader that they have the ability, knowledge, and resources to execute on the proposed work. Furthermore, one must make an argument that they themselves are the best person to execute this work.

Credibility can be demonstrated in a scientific proposal in several ways:

- What experiences do you have that point to your success in this field?
- Do you have the resources necessary to execute the proposed work? Does your research group/PI have the expertise to support you?
- Have you done due diligence in accurately framing your proposed ideas in the context of the literature? Do you cite appropriate and relevant studies?
- Does your writing demonstrate confidence in the proposed approach?
- Have you identified potential pitfalls and risks and considered how to address them?
- Are you honest and realistic about the potential impact of your proposed work?

❤ **Pathos.** *Pathos* appeals to the reader's *emotions and values.* "Tug on their heart-strings so they tug on their purse-strings", as it were. This could appeal to a broader societal impact (e.g., climate change) or more personal/human impacts (e.g., curing cancer). Be careful here: it is easy (lazy) to overpromise that your proposal will cure humanity's general apathy towards global warming or solve a problem that has eluded scientists for decades. Realistically, it won't – sorry. However, *it is not necessary to save the world or have an end-use application to strongly motivate a proposal!* It is up to you as the writer to identify the core values that your reader (and funding agency) care about and to write a narrative that empathizes with these values!

Pathos will be unique to every proposal, and there is not necessarily a one-size-fits-all approach to incorporating pathos. However, you will likely find evidence of pathos within the "Motivation" and "Impact/Significance" sections – this is where you have an opportunity to appeal to a broader set of readers and to the potential societal impact of the work. Successful use of pathos should make the reader/funding agency think "Wow yeah, that would be great if we could solve that problem!"

🧠 **Logos.** *Logos* appeals to the reader's *logic and rationality.* As this is a technical proposal, logos pervades throughout the document. Successful logos must be accomplished through both the structure and organization of the document as well as within the technical arguments occurring at the sentence/word level.

Anatomy-level logos considerations:

- Does the document flow logically?

- Does the structure of the document follow the guidelines of the funding opportunity?
- Are the sections clearly delineated?
- Do the figures bolster the narrative?
- Is the "shape" of the narrative – including breadth and depth – appropriate? (More on this later).
- Is the scope of work achievable in the proposal timeline? Is the scope too narrow? (Note a little bit of ethos 💎 here!)

Argument-level logos considerations:

- Are the arguments sound?
- Do the proposed activities address both the specific *and* high-level technical goals of the proposal?
- Do the specific activities tie together in a way that is logical?
- Do you appropriately consider alternative hypotheses and understand potential pitfalls and risks?
- Do your prior experiences logically lead to the proposed activities? (More ethos 💎!)
- Are the proposed hypothesis testable and falsifiable? Are alternative hypotheses considered?

4 Proposal Anatomy

The purpose of this section is to describe, qualitatively, the general components of proposals and how to construct them. **Pitfall Alerts!** are included throughout this section – these alerts are to warn you of traps that are easy to fall into when writing and are often reflections on mistakes I have personally made.

4.1 Motivation

Although the actual sections of a proposal may differ based on the program, one thing is common between all successful proposals: a strong motivation at the beginning of the proposal. This sets the stage for your proposal and can make or break it. This is your opportunity to capture the intrigue of your reader – do not waste it! It can be *extremely* tempting to begin your proposal with an exhaustive literature review and introduction that illuminates the current state of the art in your field in all of its glory. **RESIST!** This is a proposal, not a journal article or a laboratory report! Don't "bury the lede"![†] The reader should be able to identify the core problem you are going to solve within the first 1-2 paragraphs ($^1/_2$ page) of your proposal.

4.1.1 But & Therefore / Happy-Sad-Happy+Goal

The opening statements in the Motivation section of a proposal tend to follow a specific "mad libs"-esque format that has been coined in storytelling as the "But & Therefore" structure. This structure was actually popularized by South Park creators, Trey Parker and Matt Stone! (Check it out!) This narrative format is used widely – from public speeches to persuasive rhetoric to screenwriting to scientific proposals. It works because it generates *tension*, which drives the (scientific) narrative forward.

Here, we will build on the O.G. "But & Therefore" method and instead refer to it as "Happy Sad Happy + Goal" (HSH + G), (term coined by Prof. Eric Toberer).

Happy Face 1. This statement (or statements) illustrate the rad topic of your proposal/field. This is the first sentence (or sentences) of your proposal, and should be punchy! The reader should immediately know what the proposal is going to be about, and it should hint at the stakes/impact.

Note: The scope of Happy Face 1 is important to consider, because it sets the scope of the problem you seek to solve. In 3 years, you are realistically not going to solve a huge, broad problem. E.g. Leading with "Solar energy will revolutionize our future" is super broad and could point to any number of potential proposal directions. Because graduate proposals are relatively short, you just don't have the real estate to spare. Get to the point: "Hybrid perovskite semiconductors have revolutionized solar energy conversion, enabling device efficiencies that rival those of conventional silicon solar cells." This Happy Face is far more specific (though is still broad in the context of the hybrid perovskite field). The reader immediately knows that the proposal will be focused on hybrid perovskites for solar energy.

Sad Face. This statement or statements highlight a key problem associated with **Happy Face 1**. Often, these statements begin with contradictory words, such as "**But**", "However", "Yet", "Despite", etc. This conflict generates excitement and drives your research proposal forward. The Sad Face should lay out the stakes and strike the right level of specificity. For example, a Sad Face that is too specific will lose the reader in the details (e.g., "However, no one understands how

[†] A lede is the introductory section in journalism and thus to bury the lede refers to hiding the most important and relevant pieces of a story within other distracting information.

systematically replacing potassium for sodium will affect XX.” This is way too specific in scope, and leaves the reader wondering why potassium should or shouldn’t be replaced with sodium or why this is a problem in the first place. On the flip side, a Sad Face that is too broad will appear unfocused (e.g., “However, the impact of chemical substitution is not understood.”). This scenario leads the reader to panic a bit: What chemical substitutions?! Impact on what?! *Your reader should feel urgency, not anxiety.*

Happy Face 2. The second Happy Face is your “**Therefore**” statement, and can be addressed a few different ways. (1) Highlight a new approach that has never been applied to this problem before, but could really address this challenge. (2) Highlight the opportunity that this challenge presents and the impact that solving the Sad Face would have on the field. (3) Highlight preliminary work that shows you have been trying to address this challenge – essentially, answers the question: “Why you, and why now?” Happy Face 2 should also directly lead to the goal of your proposal.

Goal. This statement (or statements) should highlight what you are going to do in the proposal. This statement must directly address the Sad Face and should feel like a natural evolution that falls out of Happy Face 2. This statement should be bolded or italicized – that way, your reader cannot miss it. You may also choose to frame this as a broad scientific question instead. Example: “The goal of this proposal is to XX.” or “This proposal will address the following scientific question: How does XX lead to YY?” You may also include a hypothesis that you will test immediately after your goal statement. Remember that the hypothesis should be testable and falsifiable, and should directly couple to the Goal statement. More on hypotheses in Section 5.

Happy-Sad-Happy-Goal Examples. Can you identify the components of the Happy-Sad-Happy-Goal structure?

