2020/2021

Excellence in Upper-Level *Writing*

The Gayle Morris Sweetland Center for Writing

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Excellence in Upper-Level Writing

2020/2021

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Excellence in Upper-Level Writing 2020/2021

Sweetland Writing Prize Chair

Gina Brandolino

Sweetland Writing Prize Judges

Andrew Bernard

Louis Cicciarelli

Jennifer Cummings

Domenic DeSocio

Marisol Fila

Sofya Khagi

Jie (Jackie) Li

Michael Martin

Wilson Merrell

Katy Rossing

Marissa Spada

Theresa Tinkle

Field Watts

Administrative Support

Laura Schulyer

Aaron Valdez

Winners List

Excellence in Upper-Level Writing (Sciences)

Puneet Dhatt

"A Review of Titin: The Titans of Human Muscle"

Nominated by Nicholas Garza, CHEM 353: Introduction to Biochemical Research Techniques and Scientific Writing

Kateryna Karpoff

"TGF-β1: Unraveling the Applications of a Versatile Cytokine"

Nominated by Nicholas Garza, CHEM 353: Introduction to Biochemical Research Techniques and Scientific Writing

Excellence in Upper-Level Writing (Social Sciences)

Angelina Little

"Research Proposal: Reevaluating the Economic Imperative to Learn"

Nominated by Nancy Burns and Ben Goehring (GSI), POLSCI 381: Political Science Research Design

Sahil Tolia

"The Social Brain Hypothesis: An Evolutionary Explanation for Our Big Brains"

Nominated by Andrew Bernard, ANTHRBIO 368: Primate Social Behavior

Excellence in Upper-Level Writing (Humanities)

Leah Marks

"A Review of PLA's Sustainability as the Future of Bioplastics"

Nominated by Jimmy Brancho, WRITING 400: Advanced Rhetoric and Research, Writing and Research in the Sciences

Julia Van Goor

"A Handful of Walnuts"

Nominated by Jamien Delp, ENG 325: Art of the Essay

Nominees List

Student	Instructor
Dina Ahmad, Lauren Guido, & Jaya Thyagarajan (collaboration)	Michelle Bellino
Allegra Baird	Madelyn Cook
Mikayla Lilly Bosma	Marlon James Sales
Benjamin Bronkema-Bekker	Vedran Catovic
Isabel Brush-Mindell	Emilia Askari
Zoe Bultman	Rolf Bouma
Isabella Buzynski	Cameron Cross
Jay Campbell	Jennifer Metsker
Olivia Chang	Kevin Miller
Deeya Chaturvedi	Omolade Adunbi
Elizabeth Cho	Brian Remlinger
Claire Pajka	Julie Halpert
Conor Rafferty	Julie Halpert
Liam Corriston	Gabriel VanLoozen
Danielle Crasiuc	Sara Ahbel-Rappe
Hannah Davies	Andrew Bernard
Julia Dean	Wilson Merrell
Puneet Dhatt	Nicholas Garza
Viviana Flores	Emily P. Lawsin, (Paulina Fraser, GSI)
Carter Fox	Roy Clarke
Dequan Gambrell	Cameron Cross
Catherine Garton	Stephanie Preston
Tanner Gritzmaker	Christine Chalifoux
Kamryn Hayes	Rolf Bouma
Alice Hill	Lynn Carpenter
Alice Hill	Julian Schultz
Vasili Ioannidis	Yehia Mekawi
Emily Johnson	Yehia Mekawi

Student	Instructor
Kateryna Karpoff	Nicholas Garza
Daniella Kay	David Gold
Alyssa Klotz	Vedran Catovic
Alex Kocheril	Omolade Adunbi
Alexia LaLonde	Allie Hirsch
Angelina Little	Nancy Burns (Ben Goehring, GSI)
Gina Liu	Omolade Adunbi
Anthony Lohmeier	Omolade Adunbi
Christine Chia-Rong Lu	Jimmy Brancho
Anshuman Madhukar	San Duanmu
Allison Malkowski	Ben Hansen
Brianna Marble	Lynn Carpenter
Leah Marks	Jimmy Brancho
Michael Moynihan	Lisa Koo
Celene Philip	Brian Remlinger
Claire Ramsey	Lisa Koo
Sayan Raychaudhuri	Roy Clarke
Robin Rong	Emilia Askari
Samuel Rosenblum	David Gold
Aryanna Rudolph	Benjamin Hsu
Jared Stolove	Ashley Craig
Sahil Tolia	Andrew Bernard
Aria Trager	Omolade Adunbi
Julia Van Goor	Jaimien Delp
Erin Walski	Gabriel VanLoozen
Levana Wang	Jaimien Delp
Griffin Zdrojewski	Wilson Merrell
Keri Zhang	San Duanmu
Michael Zhang	Julian Schultz

Introduction

All LSA undergraduates take at least one upper-level writing-intensive course, often in their major or minor, and frequently in another field of interest. Those of us who teach these courses discover anew each term how a focus on writing improves students' thinking, learning, and rhetorical creativity. At the end of each term, we applaud our students' various achievements and the ways they have grown by applying themselves seriously to the hard work of designing a study, conducting research, addressing an audience effectively, crafting a multimedia essay, refining their prose style, reading and giving feedback on peers' drafts, or engaging with counter-arguments. These are rewarding courses to teach, as witnessed by the significant number of faculty from all disciplines who participate robustly in the upper-level writing program each year.

Each year, faculty and graduate student instructors encourage undergraduates to submit their very best essay for the Upper-Level Writing Prizes. Fellows in the interdisciplinary Sweetland Seminar for Writing Pedagogy read the submissions and rank them according to their overall excellence. This is an intellectually interesting exercise and generates considerable discussion about what we value when we read students' work. The Fellows this year described for each other the qualities they admired in the submissions. Here are some of the ways they defined excellent writing: the relationship between existing scholarship and a student's position is clearly detailed and persuasive; the argument is complex without loss of clarity or purpose; the piece presents a novel argument or assertion (e.g., coming to their own conclusions based on multiple texts); quotes are thoughtfully introduced and integrated into the argument; the evidence is compelling; and the writers use rich, evocative language. All of the essays submitted were outstanding, and all of the students should feel very proud of what they accomplished.

This volume showcases the prize-winning essays, which are truly impressive. They witness to the robust intellectual life of the university, and to the splendid courses and instructors who inspired and supported the writers' accomplishments. Each essay speaks to how much our students contribute to the creation of new knowledge.

Thanks are due to the many people who made this volume possible. The Senior Fellows who thoughtfully judged the essays are Louis Cicciarelli, Sweetland Center for Writing; Jennifer Cummings, Psychology, Biopsychology; Sofya Khagi, Slavic Language and Literatures; and Jie (Jackie) Li, Earth and Environmental Sciences. The Junior Fellows (Graduate Students) are Andrew Bernard, Anthropology; Domenic DeSocio, Germanic Language and Literature; Marisol Fila, Romance Languages; Michael Martin, Slavic Language and Literatures; Wilson Merrell, Psychology; Katy Rossing, English Language and Literature; Marissa Spada, Film, Television, Media; and Field Watts, Chemistry. Much gratitude is also due to Aaron Valdez, who designed this volume; Laura Schuyler, who coordinated the submission and judging process; and Gina Brandolino, who chaired the Sweetland Prize Committee and edited the volume. Finally, thank you to the students and instructors who strive for—and achieve—excellence in writing and writing pedagogy.

Theresa Tinkle
Sweetland Center for Writing
Arthur F. Thurnau Professor and Professor of English

Excellence in Upper-Level Writing (Sciences)

A Review of Titin: The Titans of Human Muscle

by Puneet Dhatt

From CHEM 353: Introduction to Biochemical Research Techniques and Scientific Writing

Nominated by Nicolas Garza

In his review paper, Puneet struck an elegant balance between the scientific format and narrating the results. Many scientists struggle to make their written works flow naturally while still conveying the content, and Puneet excelled at that in his exploration of the protein titin. His introduction and function sections were particularly engaging, and at times I forgot I was reading a student paper instead of a published article.

-- Nicolas Garza

A Review of Titin: The Titans of Human Muscle

Abstract:

Titin is the largest protein known to exist in the human body. Composed of more than 24,000 amino acids, titin has a remarkable molecular weight of over 33,000kDa. As such a large protein, it would be logical to assume titin has many different subdomains. However, having recently fully discovered the structure of titin, we now know that 90% of these domains are Ig and Ig-FNIII. Titin's main function is structural, providing a passive force with muscle contraction that allows the myocytes' sarcomeres their elasticity. Recently, many strides have been made in the field of titin's structure and function. In this review, we analyze such recent strides and how they convey the essential role titin plays in the body. Then, we will examine how titin's structure can mutate and how these mutations lead to many neuromuscular diseases.

Introduction:

Central to Greek mythology is the old god, the Titan, Atlas. A Titan leader, Atlas is punished for his uprising against Zeus, condemned to hold up the Earth. Allegorical to this mythic great, the protein titin exists in our muscles, condemned by evolution to provide them with the elasticity they need to function. It has been over 40 years since titin (also known as connectin) was discovered and characterized.[1,2,3] After its discovery as a novel elastic element of myofibrils,[1] it was found that titin was the third principle element of the myofibril, suggesting a new three filament model instead of the previously accepted two filament model.[4,5] Titin falls into the class of structural proteins, and though it is in many cells, it mainly functions as a component of the myocyte's sarcomere.[4,20] Titin's discovery meant the characterization of the now largest known protein (~3MDa).[6] It has been known since its discovery that titin is an important elastic element of striated muscle assembly -known as the "muscular spring".[7] Specifically, titin's >33000 residues can be found in the sarcomere where this giant protein spans half of the sarcomere from the Z-disk to the M-band, as seen in Figure 1.[8] Being such a large

protein, titin has many domains as it stretches across the half-sarcomere, each with its own unique function as will be described (Figure 1).

Many investigations into this protein's structure and function have begun to elucidate how titin's cycling works and contributes to the contraction and relaxation of the sarcomere.[7] Starting with structure, this review will examine the role of titin's immunoglobulin and fibronectin domains and their contribution to the muscle contraction mechanism.[6,7,9] Then, we will move on to examine advances in the field studying titin's function as a large-scale regulatory node for muscle cells remodeling and signaling pathways.[10,11] In addition, we will discuss different mutations and titin variants that can lead to the emergence of disease, especially in terms of titin's developing role in causing neuromuscular disorders.[8] Finally, titin's newfound role in contributing to heart disease and failure will be focused on.[12,13,14] As heart disease is the leading cause of death in the United States today, this field could yield promising information for future therapies. In order for this to occur, first the true mechanism of how titin causes these diseases has to be elucidated, for which there is currently little information.[13]

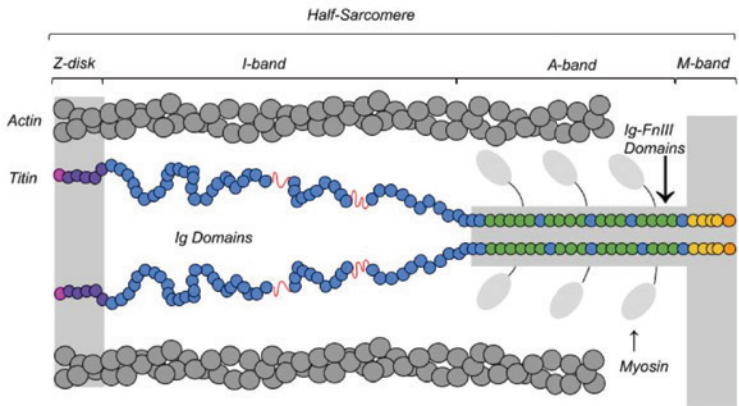

Figure 1: The titin filament stretches across the half-sarcomere. Titin stretches from the Z-disk (purple), where it is anchored by its N-terminus (pink). The filament extends to its C-terminus (orange), where it is anchored (yellow) to the M-band. The titin filament is made up of folded Ig and Ig-FNIII domains (blue

and green respectively) and intrinsically disordered structures (N2-B and PEVK, in red). Thus, titin has 4 regions: Z-disk (purple), tandem Ig domains (blue), A-band region (green and blue), and the M-band (yellow).[20]

Titin Structure and Subdomains

Spanning the half-sarcomere, titin is the largest known protein.[6] Most of this protein, about 90%, is composed of Ig and fibronectin (Ig-FNIII) domains.[6] Conventionally, this gigantic protein is understood in smaller groupings of domains known as regions.[18,19] There are 4 such regions: the Z-disk region, the M-band region, the I-band region, and the A-band region, organized by region and function in the sarcomere (Figure 1).[19] In the Z-disk domain, the titin filament is anchored to the Z-disk, allowing it its stability and ability to provide passive tension with the muscle contraction driven by the active myosin and actin filament (Figure 1).[19] The Z-disk is also the location of the N-terminus of the protein (Figure 1).[19] The M-band region encompasses another titin anchoring domain and its C-terminus (Figure 1).[19]

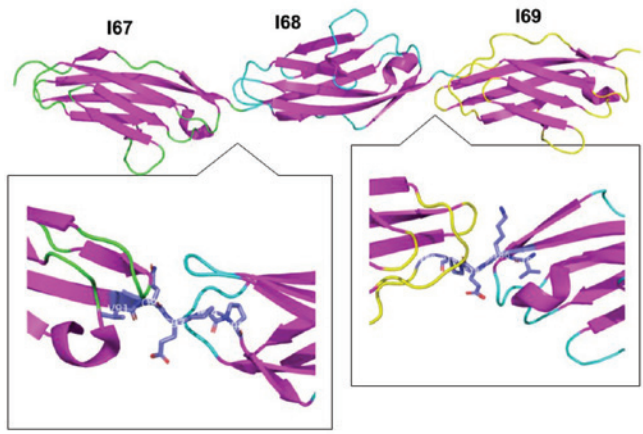

Figure 2: Structure of Ig domains. Figure created in Pymol. I67-I69 are shown here from the I-band elastic region of the titin filament. (Left) the I67(green)-I68(cyan)linker domain is the VQEPP motif (purple). (Right) the I68(cyan)-I69(yellow)linker domain is the VKEPP motif (purple). NOTE:

image is positioned such that I69(yellow) is on the left for better visualization of the linker bonds (pdb: 2RIK).

The most important regions to titin's function are the I-and A-band regions. The I-band region is composed of many differentially spliced Ig (immunoglobulin) domains in repetition and is responsible for the elasticity of titin (Figure 2).[19,20,25] This means that there are a varying number of Ig domains that make up this region. Specifically, this number is thought to vary between myocytes of different muscle groups, as well as between individuals.[20] Principally, this region confers titin its elasticity, a defining characteristic of the filament we call the "muscular spring".[20] The orientation of these domains, when the muscle is relaxed, is similar to that seen in Figure 2, with the Ig domains curled up and free to move around.[19] The exact mechanism for the muscle contraction rebound will be discussed later on. Understanding titin's role as the elastic element in the sarcomere is essential to comprehending the protein's function itself. In addition to these Ig domains,there are also 2 intrinsically disordered domains found in the I-band region, N2-A/B and PEVK.[19,20] These regions allow an additional spring-like nature to the protein.[19] The N2-domain comes in 3 flavors, N2-A, N2-B, and N2-BA (most commonly found in the heart).[8] Figure 2 shows the binding between these Ig domains in the I-band.[25] There is a dedicated linker domain that varies for different Ig domains, but that is used to hold the domains together(Figure 2). In the I67-69 stretch, these motifs consist of VQEPP and VKEPP, or a hydrophobic sandwiching of hydrophilic residues (Figure 2).[25]

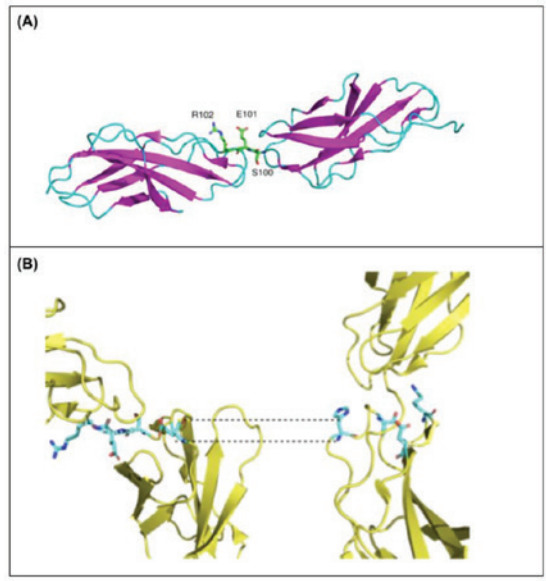

Figure 3: The protein structure and of Fibronectin domains. (A) Figure created in Pymol. Representation of Fibronectin domain of A77, along with linker domain S100-E101-R102 (green).[16] **(B)** Domains A77 (left) and A78 (right) are connected by a three-residue hydrophilic linker S100-E101-R102 on A77 connecting to H128, S132, K182, D185 on A78.[16] This forms a rich network of polar interactions that holds these two domains rigidly anti-oriented with respect to each other (pdb:3LPW).

