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An Engineering Perspective on the Importance of Obtaining Operational Stability in Graduate School

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Received: 30 September 2025 | **Revised:** 11 May 2026 | **Accepted:** 20 May 2026

Keywords: career development | mentoring | research capacity | training

ABSTRACT

Student navigation through a PhD Program is marked by intellectual challenges, emotional fluctuations, and personal growth. Students develop excellence by absorbing and adjusting, recovering, and improving in response to challenges. The ability to bounce back is termed elasticity, an engineering principle where systems are designed to withstand stress, recover from disruptions, and maintain functionality. Students can proceed from elasticity (resilience) to then develop antifragility, the ability to become better from an experience. It occurred to the first author (a PhD graduate student in biomedical sciences) that developing antifragility is conceptually easier to understand by applying basic engineering concepts. We examine five thematic categories that connect engineering concepts with practical realities of graduate study: (1) load and stress management; (2) redundancy and backup systems; (3) setback modes and recovery; (4) adaptive capacity and flexibility; and (5) sustainability and long-term performance. By understanding how to gain antifragility, one can navigate demands more effectively.

1 | Introduction

PhD Programs represent a demanding landscape filled with intellectual rigor, emotional highs and lows, and transformative personal development. Success requires more than academic aptitude; success also calls for a steady commitment to excellence and capacity to adapt and recover from setbacks. The ability to rebound and maintain performance under pressure is known as resilience or elasticity. Extending further, antifragility allows a system to improve and even thrive in response to stressors, shocks, volatility, and disorder. Elasticity and antifragility are foundational concepts in engineering, where systems are designed to endure stress, recover and grow stronger from disruptions, and continue functioning effectively. Students may be able to adopt these concepts for workload management to engage stressors that promote skill acquisition without exceeding capacity. Drawing inspiration from parallels, the first author—a second year PhD graduate student in biomedical sciences—approached the concept of building resilience and antifragility through the lens of engineering principles. This perspective is grounded in a U.S. science, technology, engineering, mathematics, and medicine (STEMM) graduate education context and recommendations given may need to be translated for humanities and social sciences as well as international and resource-limited institutions. Applying these principles throughout and beyond can provide a strong foundation for current and future career navigation.

This essay explores five thematic areas that bridge engineering concepts of elasticity with the lived experience of graduate students in a PhD Program: (1) load and stress management (2), redundancy and backup systems (3), setback modes and recovery (4), adaptive capacity and flexibility, and (5), sustainability for long-term performance. By applying these frameworks, students can cultivate resilience and antifragility to maintain well-being throughout the academic journey. Viewing the PhD program through the lens of elasticity offers practical and empowering approaches to navigate challenges with clarity.

2 | Load and Stress Management

Success stems from putting in effort and is reliant on knowing when to step back and avoid comparing yourself to others. Engineers design systems for stability under varying loads and graduate students must protect their own equilibrium through self-regulation, even when surrounded by pressures from peers, mentors, and self. The concept of load-bearing capacity is a representation of where the development of elasticity begins. Elasticity refers to the ability of a material or a process to return to original form after being stretched or deformed by stress. Elasticity reflects a student's ability to recover academic and emotional equilibrium after intense periods of stress or pressure. Engineers schedule routine maintenance and load balancing to prevent system breakdowns and students in STEMM can practice deliberate time management to navigate competing demands. Effective scheduling and prioritization improve productivity and reduce stress that arises when academic course work, research, and personal obligations converge. Intentional time management strategies are critical for helping students adapt to fluctuating expectations while maintaining progress toward long-term goals. The equivalence of elasticity is grit, the persistent passion and long-term perseverance that drives someone to pursue meaningful goals with steady effort and a refusal to give up, even when progress is slow [1].

Architectural structures are designed to handle and oversee loads (static and dynamic) without breakdown while following a set of standards for construction. Furthermore, stress analysis can predict how materials respond under pressure to ensure safety and reliability. This same approach can be applied to a PhD student setting, as students are often faced with intellectual, emotional, and logistical loads. These responsibilities create a matrix of demands on students. Elasticity involves expanding the assumed limits of mental and physical endurance to achieve optimal stress management. Ways to combat this include time management and delegating tasks across your team to ensure safety while meeting the time demands of the assignments. Support systems serve as reinforcement. Engineers use support beams and columns and students can use peers and counseling services to promote a better training journey. Stress management is not about avoiding but rather effectively balancing stress [2].