Example 1. Solid-state batteries hold the potential to advance energy storage technologies by replacing the flammable liquid electrolyte with a solid-state ion conductor. Yet, their widespread utilization is limited by the lack of solid-state electrolytes (SSEs) made from locally-sourced chemistries that simultaneously exhibit high room temperature ionic conductivity and wide electrochemical stability windows that may enable their use of lithium metal anodes and high voltage cathodes. Ternary lithium metal chlorides, such as Li_3MCl_6 and $Li_2M_{2/3}Cl_4$ ($M = Sc^{3+}$, Y^{3+}, In^{3+}), are an exciting class of candidate SSEs; they can exhibit moderate to high ionic conductivities and improved electrochemical stability with oxide cathodes and lithium anodes compared to many state-of-the-art SSEs. While these materials show exciting properties, they are comprised of expensive rare-earth metals that will limit their widespread applicability in solid-state batteries. Identifying new lithium metal halides comprised of earth-abundant materials that exhibit fast ionic conductivity and wide electrochemical stability windows are crucial to accelerate the development of electrolytes for all-solid-state-batteries. **The goal of this proposal is to enhance the ionic conductivity of earth-abundant, halospinel-based solid-state electrolytes by controlling lithium conduction pathways, and to understand how cation composition impacts electrochemical stability with Li anodes.** (*Credit: Abby Cardoza*)

Example 2: Functionally Graded Materials (FGMs) are sophisticated composites that can be produced through advanced additive manufacturing (AM) techniques, allowing for the customization of material properties in components that must endure extreme conditions [1]. This will enable the next generation of materials, essential for enhancing operational performance and endurance, by leveraging additive manufacturing to tailor material properties, improve structural efficiency, and integrate the ability to repair existing structures; furthermore, directly aligning with the “Aerospace

Structures and Materials" research focus area found in BAA N0001425SB001 [2]. By blending two or more materials, FGMs optimize mechanical and thermal properties through a gradual transition in composition, resulting in a bulk structure that harnesses the advantages of each component. However, a significant challenge in metal FGMs lies in the presence of internal defects, particularly pore characteristics, introduced during the additive manufacturing (AM) process at the interface between dissimilar metals [3]. Internal defects in AM metals can cause stress concentrations, which compromise mechanical performance and can lead to catastrophic failure. Concurrently, recent studies demonstrate that AM processed SS316 leads to double the yield and ultimate strength than that of wrought materials while, provided defects are minimized [3]. Despite these advances, much of the existing research has focused on quasi-static loading, with limited exploration of high strain rate, high temperature behavior. While some progress has been made, the role of internal defects on the dynamic thermo-mechanical behavior of these materials reamin poorly understood. **With the support of the NDSEG fellowship, I will investigate the dynamic thermo-mechanical behavior of internal defects in additively manufactured functionally graded materials, focusing on stainless steel 316L / Inconel 718 pore morphology and distribution of as a model material system.** (*Credit: Max Kephart*)

Example 3: Hybrid organic-inorganic perovskite halide semiconductors challenge existing crystal-chemical paradigms of semiconductor materials, in that they exhibit excellent electrical performance in photovoltaic devices despite the presence of significant crystallographic disorder. The apparent tolerance of these materials, including $CH_3NH_3PbI_3$ and Cs_2SnI_6, to the presence of both a) intrinsic point defects and b) local distortions of the crystallographic lattice remains poorly understood, and a thorough understanding of the interplay of disorder and functional properties is paramount in designing improved materials for applications such as photovoltaics. While the organic components do not comprise the frontier electronic states responsible for the electronic properties, recent reports have suggested that the long carrier lifetimes observed in materials such as $CH_3NH_3PbI_3$ may originate from domains of permanent polarization from preferred orientations of the dipolar methylammonium cation or dynamic local distortions of the inorganic framework caused by H-bonding-like interactions of the NH_3^+ group with nearby halogens. **The purpose of my research is to elucidate the role of organic inorganic coupling in local structural distortions of the hybrid vacancy-ordered double perovskite $(CH_3NH_3)_2SnI_6$ in order to understand the influence of disorder on optical and electronic properties in these materials.**

Note: In very short proposals (NSF GRFP, 2 pages), the Motivation and Background sections are often interleaved. In this case, the Happy-Sad-Happy structure is interwoven with literature examples that highlight the state-of-the-art and support the motivation for the proposal. Below is an example in which both the Motivation and Background sections are combined.

Example 4 (Motivation-Background Combo). Multivalent Mg batteries enabled by solid-state electrolytes (SSEs) offer higher volumetric energy density and improved sustainability over Li ion batteries. However, fast, low-temperature Mg-ion conductivity in the solid-state is challenging due to the strong Coulombic attraction of the divalent Mg ion to the anionic lattice. This challenge is reflected in the scarcity of known solid-state Mg-ion conductors. 12408 Mg-containing compounds are listed in the Inorganic Crystal Structure Database (ICSD), but Edisonian efforts to discover Mg ion conductors have generated only eight experimentally-reported solid-state Mg ion conductivity values. Among these, Mg SSEs with the highest reported ionic conductivities include $MgZr_4(PO_4)_6$,[REF] spinel $MgSc_2Se_4$,[REF] and hybrid organic-inorganic $Mg(BH_4)_2(NH_3BH_3)_2$.[REF] These materials have wildly different compositions and crystal structures, which has prevented establishment of a cohesive set of materials design principles for fast Mg-ion transport. Therefore, transformative advances in Mg SSEs will require capitalizing on limited Mg ion conductivity data to develop ubiquitous design principles for solid-state Mg^{2+} transport.

Semi-supervised machine learning (SSML) has been previously shown to leverage sparse conductivity data sets to identify descriptors for high conductivity SSEs.[REF] SSML is especially valuable when experimental data is limited because it uses computational descriptors to organize materials into clusters. These descriptors (e.g., bonding, electronics) can be universally applied to all structures, even if experimental data points may only exist for a few structures. When experimental labels are then applied to the clustered data, it becomes possible to identify novel, promising materials via their association with known high performing materials within the same cluster. SSML can be adapted from previous methods to harness a much smaller data set of Mg ion conductivities, enabling identification of high-performing Mg conductors. **The goal of this proposal is to couple semi-supervised machine learning (SSML) with experimental synthesis and validation to enable discovery of new Mg ion conductors.** *Hypothesis: Large lattice volume, high concentration of vacancies, polarizable host ions, and low Mg coordination will correlate with high Mg-ion conductivity.* (*Credit: Shelby Galinat*)

4.2 Significance/Impact

The purpose of this section is to convey the broader importance of your work beyond the immediate Sad Face you will solve in the proposal. You should answer the question: "How does this work benefit the funding agency, science, humanity, or society?" (Pathos alert! 💗) Are there other scientific fields/technologies that would benefit from this work beyond the Science Silo you live in? (Logos alert! 🧠)

Where does this section go? Great question, I'm glad you asked. Personally, I like it to follow the Motivation section – this is because it punches the reader in the face with why this idea is important. In many graduate fellowship proposals, the *how* is often much less important than the *why*; i.e., your ability to articulate the importance of solving a problem is more critical than the description of how you will solve it. (At the professional level, this is no longer strictly true, but I digress). So, I like putting it early in the proposal.