The A-band region is mostly composed of Ig-FNIII (fibronectin type III) domains.[19] The main role of this region of the filament is to tightly bind the thick filament (myosin) to allow for muscle rebound.[19] How the Ig-FNIII domains link to each other is visualized in Figure 3. In Figure 3, the linker domain is seen to be a hydrophilic S100-E101-R102 motif.[16] This motif of A77 associated with more hydrophilic residues on A78 (such as H128 and S132).[16] Such a rich network of polar associations differs from how Ig domains link to each other, as they use both hydrophobic and hydrophilic interactions. This increase in hydrophilic association allows the Ig-FNIII domains to remain more rigid, and conversely the Ig domains of the I-band to remain more fluid or elastic.[16] This rigidity allows the domains to

remain anti-oriented with respect to each other, an element of their rigid structure that is essential to the function of the A-band of the filament(Figure 3).[16]

The main method by which we know these structures of titin is through x-ray crystallographic studies.[25] Both Figure 2 and 3 were derived from such studies. The other main method of structural analysis is through NMR studies, including 2D NMR studies such as TOCSY and NOESY.[6] The 2D NMR studies in particular reveal through space (NOESY) and through bond (TOCSY) interactions that are central to elucidating interacting pairs of amino acid side chains that serve key roles in the tertiary and quaternary structure of the polypeptide sequence.

Titin Function and Three-Filament Muscle Contraction Mechanism

As previously mentioned, titin confers elasticity to the sarcomere through its I-band domains.[19,20] This elasticity is key to supply the sarcomere with passive force that compliments the active contraction driven by actin and myosin.[7] Before the discovery of titin, this passive force was contributed to structural elements of the sarcomere such as collagen.[7] The discovery of titin also revolutionized thinking about the structure of the sarcomere.[7] Initially, the two-filament model of muscle contraction was accepted.[4,5] In this two-filament model that is commonplace in an introductory course in biology, actin is pulled by myosin to bring together the Z-disk and M-line, a process that requires metabolic input to power (Figure 1). However, after titin's discovery, a three-filament model–one that depends on actin, myosin, and titin – has become increasingly popular.[5] The mechanism of titin's influence on muscle contraction has not yet been entirely realized but there have been some major advancements in this field recently thanks to atomic force microscopy (AFM) studies.[18,23] These studies use magnetic tweezers for single molecule microscopy that allow nanoscale mechanics of titin to be realized.[18,23]

Though not entirely realized, we do now understand the basics of titin's role in muscle contraction. In its relaxed state, titin exists stretched out, with its Ig domains elongated due to the sarcomere pulling against titin to stretch

the muscle to its relaxed state. This passive tension that is supplied by titin is the "passive force" that is often referenced in titin's function.[7] As the muscle contracts, cross bridges are formed between actin and myosin filaments and the force on titin decreases.[18,19,22] The force decreasing as the sarcomere contracts allows titin's I-band Ig domains to fold.[22] This folding is favorable for the domain but was disallowed by the stretched conformation of the relaxed muscle.[18,19,22] Furthermore, this folding is cooperative, such that one domain spontaneously folding will increase the probability that those around it will also fold.[22]

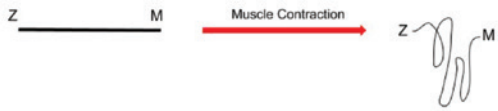

Figure 4: Entropic Recoil of Titin. When there is a force to maintain stretched, during muscle relaxation, titin remains stretched out (left). However, as the muscle contracts, the filament coils, and as a result has many more conformations open to it that it can sweep through (right). This increase in conformations to sweep through means a favorable increase in the entropy of the system.

Another mechanistic reasoning for titin contraction during muscle contraction is that as the sarcomere shrinks in size due to the active filaments work, there is an entropic driving force for titin to rebound.[6,18] In its relaxed state, sarcomeric titin is disallowed from occupying many microstates, as the stretched conformation of the filament is more controlled and rigid. This low microstate count means a lower entropy for this state. As the sarcomere contracts, titin is no longer forced to hold such a stretched conformation. As such, many more microstates open up, increasing the entropy of the filament. This can be seen in Figure 4 wherein the straight conformation on the left has a single conformation but there are many more conformations that open up as the filament coils. This coined "entropic rebound" has been used to explain titin passive force mechanics as well.[6,18] In reality, though both of these mechanisms provide some insight

into titin's rebound reasoning. Through AFM studies we know that the folding contraction of just one Ig domain generates twice the work of just the entropic recoiling in the physiological 4-15pN force range wherein titin operates.[18] This means that current evidence points toward the folding work of the individual Ig domains driving titin rebound.[8]

Titin's Role as a Regulatory Node

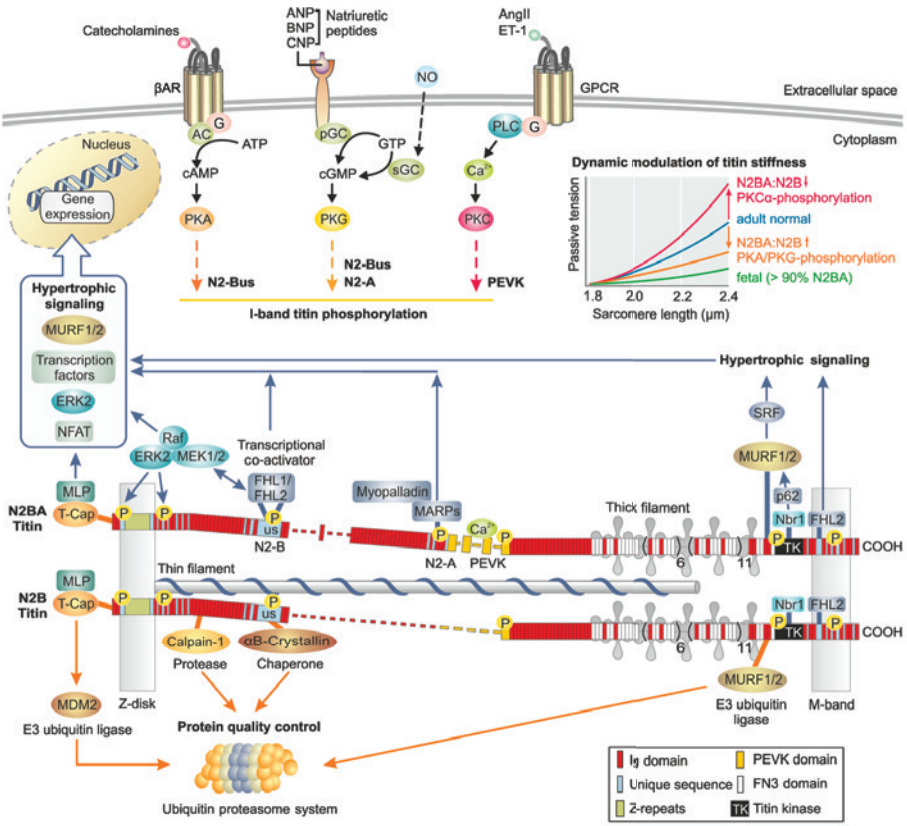

Figure 5: Cardiomyocyte signaling pathways involving titin. Cardiac forms of titin (N2-BA and N2-B) are here seen as binding partners and involved in hypertrophic signaling pathways. Keywords: ERK2, extracellular signal-regulated kinase 2; G, small G-protein; MLP, muscle LIM protein; MURF1/2, muscle

RING finger protein-1/2; P, titin phosphorylation site; sGC, soluble guanylyl cyclase. (Figure from Krüger and Linke, 2011).[10,21]

Along with its key structural features, titin has a newly discovered and emerging role as a key regulatory node.[10,21] Seen in Figure 5, many signaling cascades end on the titin filament, especially in cardiomyocyte signaling.[10] These cascades are initiated by many peptides landing on different cellular receptors. Recently, titin's role in cellular signaling cascades in cardiomyocytes has been elucidated.[10] During fetal development, it has been discovered that the N2BA/N2B ratio increases, increasing the stiffness of titin in the heart, and therefore the passive force for contraction.[10] In addition, titin phosphorylation and its modulations have recently been uncovered. Phosphorylation is a common way to regulate protein function. The addition or removal of a phosphate group leads to changes in a protein's tertiary or quaternary structure such that its function is modulated. As such, phosphorylation is key to titin's function and regulation.[10,21] In fact, it is phosphorylation of the XSPXR motif of titin that initiates myogenesis.[10] The titin filament needs this phosphorylation to recruit the necessary cofactors to initiate the construction of myofibrils.[10] Additionally, not only serving as a scaffold, titin also organizes the sarcomere.[10] At titin's carboxyl terminus in the Z-disk, there is a Mis-4 insertion sequence.[10] This sequence contains 4 KSP motifs that are phosphorylated to regulate SH3 (Src homology 3) binding for Bin1, a protein that organizes the sarcomere.[10]

Phosphorylation of titin can also control its passive mechanistic qualities. For example, phosphorylation of S469 in the N2-B intrinsically disordered structure can reduce titin's passive tension by up to 20%.[10,21] Furthermore, phosphorylation can also be used to increase passive tension in cardiomyocytes.[10,21] This occurs through PKCα phosphorylation of COOH domain of the PEVK structure of titin.[10,21] These transient phosphorylation and dephosphorylation cascades can modulate titin in a beat-by-beat manner in response to extracellular signals.[10]

Not only does titin get phosphorylated to be regulated but titin does

have a kinase domain, the titin kinase domain (TK).[10] Phosphorylation of a tyrosine residue in this domain initiates a complex activation process. TK is an autoinhibited S/T kinase.[10] The exact mechanism of its activation is unknown, as whether the active site tyrosine is activated through auto-phosphorylation or phosphorylated by some coactivatoris unknown.[10] This TK domain has also been suggested to participate in phosphorylation of Z1/Z2-BP telethonin, found at titin's N-terminus.[10] However, although there is data to suggest this phosphorylation is mechanical stress adaptations, its full effect is not yet known.[10]

Apart from phosphorylation, titin also plays a key role in muscle hypertrophic gene regulation.[10,11] Hypertrophy is when an organ is enlarged due to increases in cell size. Titin not only is a large protein but has a large network of protein it associates with that link titin signaling to pathways regulating hypertrophy.[10] TitinZ1/Z2 (Z-disk region) domains tightly bind a telethonin/T1 cap. Such an interaction links titin to the muscle LIM protein, which has many locations in the myocyte including the nucleus wherein it acts as a coactivator of transcription.[11] There are also negative regulators of gene regulation found in the signaling of titin through the node on the I-band in the N2-A region.[10,11] Binding proteins bind to the I80/81 region.[10,11] These are MARPs (muscle ankyrin repeat proteins).[10,11] They move to the nucleus in response to mechanical strain and cause negative gene regulation.[10,11] Finally, in the M-band, A168-170 interact with MURF1 and 2. MURF1/2 can translocate to the nucleus in response to stress signals and mediate transcription as well as seen in Figure 5.[10,11] All of this reveals titin's role as a regulatory crossroads for signaling, especially in cardiomyocytes.[10,11]

Titin Mutations and Associated Diseases:

The polypeptide titin is encoded by the *TTN* gene.[8] This gene is very large, containing 363 exons.[8] Mutations in the *TTN* gene have already been associated with many cardiomyopathies.[8] Such a discovery tracks with titin's essential role in cardiomyocyte signaling as described previously. These titin-associated diseases include: Late-onset autosomal dominant tibial muscular dystrophy (TMD),

Young or early adult onset recessive distal titinopathy, Congenital centronuclear myopathy (CNM), Early-onset myopathy with fatal cardiomyopathy (EOMFC), Multi-minicore disease with heart disease (MmDHD), Childhood-juvenile onset Emery-Dreifuss-like phenotype, and adult onset recessive proximal muscular dystrophy.[8,24] All of these diseases associated with titin mutations lead to phenotypes of muscular degeneration or dysfunction, revealing titin's key role in muscle contraction and the sarcomere's structure. Specifically, we have correlated numerous diseases involving fetal and adult-onset heart failure with titin mutations. As heart failure is the leading cause of death in the United States today, titin could play a pivotal role in our understanding and development of treatments for these illnesses.

Table 1
Mutations causing TMD, young or early adult onset recessive distal titinopathy, LGMD or adult proximal phenotype

		Allele 1					
		Mutation[§]	Exon[†]	Domain			
TMD	Finnish TMD	FINmaj mutation	364 (363#)	M10 (Ig 152)			
	de Seze 1998/Hackman 2002 (French family A)	c.107867T>C (p.Leu35956Pro)	364 (363#)	M10 (Ig 152)			
	Hackman 2008 (French family B)	c.107890C>T (p.Gln35964*)	364 (363#)	M10 (Ig 152)			
	Hackman 2008 (Albacete family)	c.107889delA (p.Lys35963Asnfs*9)	364 (363#)	M10 (Ig 152)			
	Hackman 2008 (Barcelona family)	c.107889delA (p.Lys35963Asnfs*9)	364 (363#)	M10 (Ig 152)			
	Van den Bergh 2003 (Belgian family)	c.107840T>A (p.Ile35947Asn)	364 (363#)	M10 (Ig 152)			
	Pollazzon 2010 (Italian family)	c.107837A>C (p.His35946Pro)	364 (363#)	M10 (Ig 152)			
		Allele 1			Allele 2		
		Mutation[§]	Exon[†]	Domain	Mutation[§]	Exon[†]	Domain
Young or early adult onset recessive distal titinopathy	Hackman 2008 (French family C - Proband) and Evila2015 (pt.5b)	c.100558-100561dup (p.Gly33521Aspfs*25)	358 (357#)	A169 (Ig 141)	c.107647delT (p.Ser35883Glnfs*10)	363 (362#)	M-is7
	Hackman 2008 (French family C - Mother) and Evila2014 (pt.5a)	c.98105delC (p.Pro32702Leufs*15)	353 (352#)	A160 (Ig 139)	c.107647delT (p.Ser35883Glnfs*10)	363 (362#)	M-is7
	Evila2014 (pt.6)	c.67089delT (p.Lys22364Argfs*24)	319 (318#)	A55 (FN3 50)	c.107889delA (p.Lys35963Asnfs*9)	364 (363#)	M10 (Ig 152)
	Evila2014 (pt.7)	c.107889delA (p.Lys35963Asnfs*9)	364 (363#)	M10 (Ig 152)	c.107889delA (p.Lys35963Asnfs*9)	364 (363#)	M10 (Ig 152)
LGMD	Finnish original cases	FINmaj	364 (363#)	M10 (Ig 152)	FINmaj	364 (363#)	M10 (Ig 152)
	Penisson-Besnier 2010 (French family B - pt.IV-5)	c.107890C>T (p.Gln35964*)	364 (363#)	M10 (Ig 152)	c.107890C>T (p.Gln35964*)	364 (363#)	M10 (Ig 152)
	Evila 2014 (pt.1)	c.101113delT (p.Ser33705Leufs*4)	359 (358#)	A170 (FN3 132)	FINmaj	364 (363#)	M10 (Ig 152)
	Evila 2014 (pt.2)	c.39492dupT (p.Glu13165*)	208 (207#)	PEVK	FINmaj	364 (363#)	M10 (Ig 152)
	Evila 2014 (pt.3)	?			FINmaj	364 (363#)	M10 (Ig 152)
	Zheng 2015	c.107788T>C (p.Trp35930Arg)	364 (363#)	M10 (Ig 152)	c.107788T>C (p.Trp35930Arg)	364 (363#)	M10 (Ig 152)
Proximal adult TMD compound heterozygotes	Evila 2014 (pt4)	c.92167C>T (p.Pro30723Ser)	340 (339#)	A140 (FN3 112)	FINmaj	364 (363#)	M10 (Ig 152)
	Evila 2015 (pt t13)	c.60494A>G (p.His20165Arg)	305 (304#)	A32 (Ig 106)	c.107837A>C (p.His35946Pro)	364 (363#)	M10 (Ig 152)

Figure 6: Disease states correlated to their relative mutations on each allele of titin. Small missense mutations can dramatically change the titin structure such that many different kinds of muscular disorders develop.[8]

Before recently, with the advancements in next-generation sequencing techniques (NGS), it was not possible to sequence the entire *TTN* gene.[24] However, even though it is now possible these data can be hard to interpret, as many genetic

variants of *TTN* do not have a known correlated disease phenotype.[8] Figure 6 shows the known mutation-disease pairings along with where and what time of mutation occurs.[8] In such tables, we see that titin mutations can be grouped into TMD, titinopathic, and LGMD categorizations. These categorizations are made based on disease phenotypes, but as seen in Figure 6 are also correlated through their respective mutation sites. For example, mutations in the M10 domain lead to phenotypes associated with TMD (Figure 6).