3 | Redundancy and Backup Systems

While redundancy means contingency plans and alternative pathways, goal achievement also depends on the ability to build a broad, cross-disciplinary professional network [3]. These networks, which can span institutions, disciplines, and technical specialties and include social media networking, act as dynamic support systems for problem-solving, resource sharing, and opportunity creation [4]. Engineers connect distributed systems for greater reliability and operational continuity, and PhD students benefit from connecting with collaborators and advisors across diverse technical areas to gain fresh insights, accelerate progress, and open new pathways for research. A key principle in computational engineering involves critical systems such as data centers, which include company infrastructures (e.g., Google, Microsoft, and Apple), hospital records, finances, and e-commerce. Designing redundant and backup storage systems is important to ensure smooth systems operation. For data loss prevention, engineers develop redundant array of independent disks arrays, snapshot recovery, and multi-location storage clusters. Given the chance of primary system failure, these fail-safe mechanisms enhance reliability, operational continuity, and elasticity. PhD students likewise should avoid limiting themselves to a single plan for experiments and project development. Odds of success rise with redundancy and backup systems in place. This means taking advantage of secondary mentors and mentoring programs to provide a variety of perspectives. Secondary mentors also serve as independent resources for career advancement opportunities. Engineers design to prevent failure, and students can prepare in the same way by intentionally incorporating redundancy and backup strategies for success in training.

4 | Setback Modes and Recovery

Setback mode and effects analysis is a process to identify potential weaknesses in a system to optimally plan for recovery if breakdown occurs. Biomedical engineers design devices such as insulin pumps and pacemakers, which require risk analysis to be assigned a classification device class by the food and drug Administration. Setback mode and effects analysis evaluate how hardware sensors, batteries, and software updates of these medical devices can impact safe device use. Engineers anticipate adverse possibilities and design software and self-healing materials, for example, as antifragile mechanisms to restore and improve function should the need arise. Moments of temporary setback are inevitable occurrences, where experiments may not work, manuscripts may receive rejection decisions, and initial deadlines may be missed. These are also opportunities for antifragile responses.

Elasticity incorporates not only surviving from a period of setback; elasticity incorporates the concept of learning from experiences to recover as a stronger individual and becoming antifragile. Incorporating a growth mindset is important; viewing setbacks as learning opportunities fosters the development of elasticity [5]. Reflection is also needed to prevent or limit a later reoccurrence, which increases completion and efficiency of future tasks. In engineering, effects analysis is used for data collection, assessment, and quality improvement. The same concept applies here. Engineers consult blueprints during repairs, and PhD students benefit from having a predefined recovery plan and trusted mentors and colleagues to help. These resources provide direction, alternative strategies, and emotional support, making the path to recovery efficient and sustainable. Elasticity is built through an ability to confront setbacks to learn and move forward.

5 | Adaptive Capacity and Flexibility

The capacity to adapt and pivot when a given problem arises is important for engineers as they continuously change conditions in a system to troubleshoot without losing functionality. In software engineering, adaptive algorithms adjust to new inputs or environments to maintain optimal performance. PhD students can practice this concept to evolve research landscapes, academic expectations, and personal life changes to better meet requirements. Incorporating interdisciplinary thinking to embrace diverse methods and perspectives enhances flexibility. Being willing to pivot research questions or career goals in response to opportunities prepares us for excellence in future endeavors. More importantly, managing emotions and expectations in the face of change is crucial.

One way to assess capacity to adapt is through the adaptability quotient. the adaptability quotient is a metric that measures how effectively an individual can adjust to changes or new conditions presented, acquire new skills including transferable skills, and maintain productivity under uncertain conditions [6] For example, a research project may become non-feasible due to funding changes, lack of equipment, or loss of reagents. In this case, a student with high adaptability quotient can pivot to alternative approaches while maintaining productivity.