Note: In very short proposals (NSF GRFP, 2 pages), this section gets eaten into the specified Intellectual Merit / Broader Impacts sections. Many folks put these at the end, but there is an argument to include them earlier.

⚠ **Pitfall Alert!** Here, it is very easy to overpromise/overexaggerate and lose credibility (Ethos! 💎). Keep your impact lofty but realistic. Consider also how the scientific principles you learn can be applicable to other scientific fields/disciplines. For example: While I might write a proposal focused on solid-state ion conduction for batteries, I could also explain that understanding these physical processes is broadly impactful for other applications (e.g. fuel cells, neuromorphic computing, etc.) This is a way to capture "Broader Impacts" in a way that has scientific credibility.

4.3 Background and Preliminary Results

You've done such a good job holding out on your desire to projectile vomit all of your considerable knowledge about your field onto the page. Now is your time! The purpose of the Background section is to "teach" the reader about the current state-of-the-art in the field. Here is where you will include substantial references to relevant scientific literature. Your focus should be on teaching the field of study, including what is known and what is not known. The unknown "white space" should also reflect your Sad Face from the Motivation page. The Background section is also the place for you to highlight your relevant prior work and to show off your credibility in this space (Ethos alert! 💎). This is also where you can highlight that you have the resources necessary to execute the proposed work.

Scope. Although you have probably (hopefully?) read **a lot** of literature surrounding your topic, you will not have the space to include all of it. Indeed, including all of it will bog the reader down in unnecessary detail and could distract from the radness of your proposal ideas. It is your duty as the writer to distill your knowledge of the state-of-the-art into the appropriate scope for your reader to understand. Be conscientious about depth and specificity, and try to avoid highlighting the minutiae of your field. On the flip side, however, a Background section that is too broad or vague will not provide ample information/context for your reader to understand how your work fits into the broader field.

⚠ **Pitfall alert!** It is tempting to include an extensive, Wikipedia-style background to teach your reader the underlying scientific concepts. RESIST! While a little bit of textbook-style teaching is okay when used with restraint and where absolutely necessary, you will lose your reader if you give them a half a page of "Background" that is just Wiki-vomit. Why? Because there is no *context*! Your reader will be trying to connect the textbook teaching to what they just read in your Motivation section, and that is a big mental lift. Be empathetic to your reader and do it for them!

Synthesizing Literature. Inclusion of literature sources in your Background section should read as a *synthesis* of the literature, not a "book report". Consider the difference below:

1. "Smoky et al. showed that mixing red and blue dye produced purple.[1] Bubbly et al. showed that mixing yellow and blue dye produced green.[2]"
2. "Prior literature has demonstrated that mixing dyes results in a product that is a linear combination of the component colors.[1,2]"

The second sentence concisely summarizes the results of the two studies. More importantly, however, it identifies a common thread that emerges out of the independent results (e.g. "the product is a linear combination of the component colors"). A sure-fire way to avoid a book report is to *not* start your Background paragraphs with a literature citation. Rather, begin your paragraphs with a true Topic Sentence/Thesis Statement and use literature examples to support the thesis.

My Approach. Honestly, I find it difficult to outline the Background section in my brain. It often takes me multiple iterations/drafts to get it right. Be not afraid of the Delete button! My approach is to first whiteboard/bullet list all possible facts, tidbits, ideas, etc. from the literature that the reader *might* need to know to understand the project goals. Then, I will group similar ideas together into themes; based on this grouping, I'll also identify things that are superfluous and remove them. With the remaining ideas, I will then write thesis sentences that form the first sentence of each of the paragraph(s) in the Background section. Then, I will revise and add in extra context that I feel may be missing. *This is NOT the only approach to developing a Background section!* This is what I have found helps my brain organize and synthesize information, particularly when I feel overwhelmed by the volume of information that exists in a given field. However, you may have an entirely different approach that sparkles for the way your brain works. Some people build logical and complete outlines first, while some mind-map concepts together. Some folks just enjoy a good word vomit session, followed by extensive editing. Develop a method that works for you and use it!

⚠ **Pitfall Alert!** Using AI to help you write a Background section is a double-edged sword. On one hand, it is okay at high-level, Wikipedia-style garbage word vomit. It is far less good at a critical synthesis of literature and identifying true research white space in a way that delivers that right amount of depth and breadth required for a good Background section (trust me, I have tried!). Do not get suckered into wasting time trying to prompt ChatGPT into oblivion to help you write this section from scratch. Instead, use AI as a tool to help you outline or condense paragraphs or rewrite clunky sentences. As always, be wary of hallucinations. Remember that large-language models are trained on *existing* ideas – as such, they don't really know how to create new ideas out of nothing. (Our jobs as human scientists are safe... for now 🤖.)

Preliminary Results. Preliminary work is *also* considered Background. In fact, including it in the Background is a Big Brain Move™, because it boosts your credibility (Ethos! 💎) as being an integral and expert part of the field. This subsection also tends to come right before you discuss your Proposed Work/Aims sections, which helps set the stage for the work you are proposing!

4.3.1 Example Background/Preliminary Results Sections

Example 1 (Background). Lithium metal chlorides have attracted significant attention as potential candidates for SSEs, due to their high oxidative stability that enables stable cycling against high voltage cathodes.[2] Halospinels are a structural derivative of the ternary metal halide family that have recently demonstrated promise as candidate SSEs. Recently, Zhou et al. demonstrated that the halospinel $Li_2Sc_{2/3}Cl_4$ exhibits outstanding electrochemical stability up to 4.6 V v. Li/Li^+, low activation barrier for Li^+ hopping (0.335 eV), and a favorable three dimensional diffusion pathway formed from Li^+ disorder along the face-sharing octahedral-tetrahedral sites, giving rise to a room temperature ionic conductivity of 1.5×10^{-3} S cm^{-1}.[3] Interestingly, the spinel Li_2ZnCl_4 and inverse spinel Li_2MgCl_4 exhibit only moderate room temperature Li^+ conductivities of 10^{-7} S cm^{-1} due to the absence of vacancies in the Li/M sublattices that enable three-dimensional diffusion pathways.[4] This observation points to the critical role of cation disorder in dictating the battery-relevant properties of these materials. (*Credit: Abby Cardoza*)

Example 2 (Preliminary Results). From afar this proposed work looks ambitious, but nonetheless it is viable within three years of active research due to preliminary results conducted by myself and prior group members. My research group has developed computational and synthetic protocols for probing stability, structure, and transport of HEAs.