Many of these diseases were of unknown cause until these links to the *TTN* gene were established.[8] There are many key outcomes to such findings. Principal among these is the stressing of the essentiality of titin.[15] Titin is a key element of the sarcomere, and as such is central to the function of the heart.[15] It is these disease correlations begin to show us just how essential a role titin plays in our bodies. We also begin to learn titin's influence outside of just being a structural scaffold for the sarcomere but extending to its roles in signaling pathways.

Aside from NGS that allows us to finally effectively sequence the entire *TTN* gene, other techniques have also revolutionized our understanding of titin: iPS-CM and CRISPR studies. iPS-CM stands for induced pluripotent stem cell-derived cardiomyocytes. In this technique, disease patients' cells are taken, and pluripotent stem cells are derived from their DNA. Thus, a line of diseased cells is sequenced and studied for morphological as well as functional deficiencies that underlie the diseased phenotype. With advances in CRISPR technology, scientists have learned how to forego the need for a diseased patient and now can target certain parts of the *TTN* gene to upregulate and downregulate its specific transcription.[17] As such, now we no longer have to wait for patients with a disease variant and can instead induce our own iPS cells with many more specific variations in the *TTN* gene. This allows for more testing and more specific analysis in which mutations in which position along the gene result in which phenotype.

There is still much work to be done in this field. Much is unknown about these disease's mechanism, including central questions like how or why they occur. However, much of the foundations have recently been lain and are propelling this

field quickly into the future. This includes developments and utilization of new cutting-edge techniques as well as an initial foray correlating *TTN* mutants with disease phenotypes.

Conclusion

Less than a half century ago we did not know titin existed. Now, we have discovered it mainly consists of Ig and Ig-FNIII domains, and its role as an elastic structural protein that provides the scaffold upon which the sarcomere is constructed. Titin has four definitional regions: Z-disk, I-band, A-band, and M-band regions. Titin is intricately and necessarily linked to the mechanism of muscle contraction, providing passive tension for the sarcomere that with the active sliding filament elements of actin and myosin allow for muscle contraction. The drive towards contraction is provided by the favorable folding and entropic rebound associated with Ig domains in the I-band region, rather than metabolic input like myosin. Thanks to recent advancements that have led to NGS and the CRISPRa/i system, we also have begun to understand how mutations in the titin gene, *TTN*, can cause disease. Titin so far has been particular associated with neuromuscular diseases such as muscular dystrophy. Finally, titin has been indicated as a key regulatory node in myocytes. From phosphorylation cascades that modulate titin to those in which titin regulates other proteins, titin has been seen to be a key node in protein regulation. However, titin is also key in genetic regulation with its interactions with MURF and LIM proteins.

Future studies of titin hold a lot of promise. For example, work to understand underlying titin-associated disease mechanisms could hold the key to unlocking a myriad of treatments for muscular and cardiac disorders that currently have none. Such studies could include exploration of the sarcomere's integrity due to titin mutations or force microscopy studies focusing on the effect of titin mutations on titin's ability to provide passive tension to the sarcomere. Moreover, further sequence testing of muscular disorders looking for titin mutants could provide integral information to treating a host of diseases that currently

are idiopathic as well as reveal clinical markers to identify these illnesses much earlier. Finally, future studies could help us understand the evolutionary ladder of life on Earth as elucidating the connection between titin and titin-like proteins found in different mammalian species could be used as an evolutionary marker. These studies could also reveal conserved domains across species and time that would provide key details to which domains of titin are the most essential for its function.

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Excellence in Upper-Level Writing (Sciences)

TGF-β1: Unraveling the Applications of a Versatile Cytokine

by Kateryna Karpoff

From CHEM 353: Introduction to Biochemical Research Techniques and Scientific Writing

Nominated by Nicolas Garza

CHEM 353 student Kateryna Karpoff did an excellent job in review of the protein TGF-β. She did an outstanding job of creating and incorporating figures into her paper. I as an instructor often find students to struggle with figure incorporation, but Kateryna excelled at this. Her signaling and disease sections were concise yet detailed at the same time, which is difficult to achieve and an indication of an excellent scientific writing piece.

-- Nicolas Garza

TGF-β1: Unraveling the Applications of a Versatile Cytokine

Abstract

The TGF-β superfamily is composed of 35 members with a vast array of signaling functions across both tissue homeostasis and cellular growth cycles. This review highlights the most populous member of the TGF-β subfamily, TGF-β1. The structure of this isoform contains both unique and conserved elements with respect to its alternate isoforms, TGF-β2 and TGF-β3. Once synthesized, TGF-β1 is released from the extracellular matrix and is ready to participate in signaling pathways. The isoform begins by forming SMAD complexes, ultimately localizing to the nucleus to behave as a transcription factor. The signaling patterns of TGF-β1 are highly pleiotropic in nature, presenting different effects across cellular environments and upon impact from alternate pathways. As these signaling cascades are widespread across body systems, their disruption may result in the onset of many human diseases, commonly causing the formation of both solid and hematopoietic tumors. This opens the potential for TGF-β as a potential target point for cancer therapy, with its inhibition slowing the uncontrolled cell growth.

Introduction

Transforming growth factor beta (TGF-β) is a multifunctional cytokine exhibiting major roles in development and homeostasis of body tissues, as well as cellular functions including proliferation, differentiation, and apoptosis.[1]

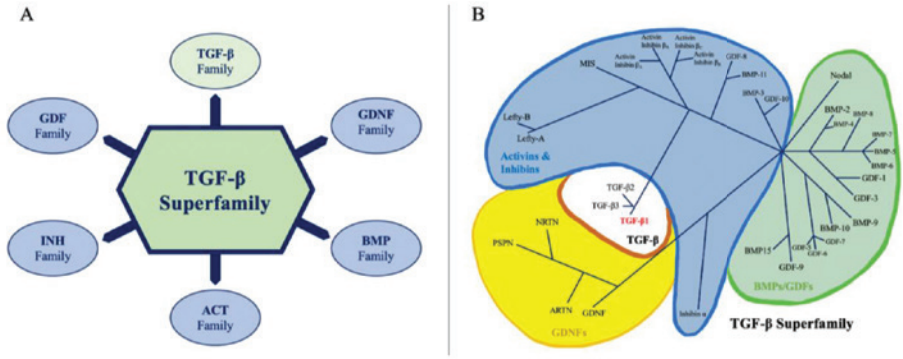

Figure 1. Diagram of the TGF-β superfamily members. (A) A schematic representation of the TGF-β superfamily subfamilies is presented. TGF-β: transforming growth factor beta; GDF: growth and differentiation factor; ACT: activin; INH: inhibin; GDNF: glial-derived neurotrophic factors; BMPs: bone morphogenetic proteins. **(B)** A web of the 35 TGF-β superfamily members organized by structural relationship is shown, placing the TGF-β1 isoform (red) in the context of related growth factors and cytokines.

The TGF-β superfamily consists of five main subfamilies – the activin/inhibin, bone morphogenetic protein (BMP) & receptor, growth differentiation factor (GDF), glial cell line-derived neurotrophic factor (GDNF), and TGF-β families (**Figure 1A**).[2] The members of these six subfamilies have varying evolutionary relationships based on their structures, and this dictates which subfamily they categorically fall under (**Figure 1B**). TGF-β was first discovered while studying the ability of polypeptide growth factors to implement autocrine secretion for the induction of uncontrolled cell growth. When the sarcoma growth factor (SGF) polypeptide was found in rat fibroblasts, studies indicated that SGF consists of two substances – TGF-β and TGF-α.[1] Roberts and Sporn later characterized TGF-β as a polypeptide secreted to promote the growth of fibroblasts and production of collagen. After several years, it was found to inhibit cell proliferation, directly connecting TGF-β inhibitors to the onset of cancer pathology.[1]

The TGF-β1 isoform of the TGF-β subfamily is the most common of three isoforms – TGF-β1, TGF-β2, and TGF-β3. While these isoforms share significant structural features, they are synthesized in different organs for the execution of varying tasks.[3] Specifically, TGF-β1 is most often found in bone, skin, and cartilage tissue with its key roles in differentiation, while TGF-β2 is expressed by neurons and is mainly responsible for the autonomic proliferation of these cells. TGF-β3 is responsible for epithelial-mesenchymal interactions and is most commonly found in lung and palate tissues. Disruptions in the functioning, production, or signaling of TGF-β proteins, as well as interference with the downstream products of TGF-β pathways, contribute to the development of many diseases. This paper will investigate the structure and localization of the TGF-β1 isoform; review the dominant TGF-β SMAD signaling pathway; cover the TGF-β signaling disruptions which amount to cancerous uncontrolled cell growth; and conclude by discussing TGF-β as a therapeutic target in cancer treatment.

TGF-β1 Key Structural Features

The 35 members of the TGF-β superfamily vary widely in structural and evolutionary relationship (**Figure 1B**). Looking at the TGF-β subfamily, the three existing isoforms share a significant conserved component in their sequences, however each has fingerprint structures which makes it unique. Specifically, the precursor polypeptide from which TGF-β1, TGF-β2, and TGF-β3 are derived is initially composed of 300-600 amino acids (**Figure 2**). This initial structure can be broken down to a variable N-terminus fragment of approximately 200-500 amino acids, as well as a conserved C-terminus fragment of about 110 amino acids.[4] Comparing the sequence similarity of the

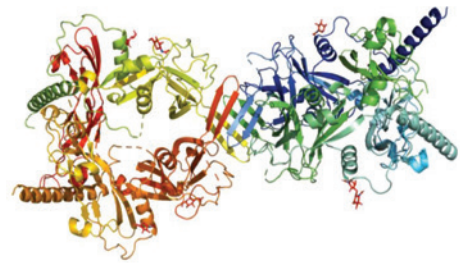

Figure 2. Structure of proStructure of pro--TGFTGF--β1β1. The two beta--pleated pleated sheets in the center highlight the TGF-β knot, marking a distinct feature of the TGF-β subfamily member structures. PMID::21677751. PDB: 3RJR.

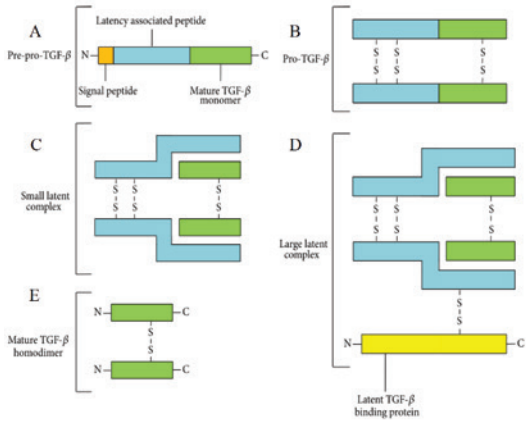

Figure 3. Structural representation of the different structural forms TGF-β1 takes during synthesis, secretion, and activation.[2] The peptide begins as a (A) pre-pro-TGF-β, transforms to a (B) pro-TGF-β, proceeds to be a (C) SLC, later matures to a (D) LLC and eventually is secreted as a mature TGF-β homodimer.

three isoforms, TGF-β1 and TGF-β2 share about 71.4% of their primary structures, TGF-β1 and TGF-β3 share about 76%, and TGF-β2 and TGF-β3 share around 80%.[2] Looking at secondary and tertiary structural features, the entire TGF-β superfamily shares seven cysteine residues that ultimately form disulfide bonds. The following specific structural similarities are responsible for defining the subfamilies. For the TGF-β subfamily, a conserved structure called the "TGF-β knot," or a set of two beta-pleated sheets anchored by a core of six cysteine residues, is seen across the three members, with its seventh cysteine functioning to dimerize the monomers through an interchain disulfide bond.[4] This knot is visible in the center of the largely unmodified dimeric pro-TGF-β1 structure (**Figure 2, Figure 3B**). The structure of TGF-β1 in particular can be described as a homodimer of two 112 amino acid polypeptide chains linked through a disulfide bond, amounting to a total molecular weight of 25 kDa.[2]

TGF-β1 Synthesis

These structural features of TGF-β1, specifically its ability to form disulfide bonds, directly influence its sequence of synthesis. TGF-β1 is synthesized through a series of modifications, allowing the pre-pro-TGF-β form to evolve into a large, latent complex (**Figure 3**). Starting with pre-pro-TGF-β, the signaling peptide is removed through proteolytic cleavage, and disulfide isomerase (PDI) catalyzes the formation of three disulfide bonds at Cys residues in positions 223, 225, and 356 to allow for the dimerization of the original two monomers (**Figure**

3A). The product of this is the linked combination of two latency associated peptide (LAP) chains and 2 mature TGF-β chains, together making up the pro-TGF-β homodimer (**Figure 3B, Figure 4**).[2] This homodimer then undergoes proteolysis catalyzed by the paired basic amino acid enzyme known as furin. This

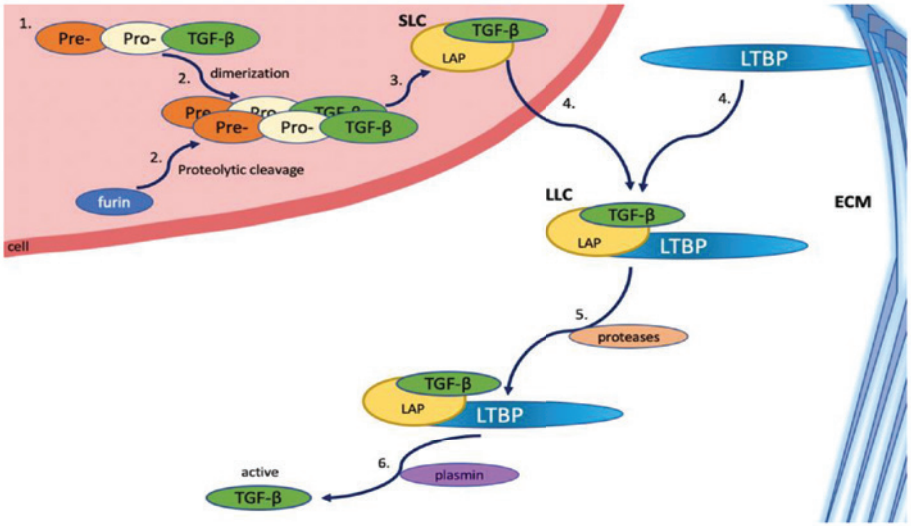

Figure 4. Synthesis and activation of TGF-β1. 1. TGF-β synthesis begins with an inactive precursor with a pre-signal peptide and a pro-N-terminal peptide. **2.** Proteolytic cleavage removes the signal peptide, followed by dimerization. **3.** Next, cleavage by proteases results in C-terminal mature peptides and N-terminal latency associated peptide (LAP), forming a small latent complex. **4.** The SLC transports to the extracellular matrix for further covalent binding to latent TGF-β binding protein (LTBP), making a large latena complex (LLC) and forms ECM proteins. **5.** Activation occurs as the LLC is released from the ECM by proteases. **6.** The mature protein is then cleaved from LTBP via acidity or plasmin, and once the TGF-β protein is released from the ECM, it can begin signaling.

is responsible for cleaving a bond between amino acid residues 278 and 279 which then separates the covalent linkages holding the LAP and TGF-β chains together. When only noncovalent forces are holding together these chains, the polypeptide is in the small latent TGF-β complex (SLC), during which these forces maintain TGF-β in its inactive form and prevent its interaction with receptors (**Figure 3C**).