Adaptability is a strength. Like adaptive engineering systems, thriving students evolve with changing inputs and self-regulation in environments to maintain progression. Part of maintaining a high adaptability quotient involves the strategic power of saying no—declining opportunities, collaborations, or tasks that do not align with core goals, available resources, or current priorities [7]. This selective approach prevents overextension and preserves bandwidth for the adaptations that matter most. Thus, the adaptability quotient can serve as a performance or elasticity metric as one navigates their career.

The Adaptability Quotient allows another aspect of engineering that extends beyond elasticity. It is the equivalent of Taleb's concept of antifragility. Whereas fragility describes how a system is harmed when environmental variability exceeds a certain threshold, antifragility describes how a system actually benefits when variability extends beyond that threshold [8]. Biomechanical engineers use this idea to create prostheses that stimulate bone remodeling and thus minimize bone loss according to Wolff's law. Wolff's Law describes the phenomenon whereby bone tissue forms and is remodeled in response to continually experienced mechanical forces. PhD students should analyze and identify those processes in their experience going through that made them stronger. Elasticity returns one to an original state after the stress subsides. Resilience absorbs stress and enables rapid recovery. Antifragility is the state of becoming stronger due to stress. Muscles become stronger with exercise and hydra are capable of extreme regeneration to the point of being able to grow another head after one has been cut off. Similarly, PhD students can emerge stronger from rigorous academic experiences, provided they are supported and reflective.

6 | Sustainability for Long-Term Performance

When material engineers design a new system, they do not focus on making the system work for merely a day. They consider performance over decades; how easily the system can be maintained; and whether system operation will remain efficient and environmentally robust. This evaluation process requires use of the most durable materials, energy efficiency, anticipating wear and tear, and built-in flexibility for future upgrades. PhD Programs are not about producing quick results for a single project. Rather, PhD students learn and cultivate productive habits, skills, and protocols to sustain a career that needs to last for decades.

Like engineers, PhD students must think long term to meet fluctuating conditions. Maintaining a high level of engagement requires surrounding yourself with a strong network of mentors, colleagues, and collaborators who can serve as sponsors and allies [9, 10]. These relationships, built over time, become the enduring support system that enables you to adapt, grow, and thrive. A great mentor can be a load-bearing beam, helping you to take on stress [11]. To maintain these relationships, one must hone leadership skills, understand what is ethical and fair, and recognize that networks improve with a plethora of mentors—including those who may be your secondary advisors. In a steel building, the primary structural frame is composed of columns and girders, and these structures are supported by secondary structures that include purlins and girts. Purlins support the roof and wall panels, transferring loads back to the main frame. Casual mentors and shadow mentors can support your career. Building and fostering relationships within your own institution may be challenging and learning to create opportunities for collaboration in other departments, institutions, or fields can expand your network and open unexpected doors. Using engineering concepts and processes to adapt will help you to continuously learn, improve, and build for the long term.

7 | Conclusions: Engineering Elasticity as a Blueprint for Success

Engineering teaches us that elasticity is not a single trait but a system of interrelated strategies that include load management, backup systems, adaptability, and recovery. We can cultivate elasticity and antifragility using a variety of strategies to overcome the unique challenges of an academic journey. Figure 1 presents a stress-strain model that examines academic performance in graduate education through the lens of stress and recovery patterns. The initial section on the left, referred to as the elastic region, depicts a state where students encounter manageable challenges, allowing them to rebound effectively and return to their original performance levels after completing introductory coursework. The left bottom right plastic region, highlights a transitional phase marked by significant setbacks, such as low scores on important assessments. Within this segment, students may experience a period of adjustment, where initial setbacks can represent resilience, though persistent pressure may result in exhaustion or prompt a reassessment of career goals. The upper right plastic region illustrates an environment of heightened demands that fosters enduring positive changes indicative of antifragility. Here, students enhance skills and work

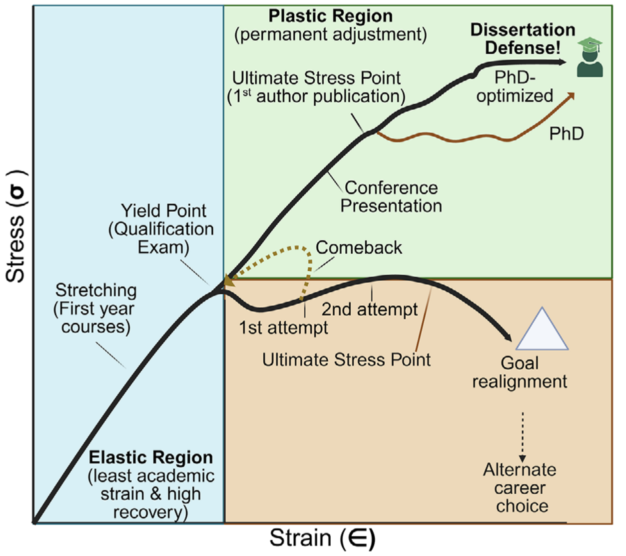

FIGURE 1 | Stress–Strain Models Applied to Performance in the PhD Program.

habits through rigorous experiences. Even after achieving notable milestones, graduates may either meet basic criteria or attain a deeper level of expertise, preparing them for competitive careers. Ultimately, success in this phase concludes with the dissertation completion.

It is important to recognize that success requires more than one rigid blueprint. Thriving demands balancing strategic planning with flexibility that incorporates both elasticity and antifragility using multiple mechanisms. This balance allows you to build capabilities needed to adapt, manage workload, create fallback options, and recover from setbacks [12]. While engineering may be viewed as a highly technical, multifaceted discipline, its core principles include designing for resilience, anticipating failure points, and optimizing recovery to build antifragility. An assumption of this essay is that we can directly apply these concepts to PhD training. Some solutions may apply uniformly and be elegant and straightforward, while others require persistence, learning from failures and drawing inspiration from your environment.

By viewing graduate student elasticity through an engineering lens, we gain a structured framework for not only surviving but thriving in academia. With the right tools, mindset, and adaptability, students can create a highly stable foundation for lifelong success.

This diagram models performance using a stress–strain curve, illustrating three distinct recovery pattern responses to academic workload: elastic region (left) and plastic region (right, top, and bottom). Elastic Region: Phase of least academic strain where PhD students can fully recover after manageable challenges (e.g., first-year coursework). Performance returns to baseline without lasting change. Plastic Region Bottom: Phase of permanent adjustment due to missed goals or setbacks (e.g., not passing qualifying exam). Refers to material stress-strain response where deformation becomes permanent and describes lasting change in academic performance or mindset from stress or burnout. Within this region lies a comeback zone, where students may recover to build resilience and antifragility under stress. Continued strain may still lead to burnout or need to identify alternate career paths. Plastic Region Top: High-pressure phase that results in permanent positive adaptations. Despite strain, students develop improved efficiency, skills, or work habits through experiences (e.g., conference presentations and first-author publications). Success in this region culminates in successful dissertation defense. Created in BioRender https://BioRender.com/nb98oag.

Author Contributions

Ashton Oliver: conceptualized the perspective article with guidance from senior authors and led the drafting of the manuscript. **Amadou Gaye:**, **Merry Lindsey:**, **Ravirajsinh Jadeja:**, and **Pamela Martin:** contributed to the development of the article framework, provided critical intellectual input, participated in manuscript writing, revision, and proofreading, and provided funding support. All authors reviewed, edited, and approved the final version of the manuscript.

Acknowledgments

This work was supported by the National Institute of Health under award numbers AI007281, EY033264, EY035336, GM144927, GM151274, GM152837, HL007737, UC2MD019626, and UC2GM162929; and by the Veterans Affairs Office of Research and Development under award number CX002780. We also acknowledge support from the Chan Zuckerberg Initiative's Foundation to Accelerate Precision Health Program and Advance Genomics Research at Meharry Medical College (award number CZIF2022-007043). Ashton F. Oliver is a Biomedical Sciences PhD student at Meharry Medical College who is fusing an engineer mindset with biomedical innovation to create affordable health therapies.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing not applicable to this article.

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