Stability: We have conducted initial experimental exploration of the (Ge,Sn,Pb)(S,Se,Te) phase diagram and computational studies of a subspace therein. To broadly understand the competing crystal structures, myself and collaborating group members have synthesized 94 unique compositions. Bulk polycrystalline samples were obtained using melt and mechanochemical processing, then hot-pressed to a dense pellet and equilibrated through high-temperature annealing. Using X-ray diffraction (XRD) and scanning electron microscopy (SEM), we have identified three unique crystal structures and the presence of miscibility gaps between them. All three crystal structures can be stabilized in high-entropy compositions. Computationally, we have demonstrated a workflow where we unite machine learned potentials (via open-source packages like NequIP) and statistical mechanics to predict alloy phase stability. Figure 1 exemplifies our work to date involving the subspace (Sn,Pb)(S,Se,Te) for supercell relaxations and prediction of local bond strains and phase stability therein. Still missing from this workflow is structural competition and active learning algorithms.[REF]

Structure: XRD has given us long-range structural insight of preliminary HEA samples, but the disordered local structure of HEAs necessitates local structural characterization and modeling. Members of our group have previously characterized (Ge,Sn)Te structures using pair distribution function (PDF) measurements from X-ray and neutron scattering.[REF] As with HEAs, this system exhibits structural disorder from multiple elements competing for the same lattice sites. This forms the basis of experimental strain analysis as a function of entropy-dependent disorder. Our computational workflow using NequIP encodes atomic structure more precisely into large supercells, enabling us to treat the crystals as ensembles of atomic motifs. Statistical mechanics analysis has shown that trends in local strain are entropy-dependent, lending confidence to entropy as a design parameter for manipulating structure-property relationships.

Transport: My first year of graduate research found experimental trends between entropy and thermal transport, justifying further exploration of this high-dimensional space. My efforts focused on a one-dimensional series ranging from PbTe to $(Ge_{0.1}Sn_{0.3}Pb_{0.6})(S_{0.1}Se_{0.3}Te_{0.6})$; all samples were successfully Bi-doped. I found that entropy is directly correlated with lower thermal conductivity, higher conduction band effective mass, and a slight increase in charge carrier scattering. Collectively, this results in a positive relationship between entropy and the thermoelectric figure of merit. Furthermore, we established that this system is flexible to doping to tune electronic transport. How these trends manifest beyond the one-dimensional series and into the Ge-Sn-Pb-S-Se-Te-Bi design space is unknown and motivates my proposed work. (*Credit: Helen Chaffee*)

4.4 Approach/Methods/Aims

This section goes by many names, but functionally serves the same purpose: What, specifically, are you going to do? What experiments will you perform, what samples will you make, what computation will you do? For a 3-year fellowship proposal, I would recommend breaking this down into three Specific Aims. Each Specific Aim should address a specific hypothesis or scientific question that lives under the umbrella of your broader Goal statement from above (Logos! 🧠).

As most graduate fellowships are short (2-3 pages), you will really only have space for about 1 (short) paragraph per Specific Aim. Consider the following formula for each Specific Aim:

1. Specific Goal of the Aim.
2. Specific hypothesis to be tested in the Aim.
3. Action(s) you will take to address the Goal and Hypothesis
4. Rationale for how each action will address the hypothesis.

⚠ **Pitfall Alert!** As a student researcher, you are often highly tuned into the *process* of doing research — e.g., the physical steps in chronological order that you will take to accomplish a goal. As such, it is extremely common to read proposals in which Aims 1-3 proceed in chronological order and in which the success of a given Aim relies on the success of the prior Aim. It is also common to read Aims that are actually tasks – e.g. Aim 1: Synthesis; Aim 2: Characterization; Aim 3: Computation. While it is not necessarily *wrong* to write Aims chronologically, it can be a bit of a trap. It leaves you open to the criticism: "What will you do if Aim 1 doesn't work?" If you find yourself falling into the Chronological Task Trap, think laterally! Rather than consider each Aim as a set of tasks, **consider each Aim as an opportunity to explore a specific sub-question of the proposal with its own specific hypothesis**. Then, each Specific Aim will have a set of tasks you will do to answer the questions. This allows you to potentially parallelize Aims and mitigates criticism from a grumpy reviewer. See the fillable worksheet in Appendix 1.

⚠ **Pitfall Alert!** It is tempting to list: "I will synthesize XX. Then I will perform NMR. Then I will collect UV-vis data." While this is the order of operations you will undertake in the lab, it does not tell the reader how these measurements will be used to address the specific goal/question/hypothesis that you set out to do! The emphasis should be on the *rationale* for the experiments rather than the details – the *why* is more important than the *how*. A rewrite of the above list could read: "In order to address this hypothesis, I will synthesize XX by prior literature methods.[REF] Proton NMR will confirm the successful integration of YY functional group onto the molecule. UV-visible spectroscopy will provide insight into how this functional group impacts the optoelectronic properties of the molecule; if my hypothesis is correct, then I expect the absorption spectrum to shift to higher energies."

⚠ **Pitfall Alert!** The Aims must be connected and cohesive (Logos alert! 🧠). All three Aims should directly address the bolded Goal statement you made in the Motivation section. Each Aim should carry its own weight (e.g., one Aim should not be substantially weaker than the others). Take care to consider how the Aims play off of one another.

4.4.1 Example Aim Paragraphs

Example 1. *Aim 1: Enhancing ionic conductivity through aliovalent substitution.* The goal of Aim 1 is to introduce lithium vacancies and understand how the vacancies change the overall crystal structure and ion transport pathways in spinel and inverse spinel structures. *I hypothesize that* Zr^{4+} *substitution in* $Li_{2-2x/3}Mg_{1-x}Zr_{2x/3}Cl_4$ *and* $Li_{2-2x/3}Zn_{1-x}Zr_{2x/3}Cl_4$ *will increase ionic conductivity by introducing lithium vacancies, and that the Mg and Zn analogs will exhibit distinct* *configurations of local cation order that impact Li^+ transport pathways.* Deficient chlorospinels, such as $Li_{1.6}Fe_{1.2}Cl_4$ and $Li_{1.52}Mn_{1.24}Cl_4$, demonstrate the highest RT ionic conductivities for halospinels due to the introduction of vacancies on the tetrahedral sites.[REF] Preliminary research in our group has demonstrated the successful synthesis of $Li_2Mg_{1/3}Zr_{1/3}Cl_4$ as an analogy to $Li_2Sc_{2/3}Cl_4$.[REF] Interestingly, we find that the preferred octahedral coordination of Mg leads unique motifs of cation disorder that lead to distinct differences in Li^+ transport pathways compared to $Li_2Sc_{2/3}Cl_4$. We will target and prepare members of the series $Li_{2-2x/3}Mg_{1-x}Zr_{2x/3}Cl_4$ and $Li_{2-2x/3}Zn_{1-x}Zr_{2x/3}Cl_4$ and evaluate their ionic conductivities. Average and local structural characterization will reveal how the cation sublattices evolve with increasing concentration of Li^+ vacancies. If vacancies are incorporated into the lattice and contribute the Li^+ transport, we would expect to observe an increase the overall conductivity across both series. From this, we will understand how cation and vacancy site preferences influence Li^+ migration pathways, as well as optimal vacancy to lithium ion ratios. (*Credit: Abby Cardoza*)