Next, the SLC forms an additional disulfide bond between Cys residue 33 and the Cys residue 8 of the third cysteine-rich domain of the latent TGF-β binding protein (LTBP), leaving the complex in its large latent TGF-β1 complex stage, or LLC (**Figure 3D**). The LTBP functions to form ECM proteins, and

protein activation occurs once proteases release the LLC from the ECM (**Figure 4**). Finally, plasmin cleaves the mature TGF-β1 protein from LTBP, freeing the TGF-β1 homodimer and leaving it ready to begin interacting in signaling pathways (**Figure 3E, Figure 4**).

TGF-β Signaling Pathway via SMAD Complexes

Once TGF-β is synthesized and activated, it may begin participating in signaling pathways by forming SMAD complexes. SMADs are a structurally similar protein family with the core physiological function of transducing TGF-β signals for ultimate effects on growth and development. These complexes then transport to the nucleus to execute roles as transcription factors, eventually activating TGF-β receptors to induce signaling.[5,6] Depending on where in the body the target cells of this process are localized and which other signaling pathways are present nearby, a variety of results can be exhibited due to SMAD complex-based signaling, making TGF-β highly pleiotropic in nature.[7] This process begins when TGF-β locates the surface of the cell it wishes to target and binds to the dual-specificity kinase receptors. Structurally, these receptors highly resemble serine/threonine and tyrosine kinases, so it logically follows that they function through phosphorylation. Once two TGF-β molecules bind to a heterotetrameric complex of two type II and two type I receptors (allowing for a symmetric 2:2:2 structure), the type II receptors phosphorylate the type I receptors to induce their activation.[5,6] Depending on the specific TGF-β superfamily in action, it will bind a specific combination of type I and type II receptors.[5] Specific to the TGF-β subfamily, all three members bind to the same type II receptor known as TβRII, as well as the ubiquitously expressed type I receptor known as TβRI, or activin receptor-like kinase 5 (ALK-5). While TβRI and TβRII are typically found as monomers, homodimers, and heterodimers, the binding of a TGF-β ligand preferentially induces their orientation in a heterotetrameric complex. While TGF-β1 and TGF-β3 bind to TβRII with a stronger affinity than to TβRI, the reverse is true for TGF-β2, indicating the respective order in which each is

recruited for the eventual complex assembly.[5] Specifically, TGF-β1 associates with TβRII to form a new high-affinity binding site for TβRI.

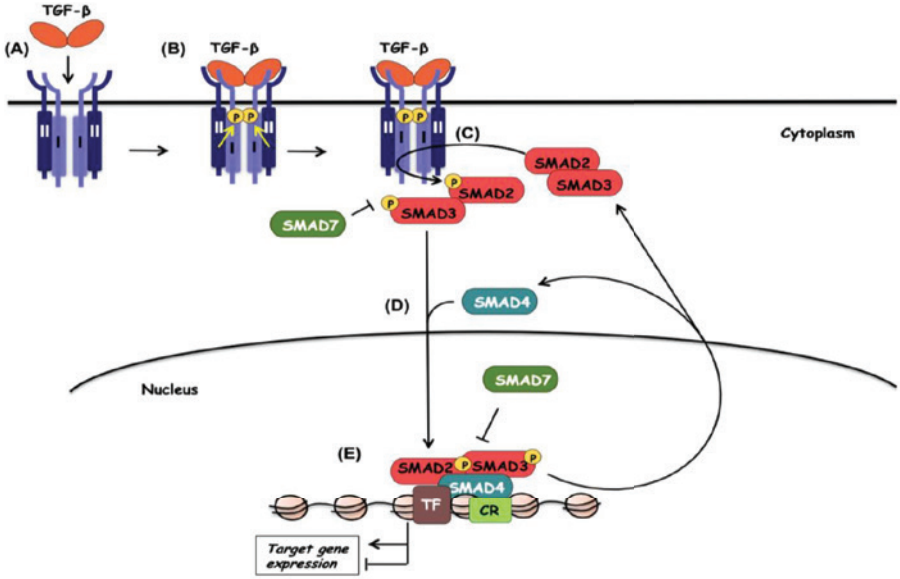

Figure 5. TGF--β/SMAD Signaling Pathway[6] TGF-β triggers phosphorylation of receptors upon binding, ultimately activating the R-SMADs. SMAD7 prohibits RSMADs. SMAD7 prohibits R-SMAD activation, allowing for complexation of R-SMADs with SMAD4. SMAD complexes ultimately associate with TFs and CRs to regulate gene transcription.

Next, the activated type I receptors proceed to activate the two receptor-activated SMADs (R-SMADs), SMAD2 and SMAD3. SMAD7 functions to compete with the R-SMADs for binding with the type I receptor, preventing the activation and signal propagation of R-SMADs. R-SMADs and the type I receptor then dissociate and SMAD2 and SMAD3 complex with SMAD4.[6] This trimeric complex of SMAD2, SMAD3, and SMAD4 all transport to the nucleus and compound with DNA binding transcription factors (TF) and chromatin remodeling proteins (CR), ultimately regulating target gene transcription negatively or positively. SMAD7 has the ability to inhibit nuclear SMAD complex transcriptional activity (**Figure 5**).[6] The SMAD signaling system has key roles in the antiproliferative properties of TGF-β as missense mutations in the pathway,

prevention of phosphorylation, and blocking complex formation between SMAD2 and SMAD3 have all demonstrated consequential tumor formation.[9]

TGF-β1 and Cancer & Therapeutic Potential for Treatment

When TGF-β is considered in the context of cancer regulation, its paradoxical role in this process is exposed. While it stunts cancer progression through preventing the transformation of cells in the earlier stages of tumorigenesis, it ultimately flips its functionality and assists the processes of tumor formation and metastasis. Specifically, the protein helps promote epithelial to mesenchymal transition (EMT), or the process by which cells lose their polarity and cell-cell adhesion properties, allowing them to migrate and invade tissues as they transform into mesenchymal stem cells. Additionally, TGF-β stimulates angiogenesis and suppresses the immune system, creating a very hospitable environment for tumor formation.[9] TGF-β normally acts as a potent inhibitor of cell proliferation and a tumor suppressor by prohibiting the progression of cell-cycle phase G1 through inducing CDK inhibitor expression (p15 and p21) and suppressing c-Myc expression.[9] When this normal signaling pattern is disrupted, tumor formation occurs, presenting as a variety of cancers.1 In these cells, TGF-β reverses its functionality and works as an oncogenic factor while losing its anti-proliferative response. Tumor cells downregulate their p15 and p21/WAF1/CIP1 signaling pathways through interacting with the Myc/SMAD3 complex and activating the P13K-AKT pathway.[9]

TGF-β may act as a tumor promoter when cancer cells begin to evade the typical inhibitory effects of the cytokine, and in turn over express its production. This leads to uncontrolled cell proliferation and eventual tumor formation. EMT, as described above, induces cytoskeletal rearrangements to allow for increased cellular invasion and migration. Additionally, TGF-β is capable of increasing the expression of vascular endothelial growth factor (VEGF) in cells, which stimulates angiogenesis to further sustain tumor cells. Finally, TGF-β is normally responsible for the development of a vast array of T cell lineages in the body. In highly

progressed malignant tumors, it inhibits NK cell activity, decreases the production of cytokines, inhibits the development of dendritic cells, and influences the cytotoxic properties of T cells. These effects collectively promote immunosuppression, debilitating the body's ability to fight cancer progression.[9] TGF-β's tumor-promoting ability has allowed for its signaling pathway to be considered for a potential cancer therapy target. This could be done in three potential ways, the first being that TGF-β synthesis can be directly inhibited through the application of antisense molecules. Alternatively, TGF-β can be blocked from receptor interactions through monoclonal antibodies and decoy receptor traps, or kinase inhibitors/aptamers which interfere with the functioning of downstream SMAD signaling protein can be used to inhibit the TGF-β signaling pathway (**Figure 6**).[9]

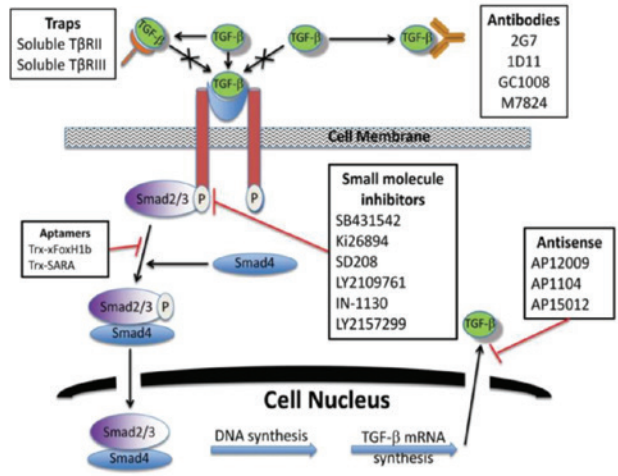

Figure 6. Potential applications of TGF-β in Cancer therapy[9]. Several control points exist for potential manipulation of TGF-β for cancer therapy. The methods represented above are direct inhibition cancer therapy. The methods represented above are direct inhibition of synthesis through antisense molecules, blocking TGF-β from receptor interaction with monoclonal antibodies or soluble decoy traps, and the inhibition or the signaling pathway through kinase inhibitors or aptamers interfering with proper function of inhibitors or aptamers interfering with proper function of downstream SMAD signaling proteins.

Conclusions

TGF-β is a highly multifunctional cytokine that plays a vast array of roles in the human body. It is highly integrated in a variety of signaling pathways and works in coordination with body organs to prevent uncontrolled cell proliferation amongst many other functions. It is now a key target for cancer prevention

therapy and shows promising results in this field. Several of these therapies are being clinically tested today, however several challenges are also presented with this work[10]. Specifically, the duality of its pleiotropic functions and implications in cancer ultimately results in the presentation of multiple side effects in patients undergoing these therapies. Targeting either TGF-β proteins themselves or the downstream product of their signaling pathways may result in the unintentional disruption of another crucial signaling pathway in the body. In order to fill in the gaps in this work, the intersection of TGF-β pathways and the implications of small molecule inhibitors on these pathways must be carefully mapped and kinetically tested. This will allow for more accurate predictions of how a particular drug therapy may positively or adversely influence a patient in clinical practice. While further work must be done to verify the safety of TGF-β inhibitors in cancer therapy, this review of the structure, synthesis, and signaling of the polypeptide presents its growing implications in the world of cancer biology.

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Excellence in Upper-Level Writing (Social Sciences)

Research Proposal: Reevaluating the Economic Imperative to Learn

by Angelina Little

From POLSCI 381: Political Science Research Design

Nominated by Nancy Burns and Ben Goehring (GSI)

Angelina Little ask how undergraduates understand the purpose of education, with a special interest in the role economic success plays in that thinking. In her proposal, she works carefully and imaginatively through the literature. She teases alternatives and distinctions from the literature that she puts into practice in her research design. She develops a plan to interview a stratified sample of undergraduates about these issues. She harnesses the intervention that COVID has made in these students' lives in her interview design. The proposal is engaging and compelling. It outlines a research project that will be an important contribution to the literature.

-- Nancy Burns and Ben Goehring (GSI)

Research Proposal:
Reevaluating the Economic Imperative to Learn

I. Introduction

What is the purpose of pursuing an education? In 375 BC, Plato wrote: "the direction in which education starts a man will determine his future life," (*Republic* IV). Plato understood education to be a lifelong process inculcating virtue in individuals. In our contemporary world, education is understood in the context of the drive to succeed in a rapidly changing world. Under late capitalism, individuals are taught to make sense of their lives in economic terms, each decision a cost-benefit analysis, each experience a potential new angle with which to market oneself. Simultaneously, American individualism instills the belief that each person is responsible for his own success and that anyone can make it if he or she simply works hard enough. American individualism in the context of capitalism thus motivates a connection between a person's esteem and his ability to produce material wealth. This sense of economic citizenship pervades all areas of life, including a person's education, valued as a path for maximizing a person's productivity and economic worth. As a result, students spend their high school careers learning to measure their worth in numbers as they strive to perfect their GPAs and SAT scores to earn admission to colleges where they will continue in a similar fashion, crafting resumes and joining organizations that might put them at an advantage over their peers in the race for employment. The intense pressure to succeed academically and its implicit connection to economic success seem to increasingly inform students' academic endeavors, while the idea that education's value lies in its opportunity for individual self-actualization becomes secondary.

In my research, I hope to shed light on the extent to which the economic rhetoric of success has trickled down into college students' understandings of the purposes of education. I believe that the prioritization of economic success comes at the cost of intellectual curiosity, student wellbeing, and a true sense of community. I hypothesize that conversations with college students will reveal such

values to come second to economic considerations in the way they conceptualize the value of higher education. Additionally, the COVID-19 pandemic has posed a unique disruption to the status quo, and has forced students, teachers, and administrators alike to reevaluate the structure of our education system. I believe that the dialogue on campuses regarding the purpose of education in the wake of the pandemic will reflect this, signalling an opportunity to reassess the individualist and economic rhetoric that dominates much of the discourse on higher education.

This research will provide unique insight into real students' perspectives as they strive for success in a time of crisis. Higher education faces a challenge unlike anything it has seen before as it adapts to the COVID-19 pandemic. The norms and values that define institutions have been called into question as leaders make difficult decisions regarding school reopening and confront how much is lost when education is remote. These challenges have led us to ask wherein lies the true value of education and what exactly students gain in return for the hefty tuition fees they pay. My research will inform policymakers, administrators, and instructors at all levels by offering a window into the current climate in institutes of higher education among students reckoning with such questions.

II. Literature Review

In 1960, Theodore Schultz introduced the idea of human capital, and with it, changed the nature of the way we view education. With the simple statement that "skills and knowledge are a form of capital," Schultz redefined education as an investment key to economic growth (Schultz 1961, 1). In *The Introduction of Human Capital Theory into Education Policy in the United States* (2017), Laura Holden and Jeff Biddle document the transformation of U.S. education policy in response to the introduction of human capital theory. Holden and Biddle write that "educational and economic policymakers at the federal level accepted the basic assumption of human capital theory, which was that the central purpose of education was to increase the productivity, and thus the future earning

power, of the student" (Holden and Biddle 2017, 539). Under human capital theory, education policy became a subset of economic policy, as focus turned to its potential to maximize earnings for both the individual and the nation as a whole. In *Measuring America: How Economic Growth Came to Define American Greatness in the Late Twentieth Century*, Andrew Yarrow identifies a parallel trend in the education sector as America came to become defined in terms of its economic prosperity. Comparing social science and history textbooks over the course of the twentieth century, Yarrow observes a shift away from emphasis on freedom and equality and toward praise of America's economic growth, with educational materials encouraging students to "work hard to create ever more abundance for all" (Yarrow 2010, 150). Yarrow argues that this shift moved Americans to understand success in terms of measures of GDP, stock market, and income rather than equity or justice. This shift had ramifications for how Americans conceptualize the world around them, even outside the realm of economics: "from politics and social science to everyday thinking, we live in the shadow of myriad economic metaphors. Even our personal lives are framed, seriously or tongue-in-cheek, as cost-benefit calculations" (Yarrow 2010, 196).