Example 2. *Aim 1. Observe Antimicrobial Mechanisms:* The goal of Aim 1 is to develop a new technique for exploring antimicrobial behavior. This will improve our understanding of the antimicrobial mechanism in carbon nanotubes by utilizing super-resolution microscopy to watch bacteria on the surface of a forest of carbon nanotubes. This is possible because of the advances in optical microscopy, which not only allows nanometer scale observations of living organisms but also the ability to capture video rate images. I will synthesize a forest of carbon nanotubes and prepare them with fluorescent dyes that will allow the capture of super-resolution images. First, I will use a dye that will allow the imaging of the outer wall of the bacteria as it interacts with the carbon nanotubes. Next, I will perform testing focusing on the internal structures and validate the results with the properties found using Density Functional Theory (DFT) from literature. (*Credit: Aryn Loew*)

Example 3. *Aim 1 - Stability:* We will pursue a temperature-sensitive picture of stability across the phase diagram of (Ge,Sn,Pb)(S,Se,Te). A NequIP interatomic potential will be trained to conduct alloy supercell energies; from an ensemble of supercell energies, alloy free energies will be produced. On account of the six-element combinatorics, obtaining supercell energies for these materials is pushing the scientific edge of what machine-learned interatomic potentials are able to model. Producing enough free energy calculations to define a convex hull is still challenging. Our Bayesian active learning algorithm will guide which compositions are sampled by NequIP, thus minimizing the necessary number of compositions needed to determine the hull. My background in entropy-centric visualization will be useful as we develop visualizations for this high-dimensional data. Ultimately we will reveal how entropy and temperature correlate with single-phase and multiphase regimes of the phase diagram, making it possible to target desirable nanoprecipitates or stable single-phases. Utilizing existing computational models from our group makes these goals achievable within the first year of active research.

We will evaluate NequIP's predictions, comparing the calculated lattice constant and coefficient of thermal expansion to measurements of experimental samples. To check stability results from the Bayesian algorithm, we will refer to X-ray diffraction and scanning electron microscopy on these experimental samples to confirm whether they are single-phase or multiphase. Our preliminary results with HEAs already use the proposed synthesis, and have historically produced new samples efficiently on a daily basis. (*Credit: Helen Chaffee*)

4.5 Wildcard Sections

Wildcard sections are those that are explicitly required by a given funding agency. Department of Defense proposals often require the proposer to identify how the proposed research aligns with the technical goals of the DoD areas of interest. The NSF explicitly scores GRFP proposals on "Intellectual Merit" and "Broader Impacts", and so these sections must be included and appropriately addressed. These sections could also be: "Significance" or "Impact to XX Field" or "Relevance to the ZZ Program". Check the review criteria for your specific program, and for each criterion listed create a section in your proposal.

If your program asks specifically about how your proposed work is relevant to their goals, it is very important that you clearly articulate this. How? Plagiarism! Look at the funding agency webpages. Many agencies publish documents that highlight needs/interest in a particular technical area; for example, "Electrochemical Energy Storage" or "Quantum Information Science". Find the document relevant to your proposal and *copy and paste the text from those documents* and then tell the reader how your proposal is connected.

4.5.1 Examples

Example (NDSEG). "The proposed project directly relates to the electrochemical research thrusts for both transport in electroactive species and REDOX chemistry under the DEVCOM ARL **BAA W911NF-23-S-0001-0002** for foundational research."

Example (Department of Energy). Transformative advances in memristors for neuromorphic computing are predicated on fundamental materials chemistry insights, including "(1) synthesis and characterization of new functional, tunable materials with enhanced properties and (2) fundamental understanding of the formation and migration of ions, defects and clusters, particularly under applied stimulus and away from equilibrium."[REF] **This program seeks to understand the fundamental relationships between structure and coupled ionic-electronic transport in solid-state materials as they pertain to potential applications in memristors**.

4.6 References

References should be appropriate and relevant. Include only references that you need. Check the application requirements if your References section must be included in the page limit or not. Also check if there are specific requirements for the format of the References.

5 Writing Scientific Questions and Hypotheses

Proposals are built upon scientific questions and hypotheses. The ability to develop compelling questions and well-crafted hypotheses are *crucial*, and seem to be a common pain point among young (and even experienced) researchers. Despite the fact that we talk about hypotheses often in the scientific process, we rarely *teach* how to construct hypotheses correctly or effectively.

5.1 Writing Scientific Questions

Scientific questions are core to doing science and therefore also proposal writing. Scientific questions should be somewhat open-ended. You may start a scientific question with *"How. . . ?"* or *"Why. . . ?"*. Alternatively, questions that begin with *"What role does XX play in YY?"* or *"What is the mechanism of. . . ?"* may also be effective.

In a proposal, questions can have various degrees of scope and breadth. For example, a proposal may have an overarching question that serves as an umbrella for multiple specific questions that form the foundation of the Aims/Proposed Work. A visual example may look something like this:

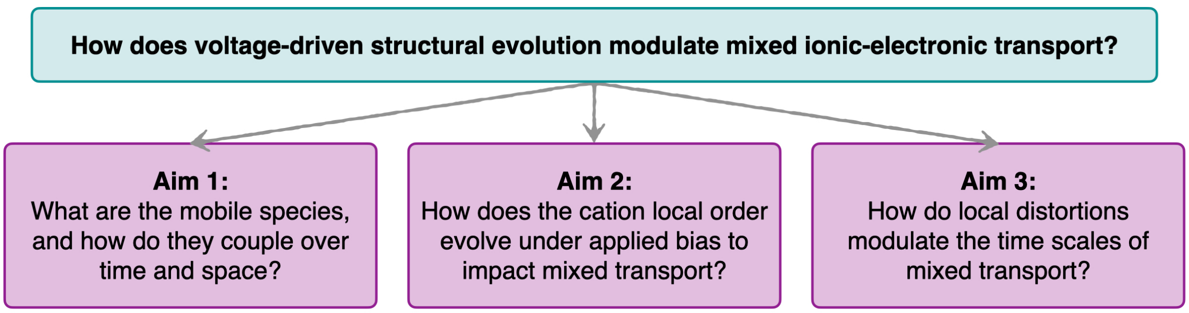


Figure 1: Example of a broad scientific question and the sub-questions that form three Aims. Note that this example is from a 5-year faculty proposal, and thus the sub-questions are still fairly broad in scope. In this proposal, each Aim had multiple specific experiments that fed into the specific hypothesis for that Aim.

⚠ **Pitfall Alert!** I often see novice proposal writers write scientific questions that can be simply answered with "yes" or "no". For example, it is common to see questions in the format of "Can XX do YY?" Frankly, this is not very compelling, because it reads as if we as scientists can all pack up and go home because, by golly, we have solved it and there's definitely nothing more to be learned in this field! To avoid the trap, keep your question more open ended.

5.2 Writing Scientific Hypotheses

⚠ **Pitfall Alert!** A hypothesis must be *testable* and *falsifiable* – this means that you must be able to design an experiment or analysis that gathers evidence for or against it, and there must be some possible result that would show the hypothesis is wrong. A hypothesis should also include a *rationale*, which points to a specific mechanism or causation for a given phenomenon. I often frequently see hypotheses that are not hypotheses. These range from tautologies ("No Duh" statements) to "Task-in-Disguise"-type statements. See examples below:

> **Example "No Duh" Hypothesis:** "I hypothesize that adding more blue dye will make the solution more blue." Yeah, No Duh!
>
> **Example Task-in-Disguise Hypothesis:** "I hypothesize that NMR will enable us to measure the environment of the protons." That is an approach to address a scientific hypothesis.

Example Good Hypothesis: "Dynamic reorientations of the cyanide anion will couple to ion motion via a paddle-wheel mechanism to enhance ionic conductivity in solid-state materials."

- ✔ *Testable:* I can measure cyanide dynamics and ion motion. If they are coupled and ionic conductivity increases, then the hypothesis is correct.
- ✔ *Falsifiable:* If cyanide dynamics and ion motion are not coupled, but ionic conductivity still increases, then coupled motion is not the driving force for this phenomenon. Alternatively, if the motions are coupled but ionic conductivity doesn't change, then the hypothesis is not true.
- ✔ *Rationale:* Li–CN coupling are predicted to occur via a paddlewheel mechanism.

6 Constructing the Proposal

Now that we understand the general components that make up a proposal, it's now time to consider the practicalities of writing the document itself.

6.1 Sectioning and Space Allocation

I find it useful to first start "blocking out" space for sections of the proposal. This should be done *before* you even consider writing an outline that includes any content. Essentially, we need to determine (*i*) what are the section headers, and (*ii*) how much space does each section need? This is helpful to visualize the proposal organization as well (Logos alert! 🧠). Make sure to consider the space for figures. Use a placeholder photo of something fun!

Figure 2: Placeholder Pupper! *Figure credit: Eric Toberer.*

This approach really helps me conceptualize how much space I have to convey a given idea. If I specify a page of Motivation and Background, that will (somewhat) prevent me from writing three pages followed by hours of weed-whacking and rewriting. For longer proposals (e.g. 15 pages+), this also helps me break a seemingly-monumental task into manageable chunks.

The specific blocks of content and space allocation will differ between funding agencies and fellowship programs, and it is up to you as the proposer to identify specific requirements that will affect the general structure of the proposal. Often, the description of the fellowship (or proposal call) will include specific review criteria or metrics that must be incorporated. For example, NSF requires "Intellectual Merit" and "Broader Impacts", and therefore you should *absolutely* include those as section headers.

6.2 Figures

Oh, how I love figures. I am of the opinion that great figures are key to distinguishing your proposal from others. In a world where funding opportunities are extremely competitive, how do you stand out? I could write an entire manifesto on the importance of informative and aesthetically-pleasing figures. For the sake of both of our sanity, I will refrain (somewhat). Instead, I'll try to touch on some of the most important things to consider when designing figures for a proposal.

Truth. A figure should convey the scientific *truth* regarding scientific phenomena as well as data analysis and interpretation. (Ethos 💎 and Logos 🧠, here!)

Legibility/Accessibility. Figures should be legible and accessible. Ensure that text sizes are adequate for your reader to view them. In a proposal, your figures will be less than half a page width, and must therefore still be readable at that size. Choose high-contrast, color-blind-friendly colors. Incorporate redundant coding (e.g., use different symbols, different colors, and different line styles) to ensure maximum readability, even in black and white. Export figures at high resolution so they are not blurry and horrible.

Aesthetics. Just because a figure is technical doesn't mean it should be ugly! While aesthetics are somewhat subjective, most folks (scientists or otherwise) can tell if something looks pleasing to the eye (Pathos alert ❤, maybe?). Keep figures simple, clean, and crisp. Ensure they are visually balanced. Choose colors that look nice together. Here's a non-exhaustive list of thoughts:

- Keep all text the same size and typeface – it is less visually distracting.
- Choose high-contrast, *off-primary* colors. For example, **primary blue** and **primary red** have reasonably good contrast, but are garish when put near each other. Maybe choose **teal** and **orange** instead!
- Find alternatives to legends where possible.
- Avoid multipanel monstrosities.

What types of figures should I include? In a scientific journal article, most of your figures are made based upon data you have collected and analyzed. However, the approach to choosing figures in a proposal is slightly different; in fact, you may not have any preliminary data to show if your proposal is in a field that is new to you!

My usual approach to figures is approximately 1 figure per page. I like a nice, schematic-type figure on Page 1 in the Motivation section. This figure should visually convey the Goal of the proposal — the figure's message should mirror your bolded Goal statement and/or overaching Hypothesis. Some examples are included on the following page.

For figures on subsequent pages, you have a few options. My opinion is that it is best to include relevant preliminary data you may have. This illustrates that you have the scientific credibility to do similar work (Ethos alert! 💎). However, you may be new to a project and a field and your preliminary data may be scarce. In this case, you have a few potential options. (1) Use published data from a similar project in your research group to highlight your group's/advisor's credibility in your discipline. (2) Include another illustrative figure. (3) Pull data from relevant literature as an illustrative example of the data you will collect.

Note: For very short proposals (e.g., NSF GRFP, 2 pages), you may find that accommodating one figure per page is very challenging. In this case, you may consider a single incredible figure to comply with the space constraints or choose something that can be incorporated at relatively small size. Do not remove all of the figures altogether!