We can see the effects of the pervasiveness of economic terms in today's education system. Discussions of "investment" in education dominate much of the discourse surrounding education policy. In *Capital or people — what is the true purpose of education?*, Tanweer Ali explores the implications of human capital theory, arguing that it "excludes a discussion of social justice and de-emphasizes the role of education in advancing individual fulfilment and in strengthening democratic values," as well as ignoring "a view of useful human activity outside of production within a corporate environment" (Ali 2017, 4). Ali's insights point to what is lost when education policy is driven by a purely economic understanding of the education system: if education is valued for its measurable outputs, the less quantifiable benefits of the education system, whether they be individual fulfilment or consideration of the common good, are pushed to the side. Education theorist Gert Biesta shares this concern throughout his writings,

questioning whether we have lost sight of the purpose of education altogether as policymakers look to data drawn from easily quantifiable measures (Biesta 2010). Put simply, "the danger is that we end up valuing what is measured, rather than that we engage in measurement of what we value" (Biesta 2010). Alisdair MacIntyre articulates a similar problem he calls the "input-output system" of education in *Alisdair MacIntyre on Education: In conversation with John Dunne* (2002). MacIntyre writes that a focus on measurable outcomes "loses sight of the end of education, the development of its students' powers, and substitutes for this end that of success by the standard of some test or examination" (Dunne and MacIntyre 2002, 4). Under the pressure to produce high-achieving individuals, institutions become narrowly focused on test scores and other clear outputs that can prove the success of programs. Under such models, education becomes valued solely in terms of its quantifiable outcomes. The work of Ali and Biesta shed light on what we lose sight of when taking a strictly quantifiable, measurement-based approach to education: the values of the education system extending beyond the production of efficient workers.

This focus on numbers and productivity in the realm of education does not just affect policy and curricula; it trickles down to the students themselves. The way students speak about their education reflects a capital-oriented understanding of its purposes. Agnes Callard's essay on *Liberal Education and the Possibility of Valuational Progress* (2017) compares three basic models of understanding college education: the parental model, under which teachers take on the responsibility of changing their students, the consumer model, which presupposes students enter college as fully informed "consumers" seeking to maximize return on investment, and the aspirant model, which allows for students to explore disciplines and discover what they seek to learn with some guidance (Callard 2017). While Callard argues in favor of the aspirant model as the best mode for students to engage with educational materials with curiosity and openness, it seems that the consumer model dominates most contemporary understandings of education. As Callard points out, students pay large tuitions, "shop" for classes, and leave with

knowledge and abilities valued in the market; it is therefore not unreasonable for them to view college as a "rational skills factory" (Callard 2017, 19). Influenced however implicitly by the advent of human capital theory amid the pressures of an increasingly competitive market, students feel the necessity of maximizing the return on the thousands of dollars they invest in their education. Such thinking, while practical in today's climate, leaves little room for the student-as-aspirant who enters the education system as an open minded explorer and finds self-fulfillment in what he or she learns.

Biesta and Deborah Osberg make a comparable claim in *Beyond curriculum: Groundwork for a non-instrumental theory of education* (2020). Biesta and Osberg criticize contemporary understandings of education as a "curricular instrument designed to facilitate a purpose external to itself," advocating instead for an emergent model that "self-generates the purpose it serves" (Biesta and Osberg 2020, 59). Education, they argue, should not be considered an instrument to success so much as an experience that generates meaning in and of itself. This emergent model lines up with Collard's aspirant model of education; neither posits that students should use education to pursue a specific outcome, but rather, discover that outcome as they engage in the educational process. Human capital theory however, with its focus on education as a means of generating greater wealth, lends itself to an instrumental model of education rather than an emergent one.

While none of these authors might put forth a comprehensive statement on what specifically education systems should aim to achieve, their analyses demonstrate the shortcomings of today's number-oriented approach. Whether you call it the consumer model, the instrumental theory, or the input-output system, the sentiment is clear: the value of one's education is not fully realized when academia is understood primarily as a means to an economic end. Students and institutions alike are prone to forgoing the less quantifiable benefits of a more balanced approach to education when they consider schooling to be a process of producing capital and maximizing return on investment without regard to personal fulfillment.

What are the consequences of such heightened emphasis on the economic value of one's education? According to Michael Sandel's account of contemporary higher education, students lose out on more than just the ability to explore their academic curiosities. In his book *Tyranny of Merit* (2020), Sandel explores the ramifications of the hyper-competitive nature of college admissions. Though Sandel frames the issue largely in terms of meritocratic hubris, or the false superiority students feel upon 'earning' admission at elite institutions, Sandel's account is useful in understanding the implications of measurement-focused education models. Referencing rising cases of depression, anxiety, and substance abuse, Sandel identifies the "mental health epidemic among privileged youth" as a consequence of students competing to achieve perfect GPAs, test scores, and extracurriculars, explaining that "years of anxious striving leave young people with a fragile sense of self-worth" (Sandel 2020, 181). It's clear that even among the most privileged students, education no longer provides a true opportunity for cultivation of the self; amidst competition and the pressure to set themselves apart, students strive to perfect their measurable attributes at the expense of their own wellbeing. Sandel explains this development as "the conversion of college into basic training for a competitive meritocracy, an education in packaging oneself and applying for stuff… the sorting and striving crowd out teaching and learning" (Sandel 2020, 182). We can intuit that these students do not understand their schooling as an opportunity for personal growth so much as an opportunity to grow their human capital in preparation to enter the market. In this way we can see some of the more dangerous consequences of teaching students to view themselves as commodities; their self worth becomes intrinsically tied to what is measurable and what is economically valuable.

Elsa Davidson's interviews with teenagers at a Silicon Valley high school in her article *Marketing the Self: The Politics of Aspiration among Middle Class Silicon Valley Youth* (2008) offer further insight into the lives of students learning to market themselves. Davidson uses interviews to examine how middle class students are taught to understand themselves as economic citizens and how

"this politics of citizenship obligates middle class youth to 'package' or market authentic personal traits to showcase their exceptional qualities, well-roundedness, and authentic originality, and to frame such acts in terms of personal choice" (Davidson 2008, 2814). In order to maximize their future earning potential, students learn to commodify and market themselves and compete against their peers. Davidson's work unveils students pursuing "passions" not out of genuine curiosity but rather as part of a performance necessary to gain access to elite institutions and maximize their human capital. Here we see the realization of Biesta's theory that "the high performing school is an organisation in which *the personal is used for the sake of the functional*: community is valued, but primarily for instrumental purposes within the context of the market-place" (Biesta 2020). Just as students perform "well roundedness" on their resumes, they might pursue involvement in a "community" that can be packaged for a personal statement essay. Biesta worries that if this trend continues, "it will inevitably result in the demise of education as a holistic process of human being and becoming" (Biesta 2020). Davidson's interviews indicate that for some students, the process of individual exploration is restricted to what is deemed desirable on a resume. She observes that the pressures of such performativity "suggest a domestic politics of 'hyper-vigilance' that may transform young people's self-perceptions, attitudes towards schooling, and aspirations, while also potentially posing risks to youth" (Davidson 2008, 2816). The lack of authenticity students experience amidst a competitive culture with the promise of potential economic prosperity guiding each aspirant compels students to build their self esteem from how well they are able to "sell" themselves.

Under today's economic impetus, students learning to market themselves to institutions and future employers as early as high school lose out on the chance to build meaning as they explore topics that truly interest them. Education takes on an individualist, hypercompetitive form devoid of authenticity as students seek only to perform rather than to truly engage in their interests or the material. Students measure themselves in terms of the numbers that define them,

understanding that this is how they will be evaluated by others. Aspiring to be the "best" has an inexplicably material connotation as students seek to maximize their human capital as they prepare to enter the market; under such a system, education becomes a zero-sum game in which students compete to demonstrate marketable skills and interests.

Such criticisms of market-oriented education beg the question of how one might imagine a system that goes beyond measures of productivity and excellence. In his famous address "Learning to be Human" (2012), philosopher John MacMurray gives an idealized vision of education that extends beyond economic success: "whilst the imperatives of earning a living… must necessarily and properly feature in education they should not comprise the whole or even the most important part of it. The key point is that they should be approached through other aspects of education as part of the whole task of learning to be human in its richest and most fulfilling sense" (MacMurray 2012, 661). While "learning to be human" may at first glance appear a luxurious goal that is not pragmatic for educational institutions to strive for, it might hold the key for a vision of education that values students for more than their future earning potentials.

MacMurray writes that "learning to live in a community" is the primary purpose of education (MacMurray 2012, 662). While this may not seem radical, when one considers this idea against the backdrop of today's individualist, competitive academic environment, living in a community with others does not appear to be a primary focus. James MacAllister explains in his piece *What should educational institutions be for?* (2016) that "if persons are only encouraged to perform the practice… with a focus on their individual desires alone then it will become all too easy for common concerns to get lost. If on the other hand persons are encouraged to consider how their performance… might influence the course of their life and those of others in the longer term then it will be much easier to raise issues concerning the public good" (MacAllister 2016, 387). A shift of focus away from individual economic contributions and toward a public good that is measured not just by GDP but by equity, justice, and democratic

values might lift reorient students to be able to learn authentically without the pressures of marketing themselves. It would also make room for learning to value political, social, and community-oriented contributions that cannot be measured in terms of economic productivity. However, such a shift would require a collective movement, as MacAllister hypothesizes that only if "parents, teachers, school pupils, students, politicians, academics and other persons besides these do together question the purpose of educational institutions it may become possible to interrupt the individualistic ideals that pervade much contemporary public life" (MacAllister 2016, 389).

The aftermath of the COVID-19 pandemic might provide a unique opportunity to do this. The upheaval and reorganization of so many institutions in the wake of COVID-19 has resulted in widespread critical questioning of the purposes of the structures we have come so accustomed to. In a short piece entitled *Have we been paying attention?* (2020) Biesta states that "the current crisis has revealed with much clarity how important public education—education funded by public means, accessible to everyone, and accountable to the public—is, particularly for those who only have limited resources of their own. We knew this, of course, but it is one of the more inconvenient truths about contemporary education that we tend not talk about," (Biesta 2020, 12). No longer are questions about the institutional structures of education restricted to educational philosophers and policymakers; they are instead at the forefront of conversations between teachers, students, and parents across the country grappling with the upheaval of the pandemic. The people are not only being reunited with the importance of education, they are also coming to terms with uncertainty of the future and the insecurity of jobs. Rachel Buchanan writes in *Philosophy of education in a new key* (2020) that "today's children need to be equipped with skills rather than content in preparation for an unknown technological future" and advocates that educators "reinvigorate education with collective thinking and ethics" to better prepare "students for existence in the contemporary world" (Buchanan et al. 2020). The idea that change is necessary is becoming mainstream

as we confront the uncertainty of the times we live in; a reframe of what is useful when it comes to education is no longer a radical idea but entirely necessary in a rapidly changing America.

A shift toward collective problem solving might be just what is needed to counteract the individualist framework that has dominated the education system in recent years. Michael Peters, Sonja Arndt and Mark Tesar claim the pandemic has provided just the environment for such a shift by changing the way we relate to others in their contribution to *Philosophy of education in a new key*. Peters et. al write that the rules citizens now follow to limit the spread of the virus, such as wearing masks to protect others from our own germs, are a first step in changing such relations: the precautions we take "indicate something more philosophical — the ethics of the other, the ethics of care for the other, the ethics of duty, of treatment of the other" (Peters et al. 2020). This community orientation, under which we understand ourselves not only as individuals but as a part of a community in which consideration of the other is essential, could lay the groundwork for a shift away from the zero-sum, competitive understanding of education we hold today. In *The disorder of things*, Peters expands upon this idea, writing that "COVID-19 exposes the significance of the public sector for our collective well-being… 'solidarity' 'community' 'collective responsibility and action' are the key words ringing out as a response" (Peters 2020). The shift toward community action necessary to combatting the pandemic could be the key to a collective overhaul of individualist attitudes driving competitive ideals of success. The movement of rhetoric away from individuals and toward community as witnessed by COVID-19 lays the potential for a similar rehaul of contemporary models of education. Perhaps we could reimagine educational institutions not as human capital producing factories, but rather, as environments for the cultivation of the self with an orientation toward the common good. Redefining success in terms of what is good for all rather than what is good for the individual has the potential to reunite education with its purposes beyond economic prosperity and endow students with true fulfillment.

The existing scholarship on the ramifications of human capital theory provides an important framework for understanding today's education system. Human capital theory works in conjunction with the reliance on quantifiable measures of educational success to produce a society more concerned with measurable outcomes and wealth creation than the cultivation of the self and the common good. I believe that students' own understandings of the purposes of education will reflect this prioritization of economic productivity and demonstrate the influence of human capital theory on students' academic decisions and experiences. Further, I believe that the COVID-19 pandemic poses an opportunity for a shift in the way we understand education's purposes and value.

III. Research Design

My research will measure student perceptions of the purposes of education and the extent to which student views are informed by individualist, economically-oriented mindsets. I expect student perceptions to be influenced by a number of environmental factors such as conversations with their peers, pressure from parents, relationships with past teachers, media consumption, and other sources of rhetoric on education. My aim is not to pinpoint which of these factors is most important in influencing student views on education, but rather to demonstrate how ideas of individualism and economic citizenship pervade the ways students speak about why they value education. Just as under human capital theory, education is valued as a key factor in economic productivity, I expect students to make sense of their education as a path to success more than as an avenue for self growth.

Because the COVID-19 pandemic has caused such a disruption to the education system, I expect it to play a significant role in the current discourse on campuses regarding education. Amidst the chaos of adjusting to living in the pandemic, many students ask what the point of paying tuition and earning a college degree is. Some have even opted to take time off and pursue alternate forms of education. I expect to find that the onset of the pandemic has pushed students

to reconsider the purposes of education and find the economic imperative to be an insufficient answer to the question, *what is this all for*?

I plan to measure students' views on education by conducting semi-structured interviews with undergraduate students at the University of Michigan. I believe participant interviews provide the most effective avenue for me to fully capture the nuanced ways in which students think about education. Each student has a unique experience with education, and at the University of Michigan, the nearly 30,000 undergraduates come from many different backgrounds. I expect to be able to identify patterns within these conversations to get a sense of general trends in the ways students are thinking about education in 2021. Although using in-depth interviews will limit the number of students I am able to include in my sample, it is essential for my research to be able to speak with students face to face (whether that is over Zoom or in person and socially distanced) in order to get an accurate understanding of the complex ways they conceptualize education.

The semi-structured nature of the interview will allow the students to use their own words and speak candidly about how they think about education. I will begin by asking open-ended questions about what they value in an education that will allow the interviewee to lead the conversation in the direction they find most interesting, allowing me to take a step back and listen without leading the conversation in any particular direction. From this I will be able to discern patterns of what topics are at the forefront of students' minds. I will also ask students to describe the climates of the high schools they attended as well as why they chose to apply to and attend the University of Michigan. Their responses to these background questions will give me insight into the extent to which they experience academic pressures and desire economic achievement, critical to my analysis of their overall understanding of education's purpose. By asking about their previous educational environments, I will also gain understanding of the influence of peers and role models in their views on education, giving me a window into how such rhetoric circulates. I will also ask how each student's educational values have influenced academic decisions they've made, such as choice of major,

to discern the concrete consequences of ideological discourse. Finally, I will ask how the pandemic might have caused them to re-evaluate any of these topics in order to ascertain the extent to which COVID-19 may have influenced their views. As I collect interviews, I will review my notes and adjust my questions if I find recurring trends in subject matter brought up by students.

To gather subjects, I will use a snowball sampling method, reaching out to students across disciplines who express willingness to have a conversation about education as the 'seeds' of my sample and then ask them to refer me to others who might be willing to participate in my study. I will start with several seeds that vary in socioeconomic status, gender, race, and ethnicity in order to ensure my sample is diverse. This sampling method will be beneficial to me because it will allow me to engage with verbose individuals willing to participate in a recorded interview, and it will help me find students with unique perspectives on education. The groups I am primarily interested in speaking with are:

- First year students: The experiences of first year students are especially valuable to me because of their unique position as they embark on their collegiate careers with fresh memories of their high school experiences. First year students will have most recently completed the college application process and will therefore likely be very in touch with their reasoning for attending college. They will also most easily be able to recall and describe the environments that shaped their perceptions on education. I hope to speak to both undeclared first year students and those who have a clear idea about their career ambitions. As these students embark on their college experiences, they will have much to consider about what they hope to get out of their higher education.
- Students in their final year: Seniors, superseniors, and students graduating early will be able to reflect on the ways their perceptions of education have shifted over the course of their collegiate careers and on the causes of these shifts. They also will be in the process of making decisions about post-graduation plans and will be able to reflect on how their academic

choices influenced these decisions. I hope to speak to a range of these students, from those with job offers to those continuing their education and those uncertain what's next for them. These students will likely feel strongly about the value of their education as they look back and prepare to move on to the next period of their lives.

- Students taking time off: Students who choose to take time off from school, whether to pursue alternate learning experiences, to work, to prioritize mental health, or for any other reason are likely to have a unique perspective on what education means to them. Students take time off for a variety of reasons, but most are thoughtful about why taking time away from the traditional schooling path is the correct choice for them. During the pandemic, taking a gap year or semester seems to be an increasingly popular choice among my peers. I'm interested to hear from these students and compare their thoughts on the purposes of education to those who take more traditional paths.

This sample of students will be most valuable to me because it will represent a diverse number of perspectives from students likely to be willing to speak about their experiences. Conducting intensive interviews with these students will allow me to gauge the current climate of student perspectives on the purposes of education. Because it is not logistically feasible for me to travel to colleges across the nation to conduct these interviews, I chose to narrow my sample to the University of Michigan. I believe that this public institution offers a promising population of students to base my research on because of its large number of undergraduates from across the nation and even the world. Further, admissions standards at the university are competitive enough that I can expect to find students cognizant of the effects of an achievement-focused, success-driven environment. It is important to recognize that students attending less prestigious universities might have different perspectives on the necessity of earning a degree. Even so, I think the University of Michigan is a particularly interesting institution

to study, given its number of different colleges and programs of study and its marketing as the home of the "leaders and the best."

One drawback of my sampling and measurement methods is that my results will not be generalizable to the entire population of college students, and I will not be able to verify them through external validity. However, because the purposes of this study are to gain a window into complex and subjective experiences, it is more important for me to be able to go in depth with some students rather than to take a more quantitative approach that would be unable to capture the nuance I hope to. Through my interviews, I will be able to take into account students' tones, ideas, attitudes, and word choice to give a nuanced analysis of their general understandings of the value of education.

To conduct my analysis, I will transcribe recordings of my conversations with students. I will use an a posteriori approach to develop a codebook based around the patterns I discern across conversations. For example, I might create a code for references to a college degree in terms of an "investment," or a code for expressions of changing attitudes in the context of the pandemic. After developing this codebook, I will apply the codes to each transcript to determine the frequency of the patterns I observe. If I am correct in my hypotheses, students' word choice will reveal primarily considerations of future economic endeavors and quantifiable measures of success when speaking about the academic choices they have made. Additionally, I expect students to express uncertainty about such priorities and possibly to even push back on their previous perceptions when speaking about how the pandemic has affected their beliefs about the purposes of education. I will supplement my frequency analysis with a qualitative description of the general attitudes and tones of students interviewed.

I am confident in my hypotheses largely because of my own identity as an undergraduate. My hypotheses in part arose from informal conversations with my peers across disciplines expressing frustrations with the pressure to succeed academically to the detriment of their personal wellbeing and the ludicrousness of such pressures pervading a time of national crisis. Even if my hypotheses are

incorrect, however, my research will have value in providing a window into the minds of University of Michigan undergraduates and how their perspectives have or have not been shaped by our current circumstances. The qualitative nature of my research will allow me to adapt my questions and focus so as to examine with nuance the current discourse on campuses like ours.

IV. Conclusion

Students of higher education in America today are expected to learn in hypercompetitive, individualist environments. As students work to maximize their productivity and economic value, our education system fails to produce balanced, intellectually curious, self-fulfilled students. The advent of the COVID-19 pandemic has illuminated this reality, laying the groundwork for a rehaul of the way we think about education.

I believe that my research will make a meaningful contribution to existing literature on the relationship between education, our political economy, and American individualism. Understanding the way these topics intersect is essential in considering the role of higher education in today's world. It is important to ask not only what we stand to gain when we tout a strong education system as essential to our country's success, but also what we stand to lose. It is my hope that this research can inform education policymakers and decisionmakers in understanding the reality of the experience of students in a candid way that course evaluations and other structural feedback mechanisms fail to provide.

Further, I believe this research will provide insight into the impact of COVID-19 on education. My work will illuminate how students might be reevaluating their education in the wake of the pandemic and the different ways in which this might manifest in their academic decisions. My aim is not, however, to analyze students' feelings about virtual learning, but rather to investigate how the disruption of educational norms has caused students to reconsider the value of education more generally. Does academic exploration feel like a waste of time during a crisis or has it gained renewed importance? Have students found

a renewed sense of community, or do they feel more isolated and focused on their individual efforts than ever before? Will COVID-19 change the way we approach the classroom long after it is no longer virtual? These questions are just the beginning of what my research hopes to shed light on. After the pandemic is over, its legacy will remain; my research will attempt to identify what lessons students are taking away from it and how they are finding value in education in this day and age.

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Excellence in Upper-Level Writing (Social Sciences)

The Social Brain Hypothesis: An Evolutionary Explanation for Our Big Brains

by Sahil Tolia

From ANTHRBIO 368: Primate Social Behavior

Nominated by Andrew Bernard

Sahil's work emerges as some of the most well-cited and researched scientific writing I have encountered in a University of Michigan classroom. In this paper, he clearly and diligently addresses the social brain hypothesis as a possible explanation for why primates have such large brains for their body size. His paper is even more remarkable as a self-claimed newcomer to the field of scientific writing; I'm not sure I believe him! I would not be surprised to encounter his name as an author on peer-reviewed published work in the not-so-distant future.

-- Andrew Bernard

The Social Brain Hypothesis: An Evolutionary Explanation for Our Big Brains

Overview

Within the animal kingdom, primates are well known for their large brains and advanced cognitive abilities. How did these phenomena manifest over time in the context of evolutionary pressures? In general, there are two classes of hypotheses that seek to explain the evolutionary drivers of primate brain size. The ecological intelligence hypothesis argues that primates evolved large brains to cope with ever-changing environmental conditions (Dunbar and Shultz, 2017). In particular, this hypothesis articulates that extractive foraging, or the process of locating and obtaining hidden foods such as roots and nuts, is of utmost importance to many primate species (King, 1986). This process requires considerable abstraction, reflection, and fine motor control, and proponents of the ecological intelligence hypothesis posit that these cognitive demands favored primates with larger brain sizes (Melin et al., 2014; Parker and Gibson, 1977). Similarly, the ability of early primates to easily detect and remember the location of ripe fruit in the forest canopy benefited from enhancing visual and cognitive skills, which in turn promoted larger brain sizes (Milton, 1993).

In contrast, the social brain hypothesis argues that primates' large brains are a product of their highly complex and demanding social lives (Dunbar, 1998; S. Roberts and A. Roberts, 2016). In recent years, further understanding of primate social lives has provided substantial evidence in favor of the social brain hypothesis. Here, I will review the evidence supporting the social brain hypothesis while focusing specifically on the use of cognition in competitive social contexts. I will consider the effects of primate group size, tactical deception within groups, and male-male competition on the evolution of larger brain sizes.

Background

Cognition broadly refers to the interpretation of perceived stimuli and applying knowledge to adapt to future environmental or social scenarios (Seyfarth and Cheney, 1990 as cited within Hopper and Brosnan, 2012). Tool use in both the wild and captivity are well-known examples of primate cognition. For instance, species such as bearded capuchin monkeys (*Cebus libidinosus*) can assess the size and weight of rocks to use as hammers to crack open nuts (Visalberghi et al., 2008). Similarly, C. Boesch and H. Boesch (1990) describes a higher level of cognitive processing known as tool manufacturing among three populations of wild chimpanzees (*Pan troglodytes*), where individuals would manipulate leafy twigs and use the stems to fish for insects. Cognitive mapping skills allow primates to discern between physical landmarks and dynamic environmental features, which is particularly useful for species like mountain gorillas (*Gorilla gorilla*) to plan travel paths to reduce energy expenditure and maximize foraging efficiency (Vedder, 1984 as cited within Hopper and Brosnan, 2012).

Each of the aforementioned scenarios is highly cognitively demanding because each requires the integration of functions from different regions of the brain. For instance, tool use and manufacturing both require input from the sensorimotor cortex (touch and feel of the tool), prefrontal cortex (overall decision-making), and the visual cortex (Visalberghi et al., 2008). The brain is the human body's most metabolically expensive organ, consuming approximately 20% of our daily energy intake (Dunbar, 1992). This suggests that natural selection in primates has selected for brain size to increase far beyond the minimum to simply stay alive (Dunbar, 1998).

Across the animal kingdom, brain size generally increases with increasing body size (Seyfarth and Cheney, 2002). However, rather than measure intelligence solely on brain size, neuroanatomists frequently refer to brain-to-body mass ratios, or the ratio of brain mass to body mass, as a proxy for animal intelligence and cognitive ability (Schoenemann, 2004). Primates have been found to have particularly large brain-to-body mass ratios compared to other, less cognitively advanced mammals

(Jerison, 1973). Also significant is that primates can pack in far more neurons in their neocortex compared to other mammals. The neocortex is the part of the brain largely responsible for controlling cognitive and social skills such as abstract thinking and planning (Lindenfors, 2005). Although mountain gorillas have brains that are about seven times lighter than African bush elephants (*Loxodonta africana*), gorillas contain nearly twice as many neurons in their neocortices (Jabr, 2015). Hominids like chimpanzees and humans have significantly larger portions of their brains dedicated to the neocortex compared to more primitive monkeys, which results in greater overall cognitive ability (Seyfarth and Cheney, 2002).

The social brain hypothesis has been an instrumental tool in explaining how social interactions have promoted the evolution of larger brain sizes and advanced cognition (van Schaik et al., 2012). We can further divide social interactions into cooperative and competitive social contexts. In group settings, primates cooperate on a wide variety of tasks, including group hunting and territorial defense (Boesch, 1994 as cited within Hopper and Brosnan, 2012). The social brain hypothesis notes that a large brain is needed to adequately handle the complexity of working towards a common goal with others (Dunbar and Shultz, 2017). In contrast, competitive social contexts are scenarios where individuals struggle over finite resources such as food and mates. For instance, male-male competition occurs when two males compete with each other to mate with a female (Miller and Somjee, 2017).

The social brain hypothesis, along with Byrne and Whiten's Machiavellian intelligence hypothesis, suggests that cognitive skills in primates were strongly selected for due to the need for skills such as deception and exploitation within groups (Byrne and Whiten, 1988; Hopper and Brosnan, 2012). This paper will focus primarily on applying the social brain hypothesis to competitive social scenarios. This will allow us to gain a better understanding of how primates promote their individual growth, survival, and reproduction in group settings.

Group Size

Among primates, studies have shown that brain neocortex size is positively correlated with group size. Dunbar (1992) compiled data on neocortex volume, total brain volume, and mean group size for 38 genera of primates. There was a clear correlation between neocortex size and group size, as primate genera with larger neocortices tended to have greater group sizes and levels of interaction within groups. Additionally, comparisons between relatively solitary prosimian species and "troop-making" prosimian species found significantly larger relative neocortex sizes among the "troop-making" species (Sawaguchi and Kudo, 1990). To better understand the effect of group size variation on brain size within a single primate species, Sandel et al. (2016) focused on 23 primate species where group size changes frequently in day-to-day life. Despite a wide range of possible group sizes, there were still strong correlations between group size and neocortex size. Within a single primate species, groups that were larger on average also tended to have individuals with larger neocortices.

These findings prompt us to think about what selection pressures led to the evolution of large social groups and larger neocortices. The two most cited hypotheses are that social groups allow for defense against predators and defense of food sources against rival groups (van Schaik, 1983 as cited within Dunbar, 1992). Each of these scenarios requires an individual to make a variety of interactions either with conspecifics or animals of a different species, and the individual's success can often be the difference between life or death (Sandel et al., 2016). As a result, it is likely that animals that were better suited to handle the cognitive requirements for managing relationships within multiple groups were more likely to succeed (Dunbar and Shultz, 2017). The larger cerebral cortex and neocortex that followed perhaps allowed these species to engage in new social opportunities over time, leading to more sophistication in other aspects of life (Dunbar, 1992).

Tactical Deception

The Machiavellian intelligence hypothesis revolves broadly around deception and the necessity to outsmart rivals to flourish (Schmelz and Call, 2016). In Machiavellian theory, individuals develop an "awareness of awareness", where they realize that other members of the same species also have similar desires (Crow, 1993). This knowledge creates inherently competitive social environments, where individuals often resort to creative measures to outcompete others for food or other resources (Byrne and Whiten, 1988 as cited within Dunbar and Shultz, 2017). These measures are best defined as social manipulation techniques that achieve small benefits without putting the individual's group membership at risk (Humphrey, 1976 as cited within Byrne and Whiten, 1988).

Tactical deception refers to when animals try to deceive one another by performing a normal behavior in an entirely different context (Byrne and Whiten, 1988). Byrne and Whiten (1985) coined the term after observing wild baboon (*Papio ursinus*) populations. The researchers noted several distinct types of deception that allowed individuals to benefit without seriously endangering their status within the group. For instance, juvenile baboons that came across an adult female digging for underground food began to loudly scream in a manner normally associated with an attack from another individual. The juvenile's mother would confront and chase the digging female, and the juvenile would start digging and eating the food left by the digging female. In other instances, male baboons would seek to divert attacks from other males by intensely gazing in the distance as if a predator were nearby (Byrne and Whiten, 1988). This would often distract the aggressor males enough to defuse the situation. Females also sought to divert male aggression against them by redirecting the male's attention to an innocent third party such as a nearby juvenile baboon (Byrne and Whiten, 1992).

Before these observations were made, tactical deception among primates was poorly understood and thought to be only found among chimpanzees (Byrne and Whiten, 1988). However, further observations and pooling of research showed that tactical deception is used by nearly all families of monkeys and apes (Byrne

and Whiten, 1992). Wheeler (2009) presents clear evidence of tactical deception among wild tufted capuchin monkeys (*Cebus apella nigritus*) using false alarm calls. In the wild, alarm calls alert capuchins of nearby predators. However, false alarm calls were discovered to be used primarily by subordinate monkeys to usurp control of resources from dominant monkeys. These calls were given more often when food was spatially clumped and when the subordinates were well-positioned to take advantage of startled dominant monkeys.

The Machiavellian intelligence hypothesis viewed through the lens of the social brain hypothesis suggests that the amount of tactical deception practiced by a primate species is directly related to the species' brain size. This theory was validated by Dunbar (1993), who found that, among primates, the level of sophistication in tactical deception was significantly related to the species' neocortical expansion. Further comparative studies of prosimians, New World Monkeys, Old World Monkeys, and apes found that the extent to which species use tactical deception is predictive of their neocortex size and overall cognitive sophistication (Byrne and Corp, 2004). Since the neocortex controls higher cognitive functions such as conscious thought and communication, these studies provide further evidence that social interactions play a significant role in primate brain enlargement and overall cognition.

Despite the presence of tactical deception, social living is still very common across nearly all primate taxonomic groups. This is in part because tactical deception is often extremely subtle and carefully perfected by individuals over time (Gavrilets and Vose, 2006). As illustrated in the previously mentioned examples, primates usually seek to manipulate the *attention* of conspecifics rather than overtly attempt to control their behavior. As a result, the deceiving individuals can accrue small benefits, such as a temporary food source or lack of aggression against them, without directly losing other benefits that come with being a part of the group (Barrett and Henzi, 2005). These acts of deception require considerable intellect, including the ability to understand how conspecifics think and weighing the pros and cons of social manipulation versus direct confrontation based on the scenario

(Byrne and Whiten, 1988). As a result, we can argue that this aspect of primate social life has played a significant role in increases in brain size and cognitive ability.

Sexual Selection

The social brain hypothesis can also be applied to male-male competition, where the complex social strategies required to successfully mate has selected for larger brains with higher cognitive abilities (Schillaci, 2006). Male-male competition occurs frequently in multimale-multifemale primate groups, particularly through a dominance hierarchy that allows high-ranking males to mate more successfully than low-ranking males (Cowlishaw and Dunbar, 1991). The evolutionary pressure of decreased access to females among subordinate males forces them to get creative. Using data collected from multiple anthropoid species, Pawlowski et al. (1997) found that species with relatively large neocortices more frequently employed social strategies to subtly undermine the high-ranking male's ability to monopolize females. Their findings ultimately suggested that as brain neocortex size increased, the correlation between dominance rank and mating success decreased.

Pawlowski et al. (1997) identified three kinds of social strategies that subordinate males could use to weaken the power dynamic in male-male competition. Subordinate baboons can form alliances with other low-ranking individuals to challenge a dominant male who has access to a female in estrus (Noe, 1992 as cited within Pawlowski et al., 1997). Secondly, subordinate chimpanzees can use bluff charges, where an individual charges toward another without making contact in hopes of appearing dominant (de Waal, 1982). Lastly, baboons and chimpanzees can form friendships with females caring for infants with the goal of mating with the female once she reenters estrus (Smuts, 1985 as cited within Pawlowski et al., 1997).

Each of the aforementioned strategies seeks to accomplish a similar goal: reduce the power hierarchy within a social group that normally prevents subordinate males from accessing females in estrus (Cowlishaw and Dunbar, 1991). This phenomenon provides these males with a greater likelihood of reproducing

and passing along their genes to the next generation. The evidence that primate species with larger neocortices had weaker correlations between rank and mating success provides further support for the social brain hypothesis (Pawlowski et al., 1997). In other words, the need to manage the complex dynamics found in social interactions like male-male competition in part led to the evolution of larger primate brain sizes.

Conclusion

On average, primates have brains that are nearly twice as large as other mammals of similar size (Passingham, 1981 as cited within Barrett and Henzi, 2005). Over the last four decades, research into the evolution of large brains in primates has primarily focused on two hypotheses. The ecological intelligence hypothesis notes that primates evolved large brains to manage difficult environmental conditions, while the social brain hypothesis argues that primates need large brains to cope with the computational demands of a highly complex social life (Dunbar, 1989). The social brain hypothesis has proven to be a durable explanation for variations in primate brain size and cognitive ability, particularly with regards to competitive social environments. Primates with larger average group sizes tend to have larger brain neocortices, suggesting that these animals require more cognitive processing power when closely interacting with more individuals. In social groups with scarce resources, numerous primate species have turned to tactical deception techniques to "out-wit" other group members. Species that practice tactical deception have been found to have larger neocortices and comparatively higher cognitive sophistication. Additionally, primate species with larger brains are more likely to practice subtle techniques to erode power hierarchies in male-male competition.

Although the social brain hypothesis has considerable support across the field of primatology, we must not disregard other evolutionary explanations such as the ecological intelligence hypothesis. Studies assessing the impact of ecological factors such as diet quality and extractive foraging on primate brain sizes have found evidence in support of the ecological intelligence hypothesis (DeCasien

et al., 2017; King, 1986; Milton 1993). Rather than view social and ecological explanations as alternatives, it is far more worthwhile to acknowledge that each has played a significant role in the evolution of primate cognition (Dunbar, 1992).

Further research into certain aspects of primate social life will be intriguing for the future of the social brain hypothesis. In particular, it is well known that male primates tend to follow female groups, which means that male and female group sizes evolve based on different demands (Dunbar, 1992). While previous studies have focused on the relationship between total group size and brain size, it would perhaps be more reasonable to analyze female and male groups separately in the future (Lindenfors, 2005). Lastly, much of the social brain hypothesis focuses on the effects of social cognition on the sizes of large brain structures. However, a more advanced understanding of microneurobiology, such as identifying specific genes that cause brain growth upon activation, may provide new insight into how social situations affect overall brain functioning (Dunbar and Shultz, 2007).

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Excellence in Upper-Level Writing (Humanities)

A Review of PLA's Sustainability as the Future of Bioplastics

by Leah Marks

From WRITING 400: Advanced Rhetoric and Research, Writing and Research in the Sciences

Nominated by Jimmy Brancho

Leah's literature review invites us into the labyrinth that is plastic recycling and degradation. Here she puts biodegradable plastics under the microscope and improves on the existing literature with a holistic investigation of their environmental merit. Leah shows very strong research acumen here, making proficient use of new literature and her background in materials science. In composing this piece, she pushes her writing craft to new heights. This review lives and breathes. The text makes inanimate plastics and invisible chemical processes into active agents through smart choices of subject and verb. The result is an effortless read, a sobering investigation into a cutting-edge topic becoming more important every day.

-- Jimmy Brancho

A Review of PLA's Sustainability as the Future of Bioplastics

Abstract

The need to address our abounding global stockpile of plastic waste is critical for preventing catastrophic pollution beyond repair. Two overlapping complications that have precipitated from this crisis are the waning supply of petroleum feedstock and the invasion of ecosystems with post-consumer plastic. These patterns may be attributed to the rampant production of non-biodegradable petroleum-based polymers—materials that expend non-renewable resources and persist in nature for decades or centuries if left unaddressed. To abate the escalation of plastic-induced pollution, bio-based biodegradable polymers are being considered as potential replacements for their problematic peers. At the forefront of these efforts is polylactic acid (PLA), a starch-based polymer praised for its low carbon footprint and similarity in behavior to commodity plastics such as polypropylene (PP), polyethylene terephthalate (PET), and polyethylene (PE). This paper sets out to provide an expanded investigation of the impact of increased PLA production beyond the canonical CO2 measures on which sustainable material selection is typically predicated. First, the sourcing of PLA feedstock is scrutinized in order to identify its impact on food source interception and pollution from fertilizer runoff. Next, PLA's mechanical performance and associated strengthening mechanisms are considered in order to determine whether it is suitable for its intended applications. Finally, PLA's end-of-life is tracked chronologically in order to elucidate whether/under what conditions proper degradation is able to ensue. While PLA demonstrates promise in areas such as land efficiency and mechanical performance, there is still considerable room for improvement in its production of toxic fertilizer runoff and degradation timeline.

Introduction

Plastics are everywhere; in our houses, cars, and phones; in our personal protective equipment, drugs, and implants—and in our oceans, soils, and livestock. While plastic usage is certainly ubiquitous now, its accompanying environmental harm cautions against a continued reliance at the same scale. Today's booming plastic market poses a dual threat in its rash consumption of non-renewable resources and unbridled output of waste: 2018 alone saw 359 million metric tons of plastic waste generated, 42% of which was either littered or sent to landfills (Silva, et al., 2020). While consistent innovation has facilitated gradual improvement in plastic sourcing and recycling, the Covid-19 pandemic has intercepted much of our existing progress. At this inflection point of plastic consumption, it is critical to establish plans for optimizing sustainability in order to prevent a worst-case scenario for our planet.

Plastic can be classified in many ways, but perhaps two of the most fundamental and potent distinctions can be found in feedstock origin and degradability. In this case, the two opposing groups are bio-based vs. petroleum-based, and biodegradable vs. non-biodegradable respectively. Together these yield four distinct combinations of properties: (1.) bio-based/biodegradable, (2.) bio-based/non-biodegradable, (3.) petroleum-based/biodegradable, and (4.) petroleum-based/non-biodegradable. While plastics falling in the fourth group dominate the industry today, they are accompanied by a litany of concerns such as a large carbon footprint and inability to decompose without industrial assistance. As landfill disposal continues to abound, bio-based biodegradable plastics have emerged as a promising alternative: a 2017 LCA conducted by Posen et al. projected that a switch from conventional petroleum-based polymers to corn-based biodegradable PLA would reduce greenhouse gas emissions by 25% (Posen, 2017).

Accounting for 27% of biodegradable plastic output in 2017, PLA is considered a leading substitute for its non-biodegradable petroleum-based counterparts such as PP, PE, and PET (Porter, 2006). Although PLA production

is less pollutive, this is not where the investigation should end—neither sustainability nor material selection are based in a monolithic criterion. This paper will therefore holistically investigate the consequences associated with increased PLA adoption beyond the context of a conventional lifecycle analysis (LCA). By tracing the behavior of PLA throughout its lifecycle in terms of diverse and pertinent metrics, I plan to delineate the benefits, drawbacks, and emerging innovations that will contribute to our understanding of whether this material is as promising a solution as its carbon footprint portends.

Feedstock and Manufacturing

PLA is a semicrystalline bio-based biodegradable thermoplastic. With applications ranging from durable industrial machinery to sophisticated medical implants, it may be surprising to learn that its robust lactide polymer chains are derived from simple starches such as corn. Thus, to investigate PLA synthesis we must start by assessing the risks associated with its reliance on agriculture.

Land Efficiency

One pervasive concern that comes with PLA's starch-dependence is the depletion of our food supply: allocating food to a format not intended for eating may seem like an inefficient use of resources amid burgeoning food shortages. However, a 2018 study conducted by European Bioplastics revealed that plants sequestered for plastic feedstock occupied less than 0.02 percent of the global agricultural area. This value is expected to remain constant in spite of projections that PLA production will double between 2018 and 2023 (European Bioplastics, 2018).

Although the spatial occupation of feedstock crops is of low concern, there is still room for improvement in how we use and treat the land on which they are grown. To maximize land yield, researchers are investigating routes for converting starch byproducts such as husks and shells into usable plastics. This would enhance plastic production and quality without increasing land dependence. One promising application of starch byproduct conversion can

be found in efforts to reinforce PLA with lignocellulose fibers. Lignocellulose is a biopolymer that comes from plant residues such as corn husk and sugarcane bagasse (Tumolva, 2016). Recognized as "the most abundant renewable biomass on earth," these fibers serve as a potential fortifier of PLA (Abdel-Hamid, et al., 2013): a 2019 study reported early success in synthesizing a PLA- coffee husk fiber reinforced composite that demonstrated a 45% and 148% increase in the 59 MPa tensile strength and 3.8 GPa elastic modulus respectively from unreinforced PLA (Collazo-Bigliardi, Ortega-Toro, and Chiralt, 2019). This discovery sets a precedent for concurrent optimization of land yield and mechanical performance in the field of bioplastics.

Pollution

While a clean environmental footprint may seem inherent to plant-based plastics, a novel 2010 case study presented the converse: in their assessment of 12 common plastics (7 petroleum-based, 4 bio-based, 1 combination), Tabone et al uncovered PLA's leading contribution to eutrophication. Considered a "leading cause of impairment of freshwater and coastal ecosystems," eutrophication promotes the excessive growth of algae and plants (Chislock, et al., 2013). For this to occur, one of the inputs for photosynthesis—sunlight, CO2, or fertilizer—must be supplied in excess. An investigation conducted by Landis et al identified fertilizer as the ingredient supplied in excess during PLA production, with high volumes added to stimulate corn growth (Lander, Miller, and Theis, 2007). When the high phosphorous and nitrogen content in fertilizer is relayed to water systems through runoff, consequences such as algae blooms, polluted drinking water, and hypoxia abound. Additional concern arises from the potential for algae to produce toxic cyanobacteria responsible for killing marine life and poisoning humans.

The high rate of eutrophication attributed to PLA production demonstrates that choosing bioplastics over petroleum-based polyolefins is not entirely favorable from an environmental standpoint. To address this concern, scientists are looking at the possibility of incorporating recycled starch in PLA feedstock, thus minimizing the need to produce new corn and its ensuing demand

for fertilizer. According to Broeren et al. (2017), using reclaimed over virgin starch may account for up to a 60% reduction in eutrophication.

Manufactured Product

PLA is expected to be highly versatile, with demands for it to be both flexible and rigid, durable in hot and cold climates, and compatible with injection-molding and extrusion (Masutani and Kimura, 2015). These properties are not necessarily inherent, but rather instilled through chemical modifications. Neglecting to transform the polymer in order to yield desired performance parameters may bring about the worst case: material failure will precipitate a ripple effect, compromising both the PLA and any adjacent product under its protection. Failure accounts for a superfluous use of critical resources, as the ruptured manufactured material will be prematurely sent to waste rather than serving its intended application. Thus, implementing PLA with unsuitable properties will render the energy and pollution associated with its production grossly wasteful upon expedited disposal. We therefore must identify methods that will fortify material properties in order to extended PLA's lifespan.

A baseline comparison of PLA, PET, and polystyrene (PS) compiled by Luckachan and Pillai (2011) presents PLA as comparable alternative to its non-biodegradable, petroleum-based counterparts:

Table 1. Mechanical Properties of PLA, PET, and PS (Adapted from Luckachan and Pillai, 2011).

	PLA	PET	PS
Modulus(GPa)	3.8	2.8–4.1	3.2
Density (kg/m3)	1.26	1.40	1.05
Modulus/density	2.8	1.71	
% Increase in stiffness	38.78	–	–
Elongation at break (%)	4–7	2.8–4.1	3
Tensile strength (MPa)	59	57	45

As seen in the chart, PLA is both able to withstand a larger load than both PET and PS and demonstrate a higher stiffness. This favors the use of PLA in high stress, load-bearing applications that desire minimized deformation. While it is promising to see that a bio-based material is able to behave similarly—if not

better—than a less sustainable petroleum-based version in many cases, it is not the end of the story either: PLA is not a monolith, but rather a blank canvas ready to be modified. We should therefore aim to improve PLA on absolute terms rather than settle for being similar to other plastics on a relative basis. With this in mind, it is critical to aim for improvement in strength, ductility, and thermal stability so that we are able to meet demanding design requirements.

Blending offers one strategy for modifying PLA's mechanical properties. In order to figure out which blends offered desired mechanical enhancements, Narancic et al. (2018) tested five different combinations of PLA blended with one of four polymers: PHB, PCL, PHO and PBS—all of which are biodegradable and bio-based (petroleum-based PBS was tested as well.) Each polymer was found to bolster different properties at varying proportions. For instance, an 80/20 blend of PLA-PCL induced a ~1000 MPa decrease in Young's modulus, and an ~215% increase in elongation. This result is indicative of the tradeoffs that must be confronted when blending polymers—while a blend may enhance one property, it can easily compromise another. Thus, it is evident that blends will likely serve as one in a series of many compounding modifications.

Another common route for improving the performance of PLA is seen in the synthesis of fiber-reinforced composites. Silica-based nanocomposites have been studied for many years, with early examples reported by Paul et al in 2003. In their research Paul was able to fabricate a novel PLA composite with layered montmorillonite fibers throughout the matrix. The addition of silicate fibers was found to enhance thermal stability and fire retardancy, and serve as a more effective gas barrier. However, it was not until the implementation of another silicate, 2-methacryloyloxyethyl isocyanate (MOI), that researchers were also able to claim the enhancement of mechanical properties in tandem: Chen et al (2012) demonstrated that the addition of MOI to PLA produced a material with 4-13 times the elongation at break of pure PLA while also maintaining its high tensile strength. While both blends and composites serve as effective enhancements in their own right, the next stage of PLA development will involve identifying

synergistic combinations of these and other potential strengthening mechanisms to create a polymer that optimizes as many properties as possible.

End of Life

Biodegradability is often perceived as a binary property—we talk about plastics as being either biodegradable or non-biodegradable. To adopt this perspective, however, is to ignore the nuances of polymer chains; different chemical structures yield different properties and thus respond to designated degradation environments differently. We should therefore move beyond simply asking *whether* a plastic can biodegrade and investigate *how* biodegradation varies for different materials.

Biodegradation is executed in two steps: first, polymers are broken into smaller oligomer chains by extracellular enzymes and abiotic reactions (Luckachan and Pillai, 2011). This process is the equivalent of cutting a pizza into slices before eating it—the smaller the piece, the easier it is to chew and digest. Furthermore, a shorter chain maximizes the surface area accessible to enzymes, allowing for expedited consumption. In this latter process, enzymes convert the polymer to either gas or mineral salts (Luckachan and Pillai, 2011). It is critical to note that aspects of this mechanism will vary based on material properties and climate-related variables such as pH, moisture, oxygen and light exposure, and ambient temperature. This is where we often face a roadblock with PLA: it is falsely assumed that just because a plastic is biodegradable it is capable of breaking down freely and quickly in *any* natural setting. In reality, PLA biodegradation is heavily reliant upon the ecosystem in which it is disposed.

Breakdown Conditions

PLA biodegradation, or "breakdown," has been studied in three main environments: industrial composting, water, and soil. Each environment is compatible with PLA to varying degrees: PLA is hydrophobic and semi-crystalline, with an average glass transition temperature (Tg) of 60°C. With the industrial composting route taking place in a facility, and soil and water existing in nature,

only the former can be expected to reach PLA's high Tg on a consistent basis. This means that composting provides the fastest and most direct route for melting secondary bonds between polylactic acid polymer and pulling them chains apart. Sangwan and Wu (2008) corroborated the time efficiency of industrial composting by showing that a 33.0*12.5*3.0 mm PLA bar could be broken down in merely 60 days at 55˚C, as opposed to the many months typically required for PLA to degrade on natural land. The fact that degradation in the facility was accomplished below the Tg may be attributed to the expeditive role of ambient moisture present during the biodegradation process.

However, time efficiency is not the only criteria we should use to evaluate the productivity and sustainability of composting. One notable downside of industrial composting can be found in the fact that it must expend energy and pollute to sustain its indoor climate. An LCA compiled by Rossi et al (2015) revealed that it may cost nearly 2 kg CO2/kg PLA to transport PLA to a composting facility and to run it. This begs the question of why we do not rely on domestic composting as a less energy-intensive and cleaner alternative. However, a field test in Greece conducted by Rudnik and Briassoulis (2011) was able to subdue any hope in this area by showing that it took at least 11 months to fully break down a 440 μm PLA film. This may be attributed to the fact that temperatures could only reach 42˚C during the experiment, far below the Tg.

A bigger problem arises when we enlist water to break down PLA. While few studies on this mechanism exist, those that do have reached the same conclusion: PLA is very stubborn in an aquatic environment. For instance, research conducted by the California Department of Resources Recycling and Recovery (2012) revealed that PLA did not break down at all after being submerged in the ocean for a year. This concerning result is likely attributed to very low water temperatures and a limited population of PLA-consuming bacteria native to aquatic climates (Haider et al, 2018). In spite of minimal success with water degradation, biodegradation in nature is not universally ineffectual; soil-based decomposition offers a middle ground between industrial composting and

water-based biodegradation in its ability to be both energy and time-efficient, and pollution-averse. In their 2011 study, Rudnik and Briassoulis (2011) reported that PLA took 11 months to decompose in 21˚C soil. Furthermore, because soil-based degradation takes place in nature rather than in a facility, it may be assumed that it mandates a much smaller energy input/pollution output than industrial composting.

Recycling Stream Contamination

While PLA is biodegradable, it can still be recycled if kept in a stream with only pure PLA. Although this is certainly a promising way to keep PLA out of the ocean, it does come with a notable caveat: according to Haider et al (2018), recycled PLA is not usable in large quantities due to a change in melt viscosity, an off-putting yellow color, and reduced film properties. To make it to market, recycled PLA must be combined with a minimum of 70% virgin PLA. This diminishes the incentive to recycle PLA, as its poor properties and resulting low demand will render it on the cheaper end of the plastic market. However, this is not the only instance in which we encounter recycled PLA, as corrupt optical sorting technology can yield significant contamination in a major single-plastic stream.

Rather than PLA being recycled with other PLA as intended, it can often be missorted and mixed into a different type of recycled plastic feedstock. For instance, a survey conducted by the European PET Bottle Platform in 2015 revealed that, on average, near-infrared (NIR) plastic sorting is conducive to a stream contamination rate of 5-14%. This means that a stream intended to contain only PET may include high quantities of another plastic. In the event that PLA is wrongly directed to the PET stream, we risk compromised quality and safety in the final recycled product: PLA has a melting point 100˚C below that of PET, a disparity which brings up concern for an overly-intense breakdown of PLA. Prolonged heating of plastic well above their melting temperature will likely result in the production of small oligomers chain through scission. Alaerts et al. (2016) report that this will not only yield a final product with very inconsistent viscosity

and processing parameters, but it will also render the feedstock an unattractive brown color with burnt black specks. This discoloration grossly devalues PET resin, resulting in a final product that is likely either undesirable or unprofitable. Furthermore, Dvorak et al (2013) report that using PET feedstock tainted with PLA in conjunction with pure PET feedstock can make processing so difficult that it risks all plastic involved becoming unusable. Thus, the invasion of PLA in recycled PET will not only create a product of suboptimal quality, but may also instigate the unprecedented disposal of a large quantity of unused PET. The presence of PLA in the PET stream evidently turns recycling into an act that derails rather than promotes sustainability efforts.

To eliminate PLA from the PET stream, we must intercept PLA contamination as early in the recycling process as possible. This is because PLA is uniquely situated to enter the PET stream due to its inability to separate from PET during the sink-float stage. This mechanism is designed to isolate PET from all other plastic in accordance with its characteristically higher density, causing it to sink in water while the remaining low-density material floats. However, PLA is one of the very few materials that will also sink in water and subsequently mix in with PET. It is therefore necessary to eliminate PLA during the one step that precedes sink-float: NIR sorting. While Alaerts et al. propose improving the sensitivity of NIR sortation technology used in recycling plants today, Flemish policy agency OVAM asserts that this would result in the unnecessary disposal of perfectly recyclable PET bottles; if a hypersensitive sorter detects even a minor non-plastic surface contaminant such as dirt, the plastic will be ejected from the recycling stream and sent straight to a landfill. Fortunately, another option can be found in the implementation of machine learning in optical sorting. While this technology is very new, it has proven to avoid future sortation mistakes by learning from past errors. Machine learning is able to consistently designate which plastic is which, leading to a higher probability of isolating PLA to its single-plastic stream.

There is another route we could take in preventing the improper disposal

of PLA in a conventional recycling bin: correcting human behavior. A 2020 survey conducted by Taufik et al. revealed that consumers are either not motivated or not aware of how to properly dispose clearly labeled bio-based plastic packaging. This is likely what is causing invasion of PLA in PET recycling bins in the first place. To intercept PLA contamination of PET at its origin means that we do not need to rely on variable sortation technology to correct our mistakes. Accomplishing this, however, is much easier said than done. While the United States Environmental Protection Agency suggests consulting local waste management to determine how/whether a plastic can be recycled, this method is both labor and time intensive. Instead, studies should be conducted to understand how to teach consumers to properly dispose of their waste. We should investigate how to optimize our plastic labelling system to incorporate clearer and more visible disposal instructions, as well as consider the impact of teaching this skill in schools.

Conclusion

It is undeniable that our unquenchable demand for plastic will persist for at least the foreseeable future. With an increasing dependence on plastic, however, comes a daunting output of waste to landfills and nature. In order to subdue the propagation of plastic waste, we must implement technology that is able to address it face on; it is true that recycling allocates plastic from end-of-life disposal to a new lifecycle. However, this does not address the inevitable introduction of plastic to nature as a symptom to improper disposal/waste sortation and rampant littering. This is where biodegradable plastics such as PLA can prevail: with their inherent ability to break down in the presence of bacteria, they present a promising route to minimizing the presence of waste.

While PLA's potential to biodegrade quickly is certainly compelling, it is irresponsible to place all of our faith on one material property. Scrutinizing PLA's potential in terms of sustainability and structural integrity reveals both a lot of promise and a lot room for improvement. While PLA does offer a lower carbon footprint than commodity polyolefins, it still struggles as one of the

leading contributors to eutrophication among major plastics. Furthermore, its failure to break down in water and proclivity to contaminate the PET recycling stream serve as major roadblocks in preventing a congregation of pollutants in our oceans. PLA does have many redeemable qualities, including durable mechanical properties and the ability to break down efficiently in soil with and without industrial assistance. Addressing PLA's pitfalls while maintaining these favorable properties will be a critical next step to take on in the coming years, with emerging technologies such as nanofiber composites and precise artificial intelligence-based sortation at recycling plants leading a promising charge. No material is or will ever be perfect. While PLA certainly poses a case for criticism, this should not outshine its imminent promise but rather inspire continued improvement.

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Excellence in Upper-Level Writing (Humanities)

A Handful of Walnuts

by Julia Van Goor

From ENG 325: Art of the Essay

Nominated by Jamien Delp

Julia's meditative analysis, "A Handful of Walnuts," is a complex, tender and deeply honest exploration of memory. She brings both a scientific and personal lens to her questions as she ponders her experiences with her grandmother - an Alzheimer's patient - her mother, and herself. Julia presses her meditation onwards with vivid, rich scenes that are both lyrical and matter-of-fact, just as she challenges her own memory and studies in the medical field to determine where (or if) a clear distinction between forgetfulness and illness might exist. Her voice is clear, accessible, vulnerable and intentional, and her analysis as authentic as it is surprising.

-- Jamien Delp

A Handful of Walnuts

Minuscule spines sink into my palms. I recoil at first, but then become impatient and tug at the offending villain. Weathered, veiny, and slightly knobby hands gently enclose my small fingers, halting me mid-tug.

"That is not how we pick cucumbers," my grandma admonishes. "You have to twist and twist until it comes off naturally. Otherwise, you'll hurt the plant."

"But it's pokeyyyy," six-year-old me whines back.

"Oh, it's not that bad. Just wipe it off - see?" And with two brisk motions she brushes the rest of the tiny spines from the vegetable. She moves off to a different patch of her vegetable garden, and I plant myself in front of the cucumber vine to start twisting. Eventually the vine gives way, gently depositing the emerald green cucumber into my expectant hands.

In this same patient way, my grandma taught me that while tomatoes and corn must also be twisted, you have to pinch green beans, and you can snap asparagus but only as long as you do it low and close to the base. I will never forget her life lessons in vegetable picking. Partly because they are skills I've repeated nearly every year in her garden and then my mom's. But mostly because these are my most cherished memories of my grandma. These are also the memories I shared while choking back tears at her funeral two years ago.

I hadn't planned to speak at her funeral. The pastor completely blindsided my cousins and I when he turned to us at the end of the service and asked if one of her seven grandchildren might share a memory. We exchanged panicked glances - not a single one of our parents had mentioned this request and we were all pretty sure that this pastor, who none of us had met until an hour before the service, was going off script.

Everyone, including myself, was surprised when I, the youngest by eight years, approached the podium. I was moved not only out of love for my grandma and pity for my cousins, but out of frustration. So far, every memory of my

grandma that had been shared was about her Alzheimer's disease. The very disease that caused the loss of her memory, and subsequently her independence, then her personality, and finally her life was now robbing her of her legacy. I was mad because her final twelve years in a memory care facility should not ablate the woman, mother, and grandmother she was before her disease.

So, as I approached the sparse podium, I scrambled to organize my swirling thoughts into a semi-cohesive narrative. With emotions strangling my vocal chords, I told the story of how my grandma taught me to pick vegetables in her garden. I concluded my impromptu speech by tearfully begging the attendees, few of whom I actually recognized, to remember her not in a nursing home but in her garden.

It's possible that I was only able to remember the woman she was before the Alzheimer's because I hadn't visited her at all in the past six years. It was too painful, so I avoided it, preferring to hold on to my warm memories of summer vegetables and games of Sequence rather than writing new memories of cold, unmemorable walls and one-sided conversations. I told the people who actually cared for her at the end to remember not the Gretchen Hollister they dressed and fed every day but the Grandma Hollister who once taught me to pick vegetables.

But I am a hypocrite.

I wrote the story of my grandma's Alzheimer's into every single one of my personal statements for my graduate school applications this year. I wrote about how the devastation of a poorly understood disease inspired my future career in biomedical research. I wrote about how the feeling of helplessness inspired me to try to make a difference. But I did not write about the specifics. I did not write about how her once meticulously coiffed hair became flat and simple. I did not write about how a warm greeting dissolved into a mere glint of recognition in her bright blue eyes, or how even that minor acknowledgement eventually faded away. And I certainly did not write about summers spent picking vegetables.

I chose to simplify my grandma's legacy down to just the name of her disease. I did the very thing I was determined to prevent when I spoke at her

funeral. Even though what I wrote was all true – her condition, among other things, led me to study the molecular basis of health and disease – I still felt cheap selling my memories for a shot at admissions.

My hypocrisy is made even worse by the fact that, based on my studies so far, science has very unsatisfactory things to say on the topic of memory. My molecular neurobiology course boils memory down to electrical signals, ions, receptors, and molecules like glutamate and dopamine. I don't understand how miniscule and near instantaneous exchanges of molecules can become images, words, and emotions in my mind. Words like "potentiation" and "excitatory post synaptic potential" swirl around my head during class. I can't make sense of how the same flow of charges that powers my phone also determines the storage of all of my life's experiences.

And the cause of Alzheimer's disease? Just accumulations of beta-amyloid plaques and neurofibrillary tangles. Small little fragments of normal proteins that clump together inside and outside of neurons in just the right place can make a person forget how to be a person. I can't comprehend my memories of my grandma's dementia in these terms.

To make matters worse, the medical recommendations that stem from these molecular explanations seem almost laughably feeble. I've watched my mom consume walnuts by the handful after hearing a news report about their ability to slow the progression of the disease. She's also religiously committed to 30 minutes of aerobic exercise a day for the same reason. That is, until the next study comes out. Or life gets too busy. Or she just forgets.

Because that's the thing: it's normal to forget some things. It's natural to walk into your room and forget your purpose for doing so, to have no clue what you ate for breakfast two days ago, or to blank on the word that's on the tip of your tongue or the name of that one relative you hardly see. But it's not normal to forget that your home is your home. It's not normal to not remember which foods you love and which you detest. It's not normal to lose sensical language altogether. And it's not normal to fail to recognize your children as more than just friendly faces.

I can't define the line between occasional forgetfulness and the onset of disease. My mom panics every time she loses her train of thought or forgets where she left her phone. The memory of the disease that robbed my grandma of her memory and its hereditary roots in our family haunts my mom, my sister, and I. The onset of dementia is a distant fear of mine, but for my mom it's an immediate threat, lurking around the corner of every additional birthday. Even though I reassure my mom that her forgetfulness still falls within the normal range, I don't know the distinction between a scattered brain and a demented brain. I don't even remember when my grandma's condition crossed the line of laughable goofs, like calling broccoli "asparagus," to a disease that required the 24/7 care only available in a nursing home. I wonder if I was too young to form a concrete memory of when that imaginary line was crossed or if that line even exists at all.

My introductory psychology course provided the most compelling analysis regarding memory formation and recall. Essentially, the more you bring a piece of information to the forefront of your mind, the easier it will be to remember that information later on. But here's the catch: every time you remember that memory, it becomes a little less accurate. That's because with each renewed recall, you're not actually thinking of the original experience but instead you're remembering the memory based on how you most recently remembered it.

Based on that theory, it's completely possible that the memory about picking a cucumber I started this essay with is entirely fiction by now. But is a memory only valid if it's true? Saying "Well, the way I remember it…" is a nice way of covering your butt just in case the information you subsequently provide is later found to be inaccurate. The question "do you remember…?" is generally a much lower stakes question than "do you know…?" Our memories aren't expected to be perfect, but that doesn't make them any less powerful.

There's something to be said for how a memory makes you feel. Your birthday, summer vacation, home – each of these words probably triggered an emotion as you read them. But, if I asked you to write down the exact memory that led to your emotional connection with each word, you would probably struggle to

pinpoint the specifics. Not because you forgot, but because the feeling triggered by each of these words is less of an exact memory and more of an amalgamation of past experiences unified by a shared context and overall emotional effect.

So, when I read the word "grandma," I have the choice of remembering the feeling of visiting her in a retirement home after she was debilitated by dementia or the feelings associated with summer evenings in her carefully tended garden. Neither memory is completely accurate, so in a roundabout way they are both equally *right*. I know which one I want to hold on to, even if the other remains an unwanted squatter in my fears.

The idea that we can choose which of our memories to hold on to is unexpectedly empowering. Our brains naturally filter out irrelevant information, choosing not to waste precious storage space on the specifics of the mundane. By making conscious decisions of what to ignore and what to remember, we can shape which memories remain relevant. Maybe there's some truth to the adage "out of mind, out of matter." The thought of your old romantic ex probably doesn't trigger the same tears that it may have right after the breakup. At some point you probably stopped seeing reminders of them, stopped pulling up their memory, and thus actively made them less relevant to your current life.

In this way we have the potential to re-write our personal histories. After seeing my grandma's loss of memory result in her loss of self, I began to realize how inextricable our past is from our present. Imagine the power that purposefully shaping your memories could give you. Instead of remembering my failures, my awkward blubbering, and my disappointments, I could prioritize the moments of success, grace, and joy. Maybe instead of fearing forgetfulness I could harness its power to build a happier history and more confident present.

I don't have control over every experience in my life. And no matter how many walnuts I eat, I also don't control (or even fully understand) the molecular mechanisms that determine the functions of my brain. But I can control the power that my memories hold over me. I can choose to remember the grandma who taught me to pick vegetables.

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