6.2.1 Example Overview/Schematic Figures

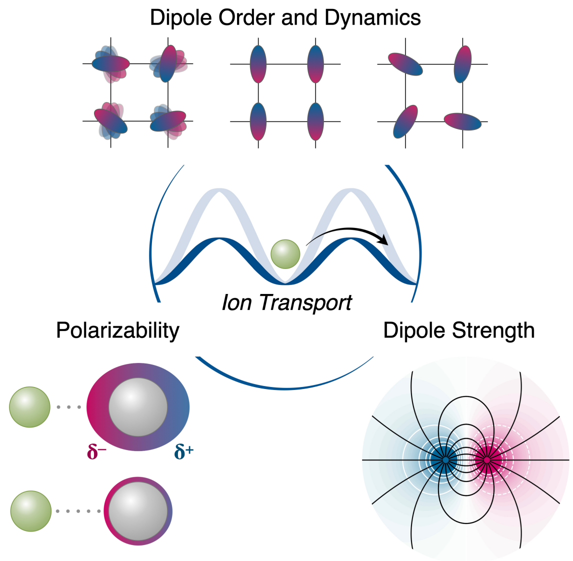


Figure 3: Overview schematic #1

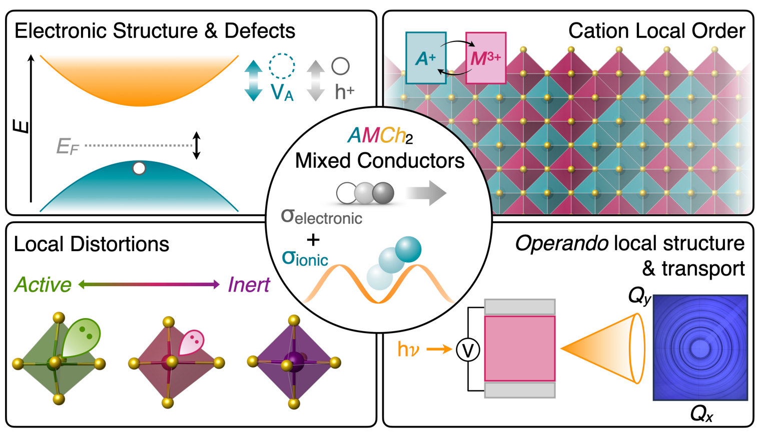


Figure 4: Overview schematic #2

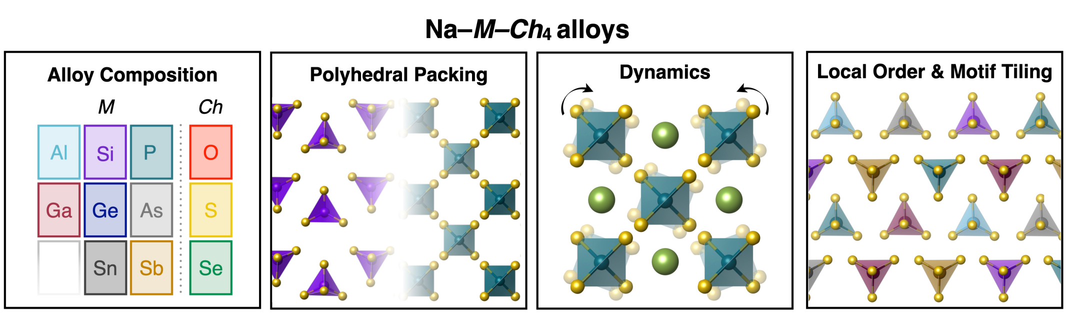


Figure 5: Overview schematic #3

7 Writing the Darn Thing

7.1 General Writing Guidance

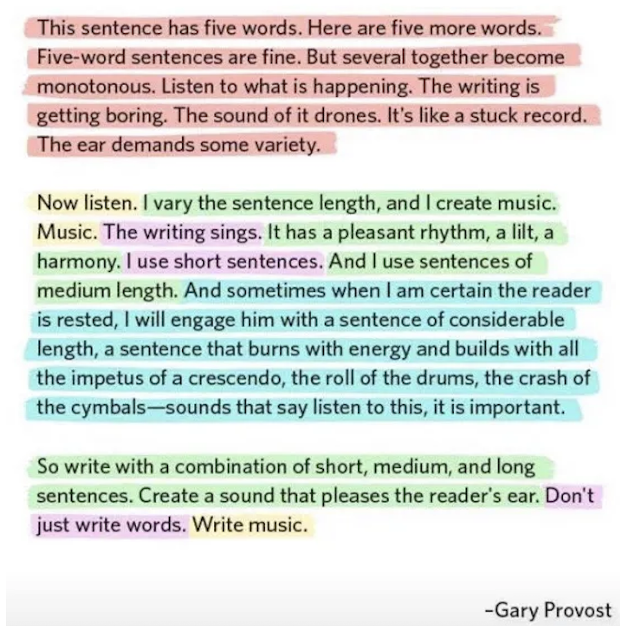
Below is some writing guidance I have assembled over the years. Much of this advice is general and may be applied beyond proposal writing.

Paragraph Structure: Topic/Thesis Statements. You learned this in the 5th grade, but I bet you forgot. Each paragraph should begin with a well-written *topic sentence.* This thesis should capture the main point of the paragraph. Every sentence after should directly support or tie into the thesis statement. When writing and editing, if a sentence does not support the thesis, then it does not belong in the paragraph! Delete it or rework. Use thesis statements to help you construct an outline.

Pitfall Alert! A reference to a single literature study is <u>not</u> a thesis statement! For example: "Smith et al. showed XX." No! The work by Smith et al. is *support* for an actual thesis statement. If you find yourself starting a paragraph with a literature reference, think bigger: What is the core takeaway of the work? How can you summarize it in 1 sentence? Are there other literature references that similarly support that statement? Are there literature references that refute it?

Clarity Over Cleverness. Writing about science is inherently tied to writing about complex phenomena. It is therefore critical that the writing be as *clear* and *concise* as possible. Be conscientious about the length of sentences. Avoid run-ons, comma splices, or em-dash (—) interjections that invariably lead to over-complicated and wandering sentences. Jargon must be used judiciously. Technical precision and terminology is important, but it can be written clearly.

Sentence Length. It is tempting to write long-winded sentences that include a lot of modifiers, qualifiers, or conditionals. I am very guilty of this! For a first draft, it is good to just get words down. But, when revising, it is important to consider breaking up monster sentences. On the flip side, short robotic sentences are jarring. Balance must be achieved between short and long sentences. See the example by Gary Provost, below:


This sentence has five words. Here are five more words. Five-word sentences are fine. But several together become monotonous. Listen to what is happening. The writing is getting boring. The sound of it drones. It's like a stuck record. The ear demands some variety.

Now listen. I vary the sentence length, and I create music. Music. The writing sings. It has a pleasant rhythm, a lilt, a harmony. I use short sentences. And I use sentences of medium length. And sometimes when I am certain the reader is rested, I will engage him with a sentence of considerable length, a sentence that burns with energy and builds with all the impetus of a crescendo, the roll of the drums, the crash of the cymbals—sounds that say listen to this, it is important.

So write with a combination of short, medium, and long sentences. Create a sound that pleases the reader's ear. Don't just write words. Write music.

–Gary Provost

Word Precision. Every word you use has context and connotation. Is the word *exactly* what you mean? (Consider: there is a big difference between "demonstrates" and "suggests"). I find it best to write a first draft with imprecise language and then pay close attention to the word choice when revising later. Eventually, I go through each sentence and ask myself "Does this sentence say what I really want it to say?"

Adverbs. Adverbs are qualifiers ending in "–ly"; e.g. incredibly, extremely, etc. Be conscientious of your adverb use! These words may seem like they add emphasis to your writing, but often they result in poor clarity and bloated sentences. Furthermore, these qualifiers are often imprecise – for example, what does it mean for something to be "extremely good" or "extremely bad"?

The "C-Word". I'm referring to the word "Can" (I gotcha, didn't I??). "Can" is a terrible word in proposals. It is wishy-washy and weak. In my opinion, it immediately diminishes my confidence in your ability as the proposer to do the work. Consider: "Electrochemical impedance spectroscopy can be used to measure ionic conductivity." vs. "Electrochemical impedance spectroscopy will be used to measure ionic conductivity." The latter statement is MUCH stronger than the first. Delete "Can" from your proposal language.

Practice, practice, practice. Good writing takes practice. You will not be good at it to start. The only way to get better at writing is to do more writing and to get feedback on your writing from people you trust.

Kill your darlings. Letting go is hard. Sometimes you write a sentence or paragraph you're proud of, but it doesn't belong in the final draft. Save it somewhere! Make a Word document somewhere else or comment it out in LaTex. But overall, your ability to reflect on your own writing and be willing to judiciously use the Delete key will only make you a better writer in the future.

Signatures of Generative AI. Large language models (e.g., ChatGPT, Gemini) have a distinct fingerprint of writing. I will not tell you *not* to use ChatGPT to help you with your writing, but with the caveat that you must be conscientious of the common patterns that LLMs fall into:

- **Comma Splices.** LLMs *frequently* use comma splices of this form: "All-solid-state batteries could potentially increase battery energy density, changing the landscape of energy storage." The last half of this sentence is a comma splice because it doesn't have a subject/noun!
- **Em-dash (—) Interjections.** Example: "The perovskite phase — stabilized only under high pressure — exhibits a dramatic increase in ionic conductivity upon cooling." This writing format can be effective when used with restraint, but it is often a flag of excessive LLM use.
- **Lofty Language.** Boy howdy, LLMs love using fluffy and lofty words that do not belong in scientific writing.

7.2 Getting Words on Page

If you're like me, you will rarely be "in the mood" to write. Staring at a blank page is daunting. Do not wait for the mood to strike you to sit down and put words to page. During this stage, this is your mantra:

A first draft is perfect, because all it needs to do is exist.

Get the words down. Vomit them. Write a detailed outline. Ask ChatGPT for some words, laugh at how bad it is, and then write your own. Do whatever it takes to get over "starting friction" or "writer's block".

Bass-Ackwards. I do not write a proposal from Page 1 to Page N. This is because I find it hard to conceptualize writing the broader aspects of the proposal (e.g. Motivation, Background) compared to the technical ones (e.g., Proposed Work). It is pretty easy for me to generate a Proposed Work section once I have rough ideas, because I have a good grasp on *how* to do the work (in the lab). Plus, my ideas often evolve as I write – as such, the Motivation and Background sections need to change. So, to save myself some heartache, I tend to write proposals out of order:

1. Identify a field and its research white space. What problem am I solving, and why would it be rad to solve it? Outline a broad Happy-Sad-Happy+Goal. Ensure that my broad HSH+G aligns with the funding agency/proposal call.
2. Block out the space I need to allocate to each section. Include Pupper Placeholder figures where I think I will need/want them.
3. Brainstorm lots of specific questions, construct hypotheses for each question, and jot down ideas of what experiments I would do to address them. Go back to the literature to see if any of my ideas have been done before.
4. Smash the above ideas into three Aims and write the Aims. Revise ideas during the writing process; often, the act of writing the Aims helps me turn the crank on my initial ideas and evolve them into something better.
5. Insert mid-proposal freak-out here ("This is garbage. . . I am garbage. . . " 💩).
6. Sketch out a rough draft of schematic-y Figure 1. Set it aside and let it percolate for a bit.
7. Write the Preliminary Work section of the Background (brag it up!). Make a figure of relevant preliminary data to show off.
8. Based on the Aims, rewrite the Happy-Sad-Happy-Goal outline. Then, write the Motivation section, Goal Statement, Overarching Hypothesis.
9. Write the Impact/Significance section.
10. Write the Background section. Based on the Aims, what context does my reader absolutely need to know to assess the impact and feasibility of the work?
11. Return to Figure 1 and edit it to perfection.
12. Read everything top to bottom and revise.
13. Fine tune the document, check for typos/grammar, etc.

Again, this guide is not to tell you that my way is the best or only way of doing things. The point of including my process is to (1) hopefully illustrate *one* way of doing this that you can adapt (or ignore!) as you see fit, (2) illustrate the iterative nature of proposal writing, and (3) to provide a candid perspective about the pain points that make proposal writing challenging, even for people who do it for a living.

8 Inevitable Rejection, the Non-Trivial Role of Luck, and Growth Mindset

I am sorry to say it – but despite your best efforts, you are more likely to be unsuccessful at writing proposals than successful. The success rate for the NSF GRFP was less than 15% (at least, it was pre-2025...). For reference, the average funding rate for most federal agencies for faculty proposals is less than 20%. Realistically, there is too little funding and too many deserving applicants. There is a non-trivial amount of luck involved. I wrote this document because I believe that it can help you make your proposal competitive enough to be in the running – after that, it is simply a game of chance.

When inevitable rejection hits either now or sometime in the future, it is okay to feel disappointed, frustrated, and ticked off. You have been trained your whole life that Hard Work = Success. It is demoralizing to work very hard on your fellowship application and not be successful. It sucks. It doesn't stop sucking as you get older and more experienced! I usually have to take several good walks around campus after a grant rejection. Ironically, I proposed to write this exact document as an Educational component of a grant. Spoiler Alert: the grant didn't get funded.

So why bother at all? *Because there is value in doing the work beyond winning money.* If you are a graduate student, creatively developing new ideas and clearly articulating your project are crucial skills that will serve you long after you get your degree. The good news is that a rejection for a graduate fellowship is in no way a determiner of your future success! I was nowhere close to winning a graduate fellowship as an early PhD student (my attempts are cringe-worthy — no happy-sad-happy to be found anywhere!). Yet here I am, still getting grants rejected and occasionally getting them funded! Maintain a **growth mindset**, and use these applications as an opportunity to learn. Use feedback and criticism from rejections to improve your ideas and your writing. Develop resilience in the face of criticism, *especially* when it feels unfair. Most importantly, do not let rejections derail you – dust yourself off and don't give up!

9 Closing Words

This document began as a collection of somewhat manic ramblings that I have hoarded in the back of my gremlin brain for the past few years. I hope that coalescing them into this document helps you to think about the technical aspects and process of writing a proposal. I also hope that it sheds a candid light on the proposal writing process and its challenges, pain points, and pitfalls.

In the spirit of "Growth Mindset", I am always interested in your feedback. What was helpful? What was distracting, annoying, or useless? Is there something missing that you wish were here? Please let me know! ✉ amaughan@mines.edu

Wishing you the best of luck on all of your proposal-writing endeavors!

10 Acknowledgments

Much of this document would not exist without others who have mentored and coached me in my own proposal writing, and whose wisdom I have shamelessly stolen and adapted. Shout out to Prof. Eric Toberer, who coined the Happy-Sad-Happy structure and who has spent many hours he will never get back giving feedback about my proposals and sharing proposal-writing strategies. Prof. Jamie Neilson's advice over the years formed much of the basis of the "How to Have Ideas" section of this document. Thanks to Prof. Eve Mozur, who is a world-class Rubber Duck. And finally, huge thanks to the exceptionally brilliant and talented students who were gracious enough to share examples of their successful fellowship research proposals for use in this document.

11 Appendix 1. Worksheet: Building a Proposed Work Section

Once you have an overarching idea and a general plan for your aims, this worksheet is intended to help you construct your Proposed Work section and the specific aims of your proposal.

Overarching Goal/Scientific Question:

Subgoal/Subquestion 1:

Specific Hypothesis 1:

Optional: Alternative Hypothesis 1:

List of Specific Tasks:

Task	What will you learn?	Rationale towards hypothesis
1		
2		
3		
4		
5		

If my hypothesis is true:

If my hypothesis is not true/if my alternative hypothesis is true:

Subgoal/Subquestion 2:

Specific Hypothesis 2:

Optional: Alternative Hypothesis 2:

List of Specific Tasks:

Task	What will you learn?	Rationale towards hypothesis
1		
2		
3		
4		
5		

If my hypothesis is true:

If my hypothesis is not true/if my alternative hypothesis is true:

Subgoal/Subquestion 3:

Specific Hypothesis 3:

Optional: Alternative Hypothesis 3:

List of Specific Tasks:

Task	What will you learn?	Rationale towards hypothesis
1		
2		
3		
4		
5		

If my hypothesis is true:

If my hypothesis is not true/if my alternative hypothesis is true: