Explaining participation: an explanatory history of select gender patterns in undergraduate STEM

Michael Pasquale Mastroianni
University at Albany, State University of New York, mastroim@gmail.com

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Explaining Participation:
An Explanatory History of Select Gender Patterns in Undergraduate STEM

By

Michael Pasquale Mastroianni

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Gender Patterns in Undergraduate STEM

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ABSTRACT

This explanatory study examines three focal periods in undergraduate STEM as related to the gender gap. Social, economic, and more general historical data are used to develop a clear and powerful explanation of baccalaureate trends in biology and engineering. Specifically, historical accounts are offered for 1) a ten-year period in undergraduate biology in which the number of baccalaureates awarded to men decreased 44 percent, while the number of baccalaureates awarded to women decreased one percent; 2) the start of a twenty-year period in which the number of bachelor’s degrees awarded in the biological sciences increased 150 percent—from 36,068 degrees in 1989, to 90,003 bachelor's degrees in 2011; and 3) a ten year period in undergraduate engineering where female graduation rates septupled—this ten-year time period is the only instance of meaningful and noteworthy growth for women in undergraduate engineering over the past half century. Findings from each history reveal a common narrative underlying baccalaureate trends. Implications for undergraduate STEM are discussed.
ACKNOWLEDGEMENTS

Novelist Thomas Mann wrote, “A writer is someone for whom writing is more difficult than it is for other people.” By that definition, I am an extraordinary writer.

To my mother, my grandmother, and Dan—I owe you life. I will never be able to repay what you have given me. I love you, and I am so proud to be your son, grandson, and stepson. This has been a long road. Thank you from the bottom of my heart. You already know this—I could not have done this without you.

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4.1 Baccalaureate snapshots, years 1976 and 1985 ....................................................... 115
Chapter 1: Introduction
Over the past fifty years, the underrepresentation of women in undergraduate science, technology, engineering, and mathematics (STEM) has become a growing national concern. The persistence of a gap in STEM baccalaureates with respect to gender has gained the attention of researchers, educators, policy makers, and the public at large. Leaky pipelines and widespread gender bias are often reported in newspapers and journal articles. Conversations surrounding why more women are not graduating from science and engineering are mainstream. And investigations of the gender gap have resulted in countless theories and frameworks—some more meritorious than others—seeking to explain the disparity in STEM gender trends. At one point in time, for example, it was argued biological and innate differences accounted for the drastic divide\(^1\)—that females were inferior in mathematical reasoning and spatial skills as compared to males and, as a result, avoided STEM fields.\(^2\) Likewise, at the undergraduate level it has been argued the combination of “chilly climates” and overtly masculine environments in STEM classrooms and departments alienated and precluded female participation.\(^3\) Eccles and Hoffman argued sex-role socialization factors and other cultural forces encouraged women to pursue “studies emphasizing nurturing while men are encouraged in domains emphasizing quantitative reasoning.”\(^4\) And Polachek postulated economic reward expectations and life-cycle investments to be an underlying mechanism of the

\(^1\) Jacob Clark Blickenstaff, "Women and Science Careers: Leaky Pipeline or Gender Filter?,” *Gender and Education* 17, no. 4 (2005).


undergraduate gender gap. His investment model proposed socialized expectations can lead “to markedly different optimal investments in human capital as captured by the choice of [undergraduate] major.”

Despite the existence of cultural, economic, disciplinary, and even sexist barriers, women have gained significant ground in select undergraduate STEM fields. In the cases of biology and chemistry, women have closed the gender gap entirely—according to the National Science Foundation’s most recent *Women, Minorities, and Persons with Disabilities in Science and Engineering* report, in 2010 women accounted for 59 percent of all bachelor’s degrees awarded in the biological sciences, and 50 percent of bachelor’s degrees awarded in chemistry. Likewise, in 2010 women accounted for 43 percent of baccalaureates in mathematics. Compared to engineering, physics, and computer science—in 2010, women earned 18% of bachelor’s degrees in engineering, 20% in physics, and 18% in computer science—the above statistics are even more noteworthy.

While contemporary research surrounding gender and undergraduate STEM is often focused on aggregate level participation, of particular interest is how to explain the divergent evolution of gender baccalaureate trends within individual STEM fields. In the early 1970s a substantial gender gap characterized every STEM field. Today, this is no longer the case. But why participation remains stalled in certain fields as opposed to others is not fully understood. As a result, it is the intent of this dissertation to investigate key female and male trends in individual STEM fields in the past fifty years. Doing so will not only provide a deeper examination of gender and STEM, but will advance

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contemporary understandings of the disciplinary, cultural, and political barriers which remain intact in some fields.

Therefore, the intent of this dissertation is to answer the following questions:

1. What mechanisms influenced the periods of increasing and decreasing patterns of participation characterizing individual STEM fields in the last fifty years?

2. How do these underlying influences inform an explanatory framework of female and male participation in undergraduate STEM as a whole?

**Research Methods**

The above objectives will be achieved through an explanatory history case study model. As discussed by Gall, Borg, and Gall, historical methodologies help “educators understand the present condition of education by shedding light on the past.”7 The need to better understand the evolution of disaggregated gender trends is underscored by several scholarly critiques of prior research. Jacobs identified flaws in research studies investigating the underrepresentation of women in higher education, including many studies misguidedly conflating distinct gender issues in higher education (i.e., secondary preparation, admissions processes, major selection, and persistence) as a singular entity—“access, process, and outcomes are distinct aspects of higher education that need to be examined separately.”8 Jesse recognizes many contemporary narratives regarding gender and higher education are often contradictory, diminishing the potential impact and/or

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transfer to practice. Blickenstaff acknowledges many explanatory models are reductionist in nature, some being harmfully so. She concludes, “the problem of female under-representation in STEM…majors is certainly not a simple one” and such “a complex problem like this requires a multi-faceted [approach].”

To address these issues, an explanatory history case study approach devoted to understanding the evolution of gender trends within individual STEM fields is appropriate. Explanatory histories seek not only to gain a deeper understanding of a specific course of events, but also present a theory of cause: a theory which “represents the researcher’s estimate of how one event or combination of events determined—entirely or at least partially—what happened later.” This method of research has been previously used to examine the development of the bureaucratic structure of contemporary schools, and governmental decision-making through the lens of the Cuban Missile Crisis. In general, an explanatory history case study approach is appropriate for studies “seek[ing] to account for why episodes occurred as they did.”

The intention in using this methodology is underscored by a desire to better understand focal baccalaureate patterns in STEM fields with respect to the gender gap. Rather than treat female underrepresentation as one monolithic STEM narrative as many studies do, this dissertation will examine disaggregated focal trends within select fields. For example, initial parity in undergraduate biology was not achieved through a steady

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10 Blickenstaff, "Women and Science Careers: Leaky Pipeline or Gender Filter?," 384.
14 Thomas, *Blending Qualitative and Quantitative Research Methods in Theses and Dissertations*, 21.
increase in female graduates, but through a large and rapid decline of male graduates. An exploration of this one-sided decline (in addition to other investigations of focal trends) would provide a more detailed and more meaningful understanding of gender trends in undergraduate STEM.

To conduct an explanatory history, multiple primary and secondary sources of data were explored. The largest sources of primary data were governmental and organizational in nature—reports, laws, policy briefs, etc. Trend data from the National Center for Science and Engineering Statistics of the National Science Foundation, the National Center for Education Statistics of the U.S. Department of Education, and the Organisation for Economic Co-operation and Development (OECD) were examined. Additional primary sources were also obtained as necessary.

In addition, the complex and interdisciplinary nature of the topic required the synthesis of a diverse, yet related, corpus of research. Topics include American social and political history;\(^{15}\) the influence of college life on major selection;\(^{16}\) the evolution of colleges and universities post World War II;\(^{17}\) theories of career development and the impact of career counseling;\(^{18}\) disciplinary-specific histories;\(^{19}\) disciplinary-specific


critiques of gender participation;\textsuperscript{20} the civil rights movement;\textsuperscript{21} and feminist critiques of
the aforementioned.

\textbf{Focal Case Studies}

To further motivate the need for this study, and to provide a clearer sense of the
periods in individual STEM fields which have produced significant events as related to
the gender gap, what follows is an overview of the focal case studies which will be
explored in this dissertation. An in-depth investigation of each will provide a thorough
understanding of each time period, and will also contribute to a more complete
understanding of gender participation in STEM as a whole.

\textit{Male Participation in the Biological Sciences, Years 1976–1986.} This chapter
will focus on a rather perplexing period in undergraduate biology. Stated in a 1989
profile of the biological sciences conducted by the National Science Foundation:

In 1986, fewer men and women earned baccalaureates in the biological sciences
than in 1976. This downward trend was more pronounced for men: the number of
baccalaureates award to men decreased by 44 percent compared to a 1-percent
decline for women.\textsuperscript{22}

In terms of raw numbers, between 1976 and 1986 male baccalaureates declined from
35,498 degrees in 1976 to 20,000 degrees (15,498 degree decline), while female
baccalaureates declined from 18,656 degrees to 18,395 degrees (261 degree decline),

\textsuperscript{20} See Elizabeth Fennema, \textit{Mathematics and Gender} (New York: Teachers College Press, 1990); Thomas J.
\textsuperscript{22} National Science Foundation, "Profiles–Biological Sciences: Human Resources and Funding (NSF 89-
respectively. As a result of this one-sided trend, virtual parity in the biological sciences was reached. Therefore, an explanatory history of this phenomenon is necessary to fully explain both the narrowing and ultimate closure of the gender gap in undergraduate biology.

*The Biological Sciences, Years 1989–1998.* Following the one-sided decline of males from undergraduate biology, between 1989 and 1998 the biological sciences became the fastest growing undergraduate category in the United States—both numerically and in percent growth. In terms of raw numbers, female trends exceeded male trends throughout the period, and in 2000 female graduates surpassed their male counterparts in proportion of biology baccalaureates conferred. As a result, an explanatory history of this period will offer additional information into undergraduate STEM’s most evolved field with respect to gender.

*Engineering, Years 1976–1985.* In stark contrast to the biological sciences, over the past fifty years engineering has remained consistently male-dominated. At no point in the last half-century have males earned less than 80 percent of engineering baccalaureates in any given year. As a result, this chapter will explore a time period where women were able to overcome the historical, social, and institutional ceilings limiting engineering participation. Between 1976 and 1985, engineering was the second fastest growing undergraduate category—male baccalaureates increased 86 percent, while female baccalaureates increased 770 percent. To better understand both female and male trends in engineering, an in-depth exploration of this time period is essential.

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Goals and Significance

Considerable interest has been paid to explaining the gender gap in science, technology, engineering, and mathematics at the undergraduate level. Less attention has been given to understanding the evolution of male and female participation within each STEM field. Such is essential if we wish to adequately address the complex issues impacting and supporting modern settings of unequal participation. Therefore, the contribution of this dissertation to the gender and STEM participation community will be a more nuanced and detailed understanding of participation patterns within individual STEM fields. Such an exploration will further enable the identification of effective practices and strategies that researchers, educators, policy makers, and academic leaders can build upon in their ongoing efforts to reconcile the persistence of invisible, but intact, barriers in certain STEM fields.
Chapter 2: Male Participation in the Biological Sciences, 1976–1986
I.  

No STEM field has undergone a greater evolution with respect to gender trends than the biological and life sciences. What was once a male dominated field is now predominantly female in undergraduate enrollment. According to the AAUW’s report *Why so few? Women in Science, Technology, Engineering and Mathematics*, one of every two STEM bachelor’s degrees awarded to women in 2007 came from the biological sciences (88,371 total female STEM degrees; 48,001 female bachelor’s degrees in the biological sciences). Compared to their male counterparts, more women earn bachelor’s degrees in biology than men earn degrees in biology, physics, chemistry, and earth science combined.¹ In fact, women earn as many degrees in biology as men earn in all traditional engineering fields. According to the National Science Foundation, the 52,878 bachelor’s degrees earned by women in biology in 2010 virtually equaled the bachelor’s degrees earned by males in mechanical, electrical, civil, chemical, industrial, aerospace, and materials engineering combined (53,014 total). For a population which was once viewed by some as biologically inferior and scientifically inept,² women’s participation in the biological sciences and the field’s transition from male-majority to female-majority is all the more remarkable.

Of particular interest for researchers and educators is understanding the factors which influenced biology’s evolution toward parity. From historic male-dominance, to reaching gender parity in the late 1980s, to the present period of female-majority participation, the collection of social, cultural, disciplinary, and political influences which

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² J. McKeen Cattell, "A Further Statistical Study of American Men of Science," *Science* 32, no. 828 (1910); As cited in Blickenstaff, "Women and Science Careers: Leaky Pipeline or Gender Filter?."
combined to alter the discipline’s trajectory in the past half century are not well understood. Much attention has been given to understanding and rectifying the persistent gender inequalities remaining, most notably, in engineering, physics, and computer science. However the outlying narrative of biology, and the reversal of male and female baccalaureates within the discipline, remains undocumented. Therefore, this present essay will investigate an anomalous ten-year period in the discipline’s history. As displayed in Figure 2.1, the outcome of this period was near-baccalaureate parity in the biological sciences.3

![Graph showing biological/biomedical bachelor's degrees by gender, years 1970-2011, with years 1976-1986 highlighted. Source: Digest of Education Statistics 2012, p. 496.]

Figure 2.1: Biological/Biomedical bachelor's degrees by gender, years 1970-2011, with years 1976-1986 highlighted. Source: Digest of Education Statistics 2012, p. 496.

3 In this chapter, I will use the terms “biology” and “biological sciences” interchangeably to refer to the constellation of related majors identified by the National Center for Education Statistics as the “biological and biomedical sciences.” See Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 456-69.
II.

As indicated above, initial gender parity in undergraduate biology was reached in the late 1980s; in 1988 women graduates in the biological sciences surpassed male graduates—the first instance for any STEM category in the past fifty years of American higher education.\(^4\) Noteworthy, however, is this surpassing was not achieved through a steady increase in female graduates, but through a large and rapid decline of male graduates. As stated in a 1989 profile of the biological sciences conducted by the National Science Foundation:

In 1986, fewer men and women earned baccalaureates in the biological sciences than in 1976. This downward trend was more pronounced for men: the number of baccalaureates award to men decreased by 44 percent compared to a 1-percent decline for women. Consequently, in 1986, the number of women baccalaureates almost equaled that of men.\(^5\)

In other words, between 1976 and 1986, the number of bachelor’s degrees in biology awarded to men decreased by almost half, while the number of bachelor’s degrees awarded to women essentially remained constant (see Figure 2.1). In terms of raw numbers, in ten years the annual output of male bachelor’s degrees in biology decreased by 15,498 degrees, compared to a decrease of 261 degrees for women.\(^6\)

Common explanations often attribute this seemingly one-sided decline to the waning influence of the baby boom generation coupled with the increasing prominence of women in higher education. However, these factors do not adequately account for the

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\(^4\) Ibid., 494-516.
\(^5\) National Science Foundation, "Profiles–Biological Sciences: Human Resources and Funding (NSF 89-318)," 31.
\(^6\) Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 496.
differences in biology baccalaureates. During the ten-year span in question, the percentage of males earning biology degrees, when compared to all male bachelor’s degrees, decreased from 7.0 percent to 4.1 percent—a 2.9 percentage point decrease. For females, the numbers decreased from 4.4 percent to 3.7 percent respectively—a 0.7 percentage point decrease. The differences in these numbers suggest a very notable paradigm shift in terms of male and female students’ enrollment.

Therefore, the present essay explores the question: why did male participation in the biological sciences decline suddenly and abruptly from 1976 to 1986? As the reader will discover, investigating the underlying mechanisms influencing the decline of males from the biological sciences during this time period will lead us to a narrative surprisingly simple, but also profound. Along the way, we will re-realize a set of institutional forces impacting male students’ decisions, their desired lives, and the preservation of both in the face of obstructions. And we will follow a decades-long chain of responses to a hostile foreign world and the preservation of democracy, capitalism, and America.

III.

To fully explain the time period in question, we must begin in 1939 with a world in the first stages of international turmoil. That September, Hitler’s Soviet Union-backed Germany declared war on Poland and invaded the country’s western border. Britain and France—Polish allies via the Anglo-Polish military alliance—issued ultimata demanding German withdrawal from the country and the ceasing of all aggressive acts towards

7 Ibid.
Poland. Germany refused, Britain and France fulfilled their ultimata, and Europe was officially at war. That evening, amplifying ferment, a German submarine torpedoed an unarmed British passenger ship carrying 1,100 passengers—three hundred of which were American—en route from Scotland to Montreal. The news shook England, America, and Canada, and made the front page of every major newspaper in the three countries\(^8\): the *New York Times* declared “First Ship Sunk in the War”\(^9\); the *Halifax Herald* reported, “Liner Athenia is Torpedoed and Sunk”; and the *Daily Telegraph* announced, “Big British Liner Torpedoed.”

The next morning Germany continued their onslaught of Poland. They “executed 1,000 Poles near Bydgoszcz, including a number of Boy Scouts.”\(^10\) Polish citizens resistant to German Gestapo found themselves killed or immediately arrested and sent to the first German concentration camp in Dachau. There, alongside anti-Nazi opponents and other alleged criminals, Polish men and women were subjected to brutal punishments and back-breaking, forced labor; donning the prison’s iron gateway was the slogan *Arbeit macht frei*—“Work will make you free.”

On September 6th, the Republic of South Africa declared war on Germany. On September 10th, Canada did so as well. The United States meanwhile announced its neutrality in the European situation, joining Switzerland, Estonia, Finland, Norway, Ireland, and Belgium.

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One week later, in concert with the Germans, the Soviet Union invaded Poland attacking the country’s eastern border. Within three weeks the Polish military surrendered, and the country partitioned into German and Soviet territories. The western provinces—twelve in all, 22 million inhabitants in total—went to Germany. The eastern provinces—eight in total, 13 million inhabitants—went to the Soviet Union. Bluntly stated by sociologist Tadeusz Piotrowski, however, for the Polish people “one hesitates to venture a guess as to whether more people died under the former or the latter regime.”

Days after Polish defeat, Hitler prepared plans to invade Belgium, the Netherlands, Luxembourg, and France. The Soviet Union, in turn, attacked Finland in November beginning a winter war resulting in 150,000 dead or missing, and over 400,000 total casualties.

On October 11th, two days after Columbus Day, a letter written months earlier by Leó Szilárd, signed by Albert Einstein, reached President Roosevelt in Washington, D.C. The letter introduced and warned the President of theoretical, but newly conceived and “extremely powerful bombs of a new type.” Stemming from the work of Szilárd and Enrico Fermi, these new weapons would be fueled by an energy-producing chain reaction via the splitting of the uranium isotope, uranium-235. Szilárd and Einstein’s letter encouraged the President to take action and institute a program of atomic research. The President would indeed do so, catalyzing what would eventually evolve into the Manhattan Project. Szilárd and Einstein’s letter also warned the President of possible German efforts to pioneer such a bomb for themselves:

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I understand that Germany has actually stopped the sale of uranium from the Czechoslovakian mines which she has taken over. That she should have taken such early action might perhaps be understood on the ground that...American work on uranium is now being repeated.12

The President, graciously thanking the scientist for the timely warning, responded to Einstein:

Dear Professor...I found this data of such import that I have convened a Board consisting of the head of the Bureau of Standards and a chosen representative of the Army and Navy to thoroughly investigate the possibilities of your suggestion regarding the element of uranium...Please accept my sincere thanks.13

Ten days later, the President’s Advisory Committee on Uranium would meet for the first time, beginning the country’s progression toward the atomic bomb.

Meanwhile five thousand miles away, in parallel with Europe, China and Japan were involved in the third year of what is now known as the Second Sino-Japanese War—a war that would eventually be swept into World War II upon the bombing of Pearl Harbor. By 1939, the Japanese controlled the most important areas of China,14 about one-third of the country.15 A civilian death total already in the many millions, mass killings, suffering, and deprivation were commonplace, and China was on the brink of collapse to the Japanese.

By the summer of 1940, a year after Hitler’s initial plans for invasion, Germany would go on to occupy the Low Countries and France. Hitler envisioned the French

12 Einstein–Szilárd Letter to President Roosevelt, Personal Letter, August 2, 1939.
13 President Roosevelt’s Response to Einstein, Personal Letter, October 19, 1939.
invasion costing the lives of almost one million German soldiers. In reality, French defeat took six weeks and cost the Germans only a few percentage points of the anticipated casualties. The speed at which the Germans conquered the French was a surprise to the Allied powers, and Hitler as well. With the country’s continuing string and ease of military success, German nationalism and military momentum was at an all-time high. Great Britain now remained the last obstacle to Nazi control.

IV.

This is the state of the world confronting the United States in 1939 and 1940. And this is the context which explains the country’s enactment of the first peacetime draft law in U.S. history—a draft law which established a system of selective service that would remain largely in place for the next thirty years.16

Upon announcement of the country’s neutrality in the European War, President Roosevelt declared the United States in a state of limited national emergency. In 1939, the American military consisted of 190,000 soldiers and 200,000 members of the National Guard. Compared to Germany which invaded Poland with 1.85 million soldiers, the Soviet Union Red Army with an estimated 1 million soldiers, and the Imperial Japanese Army with 1.7 million soldiers, the United States was severely outnumbered should it ever need to defend its neutrality or engage in war. The President’s declaration of the limited national emergency didn’t result in an immediate increase of military manpower, but it would eventually lead to the signing of the Selective Training and

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Service Act of 1940—a peacetime act with the intent of raising an army of 900,000 men.17

Unprecedented in initiation,18 the foresight of the Act proved justified fourteen months later when the torpedoing planes of the Japanese kamikaze brought war to the American homeland in Pearl Harbor, Oahu. Four days later, Germany declared war on the United States, and the unwanted outbreak of the world’s wars found the stubbornly isolationist America. The country’s “transition from peacetime to wartime operation was abrupt,” but the peacetime Selective Training and Service Act of 1940, in many ways, “cushioned the shock of [war].”19 For, in hindsight, the Act effectively served as the pilot phase of a nation-wide institutional and bureaucratic intervention—a pilot phase allowing, as tactfully stated by conscription historian George Flynn, “time for the virtues and defects in the Selective Service System to surface.”20 Problems were anticipated, and the peacetime act helped ensure the establishment of a well-tuned and healthy Selective Service operation free from glaring procedural hiccups or the unforeseen turbulence so often confronting the initiation of massive governmental institutions. When scaled to meet wartime demands in December 1941, the draft had already been operational for fourteen months, and America’s head start would prove invaluable. To the Office of Public Affairs, the peacetime era of the Selective Service System “may well have been America’s salvation. The laws and regulations were in place and the draft was working smoothly before the United States entered the war.”21

17 Ibid., 18.
The logistics of American conscription during World War II would form the foundation of the country’s Selective Service System for the next three decades. Conceived as a civilian pursuit instead of a military endeavor, American conscription at its core emphasized local involvement and local control of registrant classification and draft decisions. Rather than rely on a single, centralized office, thousands of local draft boards were established in cities and counties throughout the country. Each board consisted of three or more members, all of whom lived in the communities they represented, with “full authority to determine the classification of all [registered] men” within their jurisdiction.\(^\text{22}\) As described by Clarence Dykstra, the first director of the Selective Service System, the basis of the American draft process was not the blanket selection of individuals by a military organization in Washington, but “the selection of men by their neighbors and fellow citizens.”\(^\text{23}\)

Central to each draft board’s responsibility was the obtainment and processing of information for registrants within each community. Survey forms administered to registered males were completed by each and returned to the board:

[These] form[s] asked for data on marital status and dependents, prior military service, present occupation, education, court record, and physical condition. Based on the information supplied by the registrant, the local board classified each registrant according to availability, with 1-A representing those immediately available and 4-F representing those unfit to serve. Men with dependents, vital

\(^{22}\) Ibid.

jobs, or other qualifying characteristics which might limit their availability fell into intermediate categories.\textsuperscript{24}

After classifying crops of young men, draft boards mailed each registrant draft cards and draft card numbers corresponding to lottery-style capsules. Ultimately, the military fate of each male would be determined through combination of the board’s classification assignments and lottery number luck.

Of the 45 million American men aged 18 to 64 who, as required by law, registered with draft boards during World War II, ten million would be selected for service. “The older men,” as detailed by the Office of Public Affairs, “were not subject to military service, but their registration was used as an inventory of the available manpower for civilian jobs in industry and agriculture.”\textsuperscript{25} Of the remaining eligible, enlistment could be delayed through social or occupational draft deferments: that is, the temporary and/or permanent postponement from military induction on the basis of social criteria or occupational characteristics. At the start of World War II, this commonly meant deferments for husbands and fathers, and males whose absence would result in hardship for dependents. As war ravaged on however, mounting draft quotas resulted in the virtual elimination of dependency deferments—“from 8 million in 1943 to less than 100,000 by 1945.”\textsuperscript{26} The military duties of fathers and husbands were needed by war’s end, and the societal impact of their enlistment would be a double-edged sword: the increasing numbers of husbands and fathers sent to war would lead to large civil gains for American women—“by 1944 16.5 million women made up 36 percent of the entire civilian work force”—but large family and societal problems elsewhere—“juvenile

\textsuperscript{24} Ibid., 24-25.
\textsuperscript{25} Office of Public Affairs, "A Short History of the Selective Service System."
\textsuperscript{26} Flynn, \textit{The Draft, 1940–1973}, 74.
delinquency skyrocketed during the war years, and the divorce rate rose dramatically, from 16 per every 100 marriages in 1940 to 27 per 100 in 1944.”

Draft deferments were also commonly awarded to men in ‘vital jobs’—occupations which, as defined by law, included: “employment in industry, agriculture, or other occupations or employment, or whose activity in other endeavors, is found…necessary to the maintenance of the national health, safety, or interest.” During World War II, this led to congressional consideration and deferment for farmers and men in agriculture-based occupations. No industry was more preserved in World War II than agriculture, and such considerations paid dividends for the United States: farmers and agriculture as an industry increased “production to meet domestic and foreign needs” and “crop production rose almost 20 percent.”

The preservation of other vital industries, however, wouldn’t come as easily. Labor issues would become a common domestic theme during war, and the looming threat of conscription was invoked—loudly and routinely—by government officials in attempts to procure needed labor and quench potential wartime disruptions. The United States government “had previously hesitated to intervene in routine labor-industrial conflicts, viewing such disputes as being beyond the purview of a democratic government in a free market economy…” But the pressure of war propelled federal authorities into uncharacteristic positions; federal work-or-fight mandates—and even plant seizures—became commonplace to the point that such “policies developed into a

27 Ibid., 74-75.
major U.S. Army domestic function during” World War II.\textsuperscript{31} The “club of induction,”\textsuperscript{32} was used during war as an effective tactic to induce the procurement of industrial goods and a means to disincentivize labor disruptions, but also as a perverse power play move to undermine union authority, and in some cases support inefficient labor practices.

Ultimately, the federal government’s main aim to keep “the fighting men and the Allies supplied with the weapons, munitions, and other materiel needed to achieve victory”\textsuperscript{33} was largely accomplished, and the war ultimately won. However, in doing so, overtly intimidating and aggressive bullying tactics on the part of management and federal authorities towards workers were used to deal with an array of labor-related issues. Stories surfaced of business managers “flush[ing] out weak workers by sending their names to local boards for reclassification.”\textsuperscript{34} Striking workers similarly faced draft reclassification threats from government officials. And military interventions were proposed to combat the largest of labor disturbances. A 1941 strike by the United Mine Workers of America, for example, led to a proposed military intervention wherein “large numbers of combat troops, armed with tanks and heavy artillery” were “to be deployed to the mining areas to guard the persons, properties, and families of nonstrikers and to serve as a threat to strikers” (emphasis added).\textsuperscript{35} A separate strike by the United Mine Workers of America in 1943 caused U.S. War Department officials to propose an elaborate take-over plan of questionable legality. The plan called for “all miners and mine officials under forty-five years of age…to be drafted within forty-eight hours after the seizure of

\textsuperscript{31} Ibid.
\textsuperscript{32} “Channeling,” \textit{Ramparts} 6, no. 3 (1967): 34.
\textsuperscript{33} \textit{Industrialists in Olive Drab}: \textit{The Emergency Operation of Private Industries During World War II}, v.
\textsuperscript{34} Flynn, \textit{The Draft}, 1940–1973, 83.
\textsuperscript{35} Ohly, \textit{Industrialists in Olive Drab}: \textit{The Emergency Operation of Private Industries During World War II}, 58.
the mines… Inducted mine personnel were to be organized into work units” with “the Army administering the whole program,” and “mine officials [to become] commissioned officers” with “court-martial powers over enlisted miners.” The proposal also included an option for the imposition of “martial law if the induction of miners met ‘serious resistance and obstruction.’”

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The threat of conscription and deferment as bargaining devices, as methods for government to control the behavior of its populace in times of emergency, foreshadows the types of governmental mechanisms which would be invoked in America’s future wars to drive participation into key areas. During World War II, the Selective Service and the American draft system served primarily to meet the manpower needs of the U.S. military. In the following years, the Cold War and the rising tensions between the United States and the Soviet Union—between capitalism and communism—would evolve the mission of the Selective Service System to fulfill domestic needs as well. After World War II, deferment would be used not only to maintain the social fabric of the country or maintain agriculture production, but also to induce participation in key areas; the vehicle of deferment would be used by policymakers as a catalyst, a lightning rod to mold the American populace into pipelines of national need, and stockpile the arsenal of American capital throughout the next quarter century.

It is this new function of the Selective Service System—the channeling of young American males into predetermined pathways—which begins to explain the puzzle of

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male participation and decline in undergraduate biology. The same pressure used to quench labor disputes during World War II would be used in Vietnam to drive males into the biological sciences. Throughout the 1960s and early 1970s, deferments were granted to students in the sciences, and in particular, students in pursuit of medical fields. Ultimately, it is this seesaw of incentives, and subsequent lack thereof upon war’s end, which spurred the one-sided, non-parallel decline of males from the field.

To better understand the political forces which contributed to this reality, in the next section we will investigate the underlying mechanisms motivating the United States’ prioritization of its science pipeline. We will explore the substantial and dangerous threat of communism to America and capitalism; we will follow the chain of events which unnerved the country into the nuclear arms race; and we will learn of the state of the country’s education system, and the limited production of American scientists in comparison to its Soviet counterparts.

V.

The outcome of Szilárd and Einstein’s 1939 letter to President Roosevelt is now well known. On August 6, 1945, the United States exploded an atomic bomb on the city of Hiroshima killing 100,000 to 140,000 Japanese, and destroying over 60,000 of the city’s 90,000 buildings. Three days later on August 9th, the United States exploded a second atomic bomb on the city of Nagasaki, killing 35,000 to 40,000 more Japanese, transforming the city into a “graveyard with not a tombstone standing.”\(^37\) The two

bombings, coupled with the Soviet Union’s declaration of war against Japan on August 8th, brought an abrupt end to World War II. Emperor Hirohito announced his country’s unconditional surrender in war via radio broadcast on August 15, 1945:

The enemy has begun to employ a new and most cruel bomb, the power of which to do damage is, indeed, incalculable, taking the toll of many innocent lives. Should we continue to fight, it would not only result in an ultimate collapse and obliteration of the Japanese nation, but also it would lead to the total extinction of human civilization. Such being the case, how are we to save the millions of our subjects, or to atone ourselves before the hallowed spirits of our imperial ancestors? This is the reason why we have ordered the acceptance of the provisions of the joint declaration of the powers.

For virtually every Japanese citizen, this broadcast would mark the first time hearing their Emperor’s voice.

President Truman’s announcement of Japanese surrender and Ally acceptance led to the highest of American celebrations. Jubilation unrestrained, crowds stormed New York’s Times Square, Washington, D.C., San Francisco, and every city, town and hamlet in between. Confetti, smiles and euphoria abound—it was “ten New Year’s Eves rolled into one,” *Life Magazine* described.38 More ticker tape, ripped phone book pages, and clothes scraps fell from the sky than would ever fall before or since. In New York alone, sanitation crews estimated 5,400 tons of confetti blanketing the streets39—the equivalent

to one hundred Yankees World Series parades, and five thousand New Year’s Eve celebrations. Complete and utter rejoice marked the day, just as it would do so again three weeks later on September 2, 1945 with the official Japanese signing of surrender documentation aboard the USS *Missouri* in Tokyo Bay.

With war over, the unnatural but necessary alliance between the western democracies and the communist Soviet Union quickly unraveled. Expectations of peace and coordinated efforts toward political coexistence were extinguished by bitter mistrust and rivalrous antagonism. The exhaustion of Great Britain’s resources during war and the country’s subsequent economic instability upon Ally victory left the United States and Soviet Union as the lone superpowers in the postwar world. The seeds of the Cold War would be ultimately sown in the decaying relationship of these two countries over the next years. To one dictator in particular, this evolution of events was not unexpected—a month before his suicide death in April 1945, Hitler accurately predicted the post-war strife which would dominate much of the world for the next forty years. He wrote from his underground bunker:

> With the defeat of the Reich…there will remain in the world only two Great Powers capable of confronting each other—the United States and Soviet Russia. The laws of both history and geography will compel these two Powers to a trial of strength, either military or in the fields of economics and ideology.

> Compared to the clarity and universal acceptance of its celebrated conclusion, “no single event defined the start of the Cold War in the way that the fall of the Berlin Wall,

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on November 9, 1989, came to symbolize its end.\textsuperscript{42} To traditionalists, the Cold War was ignited by “a cynical manipulation of events in order to produce the Soviet goal of a Communist puppet government” throughout war torn Europe, and the subsequent and necessary response of the United States to counteract Soviet transgressions.\textsuperscript{43} Six months before war’s end, the United States, Great Britain, and the Soviet Union agreed on a series of provisions regarding the overthrown governments and occupied territories resultant from war, including those absorbed by the Soviet Union. To many historians, the Soviet Union’s blatant withdrawal from these agreements and forced expansion of communism throughout Eastern Europe catalyzed the political furor which would encompass the world for the foreseeable future.

To some historians, the Cold War stemmed from the United States’ reliance on heavy-handed attempts to coerce the Soviet Union into political dealings through intimidation and atomic diplomacy—that is, the tacit or explicit threat of America’s atomic capabilities to pressure diplomatic negotiations in the country’s favor.\textsuperscript{44} During a conference meeting of political heads in London a month after Ally victory, United States Secretary of State James Brynes replied to Soviet Foreign Minister Vyacheslav Molotov’s off-the-cuff question regarding atomic bombs: “You don’t know southerners. We carry our artillery in our pocket. If you don’t cut out all this stalling and let us get down to work, I’m going to pull an atomic bomb out of my hip pocket and let you have it.”\textsuperscript{45} In the immediate postwar years, the atomic bomb mushroomed from a wartime


instrument to a central component in U.S. foreign relations: “the atomic bomb was not only a powerful weapon; it was also a symbol of American power.” And to some historians, heavy-handed diplomatic tactics on the part of the United States spurred the country’s decades-long rivalry with the Soviet Union.

Ultimately, the foundations of the Cold War, like most political confrontations, are rooted in both historical positions. Communist doctrines pitted the ideology in all out war with capitalism, and Stalin himself, years earlier, acknowledged little hope for “permanent peaceful coexistence” between the two systems. In a speech given by Stalin to communist workers, he prophesied:

In the further progress of development of the international revolution, two world centers will be formed: the Socialist center, attracting to itself all the countries gravitating towards Socialism, and the Capitalist center, attracting to itself all the countries gravitating towards capitalism. The fight between these two centers for the conquest of world economy will decide the fate of Capitalism and Communism throughout the whole world, for the final defeat of world capitalism means the victory of Socialism in the arena of world economy.

Coupled with the Soviet Union’s aggressive imperialistic expansion throughout Europe, this viewpoint resulted in a reactionary and defensive United States seeking to contain the increasing threat of their rival superpower. Soviet disruptions and undermining of the free election processes in Poland, Czechoslovakia, Hungary, and Romania, and the installment of communist puppet governments within each; ambitions to spread communism to the Middle East and Asia and the Soviet’s subsequent actions in Iran and

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46 Ibid., 133.
47 G. F. Kennan, "The Charge in the Soviet Union (Kennan) to the Secretary of State," (1946).
48 J. Stalin, 1927.
Turkey; the East Germany blockade; and the postwar economic futility of Western Europe, and its not unrealistic collapse to communist ideologies: these events dominated American foreign policy and the country’s diplomatic efforts in the postwar period.

The balance of power between the United States and the Soviet Union, and the pursuit of pathways positioning capitalism and America in favorable politics became points of national importance. Counteracting the Eastern bloc, economically and militarily, spurred the country’s involvement in the *rubble-heap, charnel-house*, and *breeding-ground of pestilence and hate* which was now Western Europe.\(^4\)\(^9\) Foretold by President Truman to a joint Congress in 1947, the United States’ geopolitical agenda, for the next twenty-five years, would become containment and deterring Soviet expansion worldwide:

I believe that it must be the policy of the United States to support free peoples who are resisting attempted subjugation by armed minorities or by outside pressures…The seeds of totalitarian regimes are nurtured by misery and want. They spread and grow in the evil soil of poverty and strife. They reach their full growth when the hope of a people for a better life has died. We must keep that hope alive.\(^5\)\(^0\)

Over the next years, extension of the President’s agenda would result in the country’s restoration of Europe’s economies via the Marshall Plan, and America’s military alliance and security arrangement with Western Europe via the North Atlantic Treaty and the capsule member organization, NATO. The pre-war isolationism of the


United States a decade earlier would be replaced by far-reaching commitments to protect allies and counteract the ambitions of an aggressive and revolutionary Russia. The Joint Chiefs of Staff and the United States military prepared for the geopolitical chess match that would ensue in the next decades. The American draft system which had been in place since the start of World War II came to a halt in early 1947. One year later Soviet strife would result in its renewal, and from 1948 to 1973, in the constant shadow of the Cold War, the Selective Service System and the conscription of young men would continually remain readied and on call to serve its country and defend the free world should need be.

To some political strategists there would never be such a need: many diplomats were “convinced war was unlikely so long as the United States possessed an atomic monopoly,” and preparations by the Joints Chiefs of Staff were viewed as being of “abstract importance.”

To a large extent these sentiments proved true—for four years the White House enjoyed the advantages its atomic capabilities symbolized to its Kremlin rivals. The Soviet Union boasted an army five times larger than its U.S. counterparts, but the atomic bomb was America’s ace in the hole, and White House officials took risks they otherwise wouldn’t have dared take, nor would take, once both countries were on equal atomic footing.

Discussed by historian Melvyn Leffler:

So long as the Russian sphere was not directly challenged, State Department officials assumed that the Soviets would back down rather than allow a diplomatic crisis to come to a test of arms. U.S. officials, therefore, possessed the confidence

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to do things they might otherwise have hesitated to do if they suspected that their actions could trigger a sequence of moves that might lead to war.\(^{52}\)

America’s atomic capabilities were a political reality in foreign relations, and the power imbalance stemming from Hiroshima and Nagasaki spurred an embattled Stalin to immediately prioritize his country’s own atomic program. Both American bombs were exploded over Japanese cities, but to officials in the Kremlin the real target of the United States was the Soviet Union itself: the bombings “were, or course, not against Japan, but against the Soviet Union,” wrote Soviet Foreign Minister Vyacheslav Molotov. To him and Stalin, the Americans had arrogantly declared: “You don’t have the atomic bomb, but we do—and these are what the consequences will be if you stir.”\(^{53}\)

Days after Japanese surrender, the Soviet Union accelerated its atomic efforts and the arms race which would engulf both countries and the world for the foreseeable future had officially begun. From acceleration to detonation, Soviet scientists anticipated needing five years to achieve the country’s first atomic bomb. The United States, with an unclear understanding of the Soviet Union’s atomic status, estimated a ten year timetable for the same feat. Even as late as 1948, a memo sent from the CIA to President Truman predicted the Soviets to first explode their own atomic weapon as early as 1953: “On the basis of the evidence now in our possession, it is estimated that the earliest date by which it is remotely possible that the USSR may have completed its first atomic bomb is mid-1950, but the most probable date is believed to be mid-1953.”\(^{54}\)

The United States was very wrong. On August 29, 1949, only four years after initiation of an atomic weapons program, the Soviet Union detonated its first atomic

\(^{52}\) Ibid., 326.


On September 3rd, a United States weather plane flying over the North Pacific Ocean detected high levels of radiation in the Siberian atmosphere. Weeks of analysis led U.S. scientists to conclude the Soviet Union had tested and exploded its first atomic weapon. America’s atomic monopoly was officially over.

The news was shocking. The Soviet Union had equaled America’s atomic feat quicker than any U.S. official thought possible. What had taken the United States three years and nine months of all-out-effort to achieve was virtually matched in four years by Soviet scientists—an unbelievable achievement for a beleaguered, postbellum economy punctured by war. Like the Manhattan Project, the Soviet Union’s accomplishment was not the feat of a lone laboratory or a handful of great minds. Rather, successful atomic development was the outcome of a well-tuned industry and a scientific enterprise in geartrain lockstep.\textsuperscript{55} Research facilities, military reactors, nuclear chain reactions, enriched uranium and plutonium, the mobilization of scientists, and weapons design engineering—each its own problem, and each a separate logistic within an industrial complex. The ten-year timetable the United States envisioned for the Soviet Union’s atomic effort was not unrealistic given all that was required. The timeline of the Soviet’s accomplishment defied explanation.

As wild as any James Bond tale or Tom Clancy plot line, it didn’t take long for the United States to piece together the puzzle of Moscow’s substantial feat. In a few short weeks the United States would discover the real-life espionage ring which had infiltrated and leaked the Manhattan’s Project’s atomic secrets. Couriers and code names, dive bars and embassies, deciphered messages and military attachés, the atomic secrets of the

United States had been undermined and stolen by internal moles and spies. Described in detail by Robert Lamphere, the FBI agent who discovered the exchange:

In mid-September…I found a startling bit of information in a newly deciphered 1944 KGB message. In this cable were data and theories that seemed to have come directly from inside the Manhattan Project…When I read the KGB message, it became immediately obvious to me that the Russians had indeed stolen crucial research from us, and had undoubtedly used it to build their bomb. Part of it summarized a detailed scientific paper, while another part referred to the identity of the agent or messenger who had provided the information. This second part showed clearly that in 1944 the KGB in New York City had had an agent within the British Mission to the Manhattan Project.”

The agent was Klaus Fuchs—a German-born theoretical physicist who had gained British citizenship and worked on England’s atomic project during World War II. Upon merger with the American effort in 1943, Fuchs joined the Manhattan Project’s prestigious Theoretical Division at Los Alamos Laboratory in New Mexico. There, he roomed with Richard Feynman and worked under the direction of Hans Bethe on the implosion of fissionable materials— the heartbeat of what would become the atomic bomb. He was instrumental to the division’s efforts, and would be later described by his superiors as “one of [the] most valuable men” on the project: “If the god of war had wanted to provide [the Soviet Union] with a clear channel directly into the heart of the most important and secret work then underway at Los Alamos,” acclaimed author,

Richard Rhodes, would write, “he could not have chosen a more providential channel than Klaus Fuchs.”

His tenure at Los Alamos would end in 1946, but Fuchs’ deliberate and systematic leaks of British and American secrets would continue until 1949. Coupled with the work of other Russian spies in the United States, Canada, and England, the totality of information would accelerate the Soviet Union’s atomic progress by years: “if it weren’t for our work in Canada and the United States,” one high-ranking Soviet agent stated in 1952, “the Soviet Union would still not have the atom bomb.”

Ultimately, irreversibly—and from a U.S. standpoint, prematurely—the Soviet Union’s August 29th detonation would alter the geopolitical balance for decades to come. The United States’ failure to accurately foresee the realities of the Kremlin’s atomic timeline would have large and lasting domestic effects. Strategic bombing with atomic weapons had been central to the country’s plans to deter and/or counteract Soviet transgressions toward the U.S. or Western Europe. Moving forward, the power of America’s atomic arsenal would be grossly muted by the Soviet Union’s newfound atomic status, and the now parallel threat of atomic retaliation. This derailed the political equation guiding America’s global responsibilities and unnerved the United States into a slew of dangerous, but realistic, political what-if’s:

If Europeans concluded that the United States would not risk atomic retaliation for the defense of Europe, would they proceed with measures to integrate West Germany into Western Europe? Would they go ahead with plans to build up their military capabilities, plans that they knew the Kremlin opposed? If heretofore they had assumed that the Kremlin was deterred by the U.S. atomic monopoly,

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58 Ibid., 117.
would they now choose to forgo integration and military rearmament and avoid the attendant risks? Would they seek diplomatic accommodation rather than risk diplomatic crisis and possible war? And if war came, how indeed would the United States defend Europe if, in fact, it were unwilling to use nuclear weapons and risk atomic retaliation?  

Furthermore, the United States’ discovery of Fuchs and the Soviet espionage ring which had infiltrated the Manhattan Project, and the reality of the country’s misinformation regarding the Kremlin’s atomic status troubled officials in Washington. The Russians now had both the massive army and atomic capabilities, and new intelligence estimates and worst-case scenarios warned U.S. officials of Soviet progress toward the hydrogen bomb. In the months following August 1949, two high-ranking army generals warned then-Secretary of State Louis Johnson “that the Soviets might have been working on thermonuclear weapons [hydrogen bomb] since 1945 and that these bombs might already be in production. The Russians’ stockpile of atomic weapons might be equal to or superior to that of the United States.”  

To American policymakers, the mere notion of Soviet work toward the hydrogen bomb and the geopolitical fallout and disastrous symbolism should it upend America’s nuclear superiority would propel the United States further into the military-science arms race which would come to characterize the Cold War. Historian Melvyn Leffler expertly described the prisoner’s dilemma which the United States now faced:

If…thermonuclear weapons could be developed, the United States had to enter the race. For if the Soviets alone had the hydrogen bomb, the psychological fallout in

60 Leffler, A Preponderance of Power: National Security, the Truman Administration, and the Cold War 326.
61 Ibid., 332.
peacetime would be enormous. They would assume risks they had heretofore eschewed; they would capitalize on revolutionary unrest and social dislocation. According to [Director of Policy Planning for the State Department, Paul] Nitze, they “might dominate the world.”

On January 31, 1950, President Truman announced to the American public the country’s pursuits of the hydrogen bomb:

> It is part of my responsibility as Commander in Chief of the Armed Forces to see to it that our country is able to defend itself against any possible aggressor. Accordingly, I have directed the Atomic Energy Commission to continue its work on all forms of atomic weapons, including the so-called hydrogen or superbomb.

The “radioactive clouds floating over Hiroshima and Nagasaki,” and the start of the nuclear race in the late 1940s and early 1950s made clear to American policymakers: “the next war would be one of science and technology.”

Conscription and America’s total war effort during World War II, however, had displaced much of the country’s young intellectual capital to battlefields and navy yards. While necessary, such maneuvering depleted America of the young scientists and engineers capable of advancing the country’s future technological capabilities, or maintaining pace in the newly realized science society. Years earlier, it was a letter from a Hungarian and a German which brought the United States previously unimaginable technologies leading to the “greatest scientific achievement in [the] war.” Had the letter never been sent, or had Szilárd not understood the military implications of nuclear chain reactions, or had the life circumstances of either foreign-born physicist departed in the slightest of ways, the

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62 Ibid., 328.
64 Dobbs, Six Months in 1945, 350.
trajectory of war could have been very different and potentially catastrophic for the
United States. Future prosperity and national safety would only be ensured through
investment in America’s scientific prowess.

Assessment of America’s science situation at that time, however, would result in a
bleak portrait. Vannevar Bush, in *Science, the Endless Frontier*—the influential 1945
report which shaped the now-institutionalized properties of the American science
establishment, and led to the formation of the National Science Foundation—described
with alarm the state of the country’s educational pipeline: “for every 1,000 students in the
fifth grade, 600 are lost to education before the end of high school, and all but 72 have
ceased formal education before completion of college.”\(^{65}\) In other words, during that time
six out of ten American school children would not complete high school, and only seven
percent of American school children would ever graduate from college.

The country’s education system was unprepared for the state of the world moving
forward. Coupled with the manpower needs and the conscription policies of World War
II—policies which led draft boards to “cast [their] net[s] widely and [drag] into the
service the chemist and the street cleaner, the physicist and the plumber, the biologist and
the bookie”\(^{66}\)—the cost of war would result in the underdevelopment of America’s young
science capital. Bush would report to the President: “We have a serious deficit in
scientific personnel partly because the men who would have studied science in the
colleges and universities have been serving in the Armed Forces.”\(^{67}\) Bush continued:

Science Foundation, 1945), 26.
\(^{67}\) Bush, "Science, the Endless Frontier: A Report to the President," 25.
Science and technology students who, but for the war, would have received bachelor's degrees is about 150,000. The deficit of those holding advanced degrees—that is, young scholars trained to the point where they are capable of carrying on original work—has been estimated as amounting to about 17,000 by 1955 in chemistry, engineering, geology, mathematics, physics, psychology, and the biological sciences.\textsuperscript{68}

The realities of America's situation were even more severe as compared to the Soviet Union. In the years leading up to and during World War II and the Cold War, Soviet production of professional scientists in key areas outpaced, and sometimes lapped, those of the United States. In engineering, the Soviet Union graduated 40 percent more engineering professionals than the United States (682,000 Soviet graduates versus 480,000 American graduates). In agriculture, the Soviet Union produced 80 percent more graduates than the United States (244,000 versus 133,000 respectively). And in medicine, the Soviet Union graduated 116 percent more professional specialists than would America (320,000 versus 148,000 respectively).\textsuperscript{69}

Science as a vehicle for political influence and national security became a reality in the Cold War era. Fears of communism and the Soviet Union’s influence in geopolitical matters amplified America’s prioritization of science and nuclear supremacy. In 1949, the country’s atomic head start was undercut by espionage and a Soviet science industry accelerated by stolen secrets. Fallout from Moscow’s successful atomic detonation spurred the United States’ rush to the hydrogen bomb—a race it would ultimately win in 1952. But maintaining the breakneck pace would solidify the

\textsuperscript{68} Ibid., 24.
importance of science and America’s science pipeline to the country’s future security and prosperity. To some, an advantage in the sciences would be the country’s only salvation should a conflict with the Soviet Union ever emerge: as discussed by George Flynn, “If America is to have a chance of winning an all-out war with Russia it must plan on the most effective use of its brain power, for in manpower it is greatly outnumbered.”

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Conscription policies during World War II failed to provide for the true needs of the nation via deferment in the postwar years. In America’s next two wars policymakers would ensure history not repeat itself. Coupled with Russian production of scientists in key areas, great emphasis would be placed by the United States on developing the country’s science pipeline. To do so, the Selective Service System evolved beyond fulfilling quotas for military manpower needs, to channeling young men into domestic areas of need via deferment. Similar to the carrot-and-stick mechanisms during World War II used to quench labor disputes, deferment would be used to induce civilian males into pathways essential to the nation’s prosperity. This would have a direct impact on male participation patterns in various fields, including undergraduate biology. In the 1960s and early 1970s, the evolution of deferment policies for undergraduate and graduate students—and the tightening relationship between undergraduate biology and enrollment in medical, dental, and veterinary schools—would uniquely incentivize participation in the biological sciences. Outlined by Allen Singer, as deferment priorities evolved throughout the duration of Vietnam, students in health-oriented graduate programs retained deferment status virtually until war’s end:

In 1965, the monthly draft requirements doubled because additional troops were needed in Vietnam. Previous manpower surpluses suddenly turned into shortages, and student deferment policies were tightened…

Further tightening continued in 1967. Additional constraints were placed on undergraduate and graduate students, but students in medical, dental, veterinary, osteopathy, and optometry schools were deferred upon evidence of satisfactory progress. In 1968, postgraduate deferments were extended only to students in the health professions schools, although graduate students were usually allowed to finish an uncompleted semester if drafted during the school year.71

The ups and downs of male participation in undergraduate biology, and the growing link between the field and graduate health programs, were spurred by deferment incentives and channeling policies during Vietnam. To avoid conscription and war, young males enrolled in college and graduate schools. As war policies shifted over time, the preservation of deferments for students in medical/health fields ensured the continued inducement of undergraduate males toward biology. Conversely, it was the termination of incentives at war’s end which corresponds to the period of abrupt and sudden decline of male participation in biology between 1976 to 1986.

In the next section, we will explore the Selective Service System’s channeling policy—the reasons for its implementation as well as the strategy itself. While only referenced casually thus far, any incredulity toward the realities or explicitness of the endeavor will be extinguished. We will also learn of the philosophical disconnect

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between conscription laws in times of limited war and American democracy. What was initially instituted to procure the manpower needs for all-out and total war efforts would become a palimpsest of the intent of the initial draft system during Vietnam. Finally, we will come to understand the clarity through which the Selective Service understood its new role, and how the reverberations of its evolved policies directly impacted male participation trends in undergraduate biology.

VI.

Against the backdrop of American ideology, the role of the Selective Service System and the induction and deferment of young men during times of war—that is “determining which men should be required to serve in the armed forces and which should be required to remain at home” for the benefit of the nation—had always been fraught with tension and wide-ranging concerns of fairness and equity. “The fairest draft of all, if there has to be a draft,” the Office of Public Affairs would write, “is one in which everyone is called.” For the most part, such was the case during World War II. America’s total war effort required the full mobilization of the country’s resources, and any deferment granted for occupational reasons was done so in support of the war and the country’s immediate prosperity. Even fathers and husbands, initially deferred en masse in 1942, would be called by their country to fight as war extended into 1945.

In the Cold War era, the growing conflict with the Soviet Union and America’s opposition to the spread and influence of communism throughout the world would result

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73 Ibid., 20.
in the country’s involvement in the Korean and Vietnam Wars. Limited wars by definition, each was fashioned through foreign policy and military tactics markedly different than those known previously in the American twentieth century. Neither sought the direct protection or defense of America, nor did either require the full mobilization of American resources. Unlike World War II which called upon the services of ten million draftees, more young men were available during Korea and Vietnam “than the armed forces could possibly use.” As a result, throughout both wars the Selective Service System was left with the tricky task of inducting “some [men] for service” while “leaving others to pursue their normal lives”74—an inherently awkward problem never before encountered in United States history, and a palimpsest of the intent of the initial draft system. The American dream—the dream of being “able to grow to fullest as man and woman”; the dream of being “unhampered by the barriers which had slowly been erected in older civilizations”; the dream of being “unrepressed by social orders which had developed for the benefit of classes rather than for the simple human being of any and every class”75—runs utterly perpendicular to “law that forcibly takes certain of our young men into the military,”76 while leaving others behind untouched and unaffected. The limited needs of the military during Korea and Vietnam would effectively attempt just that, and it would result in a logistical and philosophical problem for officials in Washington. Succinctly stated by Headmaster John C. Etsy, Jr. in testimony before the U.S. Senate Subcommittee on Employment and Manpower:

74 Ibid.
75 James Truslow Adams, The Epic of America (Boston: Little, Brown, and Company, 1931), 405.
Present practice makes a mockery of the original intent that every able-bodied man serve his country. Our present difficulties arise from the strain of maintaining a semblance of universality while armed service needs dictate greater and greater selectivity. The time has come when we can no longer reconcile these opposes and must choose between them.\footnote{Ibid.}

To remedy the issue, the Selective Service relied upon a system of periodic deferments to generate the impression of national contribution and sacrifice by all registrants: “The widespread availability of deferments,” the Office of Public Affairs would write, “maintained the illusion of a universal military obligation whereby some [men] were ‘selected out’—in other words, [the illusion that] all served but in different ways.”\footnote{Office of Public Affairs, "A Short History of the Selective Service System," 20.} The outcome would result in a newfound relationship between deferment and the country’s domestic needs; conscription during America’s limited wars evolved beyond the procurement of men solely for military service, to the procurement of civilians for specific pipelines—namely science, technology, and teaching. Science pathways and higher education in general benefited greatly, and many males were coaxed into both to avoid combat. Ultimately, it is this newfound function of the Selective Service System which directly explains the phenomenon of the present investigation—that is, understanding male students’ sudden and abrupt decline in undergraduate biology from 1976 to 1986.

In 1965, the Selective Service System issued an internal orientation kit containing ten policy documents to draft boards throughout the country. One of these ten documents was entitled, “Channeling.” While the document would be withdrawn in the next years,
Ramparts magazine recovered and reprinted excerpts in its December 1967 issue. The full two-page layout reprint exposed to the public the full reach and intent of the American draft system during Vietnam, and the government’s deliberate attempt to sort males into predetermined pathways. From the reprinted document:

One of the major products of the Selective Service classification process is the channeling of manpower into many endeavors, occupations and activities that are in the national interest….

The line dividing the primary function of armed forces manpower procurement from the process of channeling manpower into civilian support is often finely drawn. The process of channeling by not taking men from certain activities who are otherwise liable for service, or by giving deferment to qualified men in certain occupations, is actual procurement by inducement of manpower for civilian activities which are manifestly in the national interest.

…Many young men would not have pursued a higher education if there had not been a program of student deferment. Many young scientists, engineers, tool and die makers, and other possessors of scarce skills would not remain in their jobs in the defense effort if it were not for a program of occupational deferments. Even though the salary of a teacher has historically been meager, many young men remain in that job, seeking the reward of a deferment. The process of channeling manpower by deferment is entitled to much credit for the large number of graduate students in technical fields and for the fact that there is not a greater shortage of teachers, engineers and other scientists working in activities which are essential to the national interest….
The System has also induced needed people to remain in these professions and in industry engaged in defense activities or in the support of national health, safety or interest.…

The first paragraphs of the document outline the rationale and logic motivating the Selective Service’s channeling policy. The American draft system sought not only to procure manpower for military functions, but also to ensure satisfactory participation in pathways related to national interests. To policymakers, it was an avenue for America to maintain pace with its global counterparts—it was “the American or indirect way of achieving what is done by direction in foreign countries where choice is not permitted.”

However, the innocuous tone laced throughout the first paragraphs would be replaced by an overtly intimidating and threatening tone in the paragraphs to come. The latter half of the document issued the subtle, yet explicit if-then statement which would come to characterize the Selective Service Systems efforts during the Vietnam War—the American government’s version of “I’ll scratch your back if you scratch mine”:

In the Selective Service System the term “deferment” has been used millions of times to describe the method and means used to attract to the kind of service considered to be most important, the individuals who were not compelled to do it.

The club of induction has been used to drive out of areas considered to be less important to the areas of greater importance in which deferments were given, the individuals who did not or could not participate in activities which were considered essential to the defense of the Nation…

[…]

It is in this atmosphere that the young man registers at age 18 and pressure begins to force his choice. He does not have the inhibitions that a philosophy of universal service in uniform would engender. The door is open for him as a student if capable in a skill badly needed by his nation. He has many choices and he is prodded to make a decision…

[...]

Throughout his career as a student, the pressure—the threat of loss of deferment—continues. It continues with equal intensity after graduation. His local board requires periodic reports to find out what he is up to. He is impelled to pursue his skill rather than embark upon some less important enterprise and is encouraged to apply his skill in an essential activity in the national interest. The loss of deferred status is the consequence for the individual who has acquired the skill and either does not use it or uses it in a nonessential activity.

[...]

From the individual’s viewpoint, he is standing in a room which has been made uncomfortably warm. Several doors are open, but they all lead to various forms of recognized, patriotic service to the Nation. Some accept the alternatives gladly—some with reluctance. The consequence is approximately the same.80

Reminiscent of ‘work-or-fight’ mandates during World War II by government to quench labor disputes, channeling and the philosophy underlying its enactment became explicit components of the American draft system during Vietnam. While such lengths were compatible with periods of total war and total mobilization of resources, parallel attempts during limited warfare were shallow and misguided. Deferment evolved from a

80 Ibid., 34.
necessary component in World War II, to a manpower solution rooted in politics rather than necessity. As seen and explicitly discussed above by the Selective Service System itself, its arm-twisting nature altered the career choices and trajectories of millions of young males, birthing into existence numerous inorganic trends and anomalous participation patterns. It is this outcome which would ultimately influence male participation in undergraduate biology, participation which the Office of Public Affairs would describe years later as convenient coxing:

Such a philosophy [of channeling] might have been valid during World War II, when almost everyone in the country contributed to the war effort in one way or another. But in a less than total mobilization, it made less sense to coax people into certain occupations because enough people would be available for such occupations even after the military had obtained all the men it needed. Thus the emphasis of deferments subtly changed— no longer was a man deferred because of the national interest but rather for convenience.81

**

Once rooted in necessity, the Selective Service System’s deferment policies evolved from a strategic component contributing to the nation’s immediate prosperity in World War II, to a remedy rectifying domestic issues during Vietnam. Periodic deferments were used to both ensure the illusion of universality and obligation to the ongoing limited war effort, as well as stockpile the arsenal of human capital desired in areas related to national interests. As a result, channeling policies would achieve anticipated participation boosts in areas related to deferment. But unforeseen and

unanticipated actions would also be taken by draft registrants in attempts to avoid war—actions which were neither beneficial to themselves nor the United States. In the next section, we will realize the large, quantitative impact of channeling on the life outcomes of young males. In each area we explore, we will learn of fluctuating trends, doubled and increased by tens of thousands in a matter of years, and the quick fall to grace and rapid return to reality at war’s end. It is this concatenation of events which prominently characterize deferment-related participation during the Vietnam era. And it is this pattern of participation which epitomizes male trends in undergraduate biology.

VII.

Efforts to channel American males into specific roles during Vietnam were extremely successful, and the Selective Service System’s “club of induction” achieved its ultimate purpose. The accelerated participation of males in various deferment-related pathways during war, and the corresponding and predictable deceleration in participation upon war’s end provide ample evidence for such effects. “Avoiding Vietnam,” historians Baskir and Strauss wrote, “became a generation-wide preoccupation.”82 In their seminal account of the Vietnam draft system, the authors continued:

Among [the Vietnam] generation, fighting for one's country was not a source of pride; it was misfortune. Going to Vietnam was the penalty for those who lacked the wherewithal to avoid it. A 1971 Harris survey found that most Americans

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believed that those who went to Vietnam were ‘suckers having to risk their lives in the wrong war, in the wrong place, at the wrong time.’\textsuperscript{83}

To avoid combat during Vietnam, young men took refuge in a variety of deferment-related pathways. This meant safety from the dangers of war, and the preservation of one’s future, but also the altering of a young man’s career path and the trajectory of his life. For some, such costs were not beneficial: “for one in four, [avoiding war] meant hurried marriages, unwanted children, misdirected careers, and physical impairments.”\textsuperscript{84} For others, escaping war was a blessing unto itself, and many were happy to accept the government’s alternatives. The club of induction, channeling, pressurized guidance—it is this framework which informs the swinging pendulums of participation in various fields coinciding with the Vietnam War years. And it is the absence of institutional channeling which explains the rapid pivot in participation in various fields at war’s end.

In a representative survey of Vietnam registrants during the 1960s, Baskir and Strauss found many males who actively sought and accepted opportunities to avoid combat:

The draft's channeling policy encouraged individuals to take fate in their own hands by rearranging their personal circumstances. According to the Notre Dame survey, three-quarters of those who never served admitted that they tried to avoid the draft. A majority (55 percent) believed that the action they took may have been responsible for keeping them out of the military.\textsuperscript{85}

\textsuperscript{83} Ibid., 6.
\textsuperscript{84} Ibid., 7.
\textsuperscript{85} Ibid., 29.
For some, this meant seeking entry in occupations and/or enrolling in college majors related to national interests. Teaching, for example, became a common asylum for young men during Vietnam. In New York City alone, male applications for teaching licenses skyrocketed during in the late 1960s. In 1968, upon the city’s announcement of automatic deferments for full-time male teachers, requests for licenses soared by 20,000 applications: “by 1969, 85 percent of New York City's teacher trainees were draft-age men, and some city universities were reporting an 800 percent increase in men taking teacher education courses.” At the aggregate level, the number of education bachelor’s degrees awarded to men swelled from 26,015 degrees in 1963 to 51,441 degrees in 1973—a 98 percent increase in 10 years. And, in perfect alignment with channeling frameworks, by the end of the decade male bachelor’s degrees in education returned to reality leveling off at 33,819 degrees in 1979, and 24,402 degrees in 1982.

Graduate schools similarly became popular havens for males during Vietnam. Examination of PhD production in the 1960s and 1970s provides compelling evidence of channeling and its impact on males’ choices. Allen Singer, in his investigation of enrollment patterns in higher education, examined the sudden uptick, and subsequent downtick, of PhD attendance and doctoral degrees coinciding with the start and end of the Vietnam War: “beginning around 1964, there was a surge of enrollments and degrees granted in higher education that began to abate only after the draft ended in 1973.” To examine the effect of Vietnam on PhD production, Singer plotted the shifting ratios of

86 Ibid., 32-33.
88 Singer, "The Effect of the Vietnam War on Numbers of Medical School Applicants," 567. It is believed fluctuations in enrollment were affected at this time also by developments in the overall economy. Some researchers believe this may have affected males more than females.
male and female PhD production versus the United States male and female civilian population aged 25–44 years.

As can be seen in Figure 2.2, the notable acceleration and corresponding deceleration of male PhDs coincides completely with the evolution of the Vietnam War. Growth hinged upward around 1964, peaked in 1971 (virtually tripling the output of 1964), and declined sharply in the latter half of the 1970s and first half of the 1980s. Why the peak in 1971? The answer: widespread deferments for male graduate students were terminated by the Selective Service System in 1967. The reverberations of this policy shift are clearly reflected in the figure above—the decline in PhD production in 1971 corresponds to the shifting landscape of available deferments to male cohorts four years earlier.89

Figure 2.2: Ratio of awarded doctoral degrees to the civilian population (in thousands) aged 25–44 for the years 1950–1986. Source: Taken from Singer, “The Effect of the Vietnam War on Numbers of Medical School Applicants,” p. 571.

Interestingly enough, the end of widespread deferments for graduate students would lead to a boon for divinity and rabbinical schools—especially programs related to secular degrees. “After the end of graduate school deferments in 1967,” Baskir and Strauss wrote, “divinity schools became increasingly popular as draft shelters—especially those that did not require strict sectarian courses of study.” Baskir and Strauss continued: “some Jewish yeshivas were ideal; they offered a complete range of secular degrees, enabling students to study what they pleased while their draft boards believed they were preparing to be rabbis.”

As noted in the examples above, many males sought deferment through pathways intended by the Selective Service to benefit the nation’s interests. Others, however, would seek to avoid war through more drastic means—means unanticipated by the Selective Service System: many “‘channeled’ themselves in directions that were in neither the country’s interests nor their own.” Analyses of American natality during Vietnam, for example, found substantial effects of war avoidance and war avoidance behavior on U.S. birth rates. In 1966, over 15,000 births were attributed to war avoidance behavior and males seeking paternity deferments. In her study of paternity deferments and its impact on natality, Kutinova concluded:

The [estimated] magnitude of the effect of the Vietnam War paternity deferments on the decision to start a family…is quite substantial. In particular, the calculated conservative increase in the number of first births by 15,532 in June and August 1966 represents more than 7% of the total number of first deliveries in those 2 mo [sic]. It also corresponds to about 28% of the Selective Service System calls for

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91 Ibid., 29.
inductees in those months (The Selective Service System 1968). This finding adds to a growing body of evidence that government interventions may indeed affect individuals’ reproductive behavior. It also adds to the list of potentially long-lasting effects of the Vietnam War draft policies.92

Similarly, marriage became a common escape route for males hoping to avoid war. Like World War II, in the beginning years of Vietnam married men received deferments from combat. However, policies granting married men special draft deferment status were terminated on August 26, 1965 through Executive Order 11241. As reported in the New York Times: “The change in the draft exemption for married men was dictated by two factors…[the second being] indications that some young men were marrying to escape the draft” (emphasis added).93

**

The characteristics, constraints, dimensions, and boundary conditions of male participation in the above examples align, without exception, to explanations of channeling, deferment incentives, and war avoidance behaviors. The upward swell in participation at the start of war, and the return to equilibrium at war’s end demonstrate the sizable impact the Selective Service System’s policies had on males’ choices. Entire fields ballooned by tens of thousands in a matter of years, only to return to normalcy at war’s end. Coupled with aberrant patterns in U.S. natality rates and marriage trends at the start of war, each of the examples discussed in this section provide tangible and robust

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evidence of channeling on the course trajectory of young American males. It is through this foundation—channeling as a framework to interpret participation—that we now turn our attention directly to undergraduate biology.

IX.

Motivated by a National Science Foundation profile of the biological sciences—a profile which outlined a 44% decline in male participation in biology over a ten-year span versus a 1% decline in female participation over the same time period—we began the present essay with a question: why did male participation in the biological sciences decline suddenly and abruptly from 1976 to 1986? We now know this question to be incomplete. For the aberrant pattern of biology was not merely the decline in male participation in the decade spanning the 1970s and 1980s, but rather the sharp increase in participation around 1964 (16,321 male bachelor’s degrees), the peak in participation in 1976 (35,520 male bachelor’s degrees; notably, this cohort of graduates corresponds to the incoming class of 1972—the last incoming class of undergraduates to face the threat of conscription: on January 27, 1973 the Selective Service System announced there would be no more draft calls), and what we realize to be the return to normalcy in the ensuing years after war’s end (20,058 bachelor’s degrees in 1984) (see Figure 2.3).

Through the lens of all that we now know, channeling and deferment as explanatory frameworks of participation provide robust inroads for understanding these trends within the discipline. Like other deferment-related pathways, the biological sciences became a popular sanctuary for males avoiding the Vietnam War. And the growing relationship between postgraduate health fields and biology ensured the incentivized participation of
males in the undergraduate field throughout the war.

Figure 2.3: Biological/Biomedical bachelor's degrees by gender, years 1970-2011, with years 1970-1986 highlighted. Source: Digest of Education Statistics 2012, pp. 496.

While widespread deferments were available to graduate students until 1967, deferments for students pursuing graduate health programs continued until the early 1970s. Stated by Singer:

[I]n 1965, the monthly draft requirements doubled because additional troops were needed in Vietnam. Previous manpower surpluses suddenly turned into shortages, and student deferment policies were tightened…

Further tightening continued in 1967. Additional constraints were placed on undergraduate and graduate students, but students in medical, dental, veterinary, osteopathy, and optometry schools were deferred upon evidence of
satisfactory progress. In 1968, postgraduate deferments were extended only to students in the health professions schools, although graduate students were usually allowed to finish an uncompleted semester if drafted during the school year.94

The impact of this policy shift for graduate students, and the continuation of deferments for health fields led to the very predictable, and very large swell of male interest for postgraduate health programs. In 1967, 18,724 applicants (16,773 male applicants) sought entrance into United States medical schools.95 Only seven years later, by 1974, the applicant pool skyrocketed to 42,624 (33,912 male applicants)—a 127 percent increase overall, and a 102 percent increase for male applicants. And, consistent with channeling, these huge gains would be erased in the next decade—male applications to medical schools decreased every year from 1974 to 1988, except for the lone exception of 1983.

Further, analysis of MCAT examination statistics provide direct evidence of the growing link between medical school deferments and undergraduate biology participation. In a series of yearly datagrams published in Academic Medicine, between 1971 and 1974,97 as well as in 1968,98 MCAT examination statistics reported at the aggregate level, by gender, and by undergraduate major demonstrate the close, parallel relationship between the two fields of study. As displayed in Table 2.1, of the almost 19,000 examinees who took the Medical College Admission Test (MCAT) in 1965—90

94 Singer, "The Effect of the Vietnam War on Numbers of Medical School Applicants," 569.
percent of which were male—43 percent of the total examinee population majored in biology. These statistics correspond to 17,030 male examinees, and an estimated 7,320 male examinees majoring in undergraduate biology. Ten years later, in 1974, the number of students taking the MCAT examination swelled to over 58,000 examinees—76 percent of whom were male—with 54 percent of the total examinee population majoring in undergraduate biology. If we assume a consistent ratio between the proportion of male and female undergraduate biology majors throughout the decade—a not too impractical assumption—the 1974 statistics approximate to roughly 23,900 male biology majors. In other words, in a ten year period, we can estimate an over 220 percent increase of male undergraduate biology majors taking the MCATs—an incredibly high upward shift in a very short period of time. These numbers demonstrate the skyrocketing popularity of both pathways during the Vietnam War, and the growing relationship between the two realms. The 117 percent increase of biology degrees awarded to males from 1964 to 1976, and the approximate 220+ percent increase of male biology majors taking the MCAT exam from 1965 to 1974 provide evidence of the growing relationship between the two options, and the influence of channeling and deferment on male participation.
Table 2.1: Select characteristics of MCAT examinees, 1962-1975

<table>
<thead>
<tr>
<th>Year</th>
<th>Total MCAT Examinees</th>
<th>Percent Male</th>
<th>Percent Undergraduate Biology</th>
<th>Estimated Male Examinees</th>
<th>Estimated Male Biology</th>
</tr>
</thead>
<tbody>
<tr>
<td>1962</td>
<td>17,270</td>
<td>–</td>
<td>36%</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1963</td>
<td>19,323</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1964</td>
<td>18,966</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>1965</td>
<td>18,922</td>
<td>90%</td>
<td>43%</td>
<td>17,030</td>
<td>7,323</td>
</tr>
<tr>
<td>1966</td>
<td>19,705</td>
<td>89%</td>
<td>45%</td>
<td>17,537</td>
<td>7,892</td>
</tr>
<tr>
<td>1967</td>
<td>22,288</td>
<td>89%</td>
<td>46%</td>
<td>19,836</td>
<td>9,125</td>
</tr>
<tr>
<td>1968</td>
<td>26,539</td>
<td>89%</td>
<td>48%</td>
<td>23,620</td>
<td>11,337</td>
</tr>
<tr>
<td>1969</td>
<td>28,880</td>
<td>88%</td>
<td>48%</td>
<td>25,414</td>
<td>12,199</td>
</tr>
<tr>
<td>1970</td>
<td>33,869</td>
<td>86%</td>
<td>49%</td>
<td>29,127</td>
<td>14,272</td>
</tr>
<tr>
<td>1971</td>
<td>45,324</td>
<td>84%</td>
<td>48%</td>
<td>38,072</td>
<td>18,275</td>
</tr>
<tr>
<td>1972</td>
<td>51,695</td>
<td>82%</td>
<td>48%</td>
<td>42,390</td>
<td>20,347</td>
</tr>
<tr>
<td>1973</td>
<td>55,017</td>
<td>79%</td>
<td>52%</td>
<td>43,463</td>
<td>22,601</td>
</tr>
<tr>
<td>1974</td>
<td>58,219</td>
<td>76%</td>
<td>54%</td>
<td>44,246</td>
<td>23,893</td>
</tr>
<tr>
<td>1975</td>
<td>57,552</td>
<td>74%</td>
<td>56%</td>
<td>42,588</td>
<td>23,850</td>
</tr>
</tbody>
</table>


The growing relationship between the biological sciences and postgraduate health fields, spurred by channeling; rooted in cultural, social, and political influences; accounts for the dramatic, and now-realized inorganic trends within the undergraduate field. Like the examples in the previous section, the upward swell in participation in the biological sciences at the start of war, spurred by the continuation of deferments related to postgraduate health fields, demonstrate the sizable impact the Selective Service System’s

policies had on males’ choices. As deferment policies evolved throughout the duration of war, the persistence of deferments for males in postgraduate health fields drove enrollment in undergraduate biology. At war’s end, the removal of conscription and deferment incentives led to another period of transition—the return to normalcy.

**

We started this essay seeking an explanation. By itself, the one-sidedness and abrupt decline of undergraduate males from the biological sciences was notable and in need of further understanding. In addition, the outcome of the decline—the reaching of male and female parity in an undergraduate STEM field—amplified the importance of the time period in question. To fully understand the context of the situation, we followed a decades-long chain of events—from World War II, to the Cold War, ending with Vietnam—and realized a narrative deep in history, but simple in intuitiveness. We learned of institutional forces rooted in national interests and prosperity, born from a world in transition, and put forth by policies stretching the limits of American ideology. We learned of channeling, an explicit function of the Selective Service System’s mission during Vietnam which incentivized males toward select pathways. And we learned to avoid war, many men were willing to accept the government’s offers and take refuge in a variety of deferment-related areas, birthing into existence anomalous participation patterns. During Vietnam, entire fields of study swelled by tens of thousands of young men, only to return to decline dramatically at war’s end. Male trends in undergraduate education, male trends in medical and PhD programs, and male trends in undergraduate biology were very prominent examples. In other words, in the 1960s and 1970s, the
history of male trends in the biological sciences and the history of American draft system
during Vietnam were one and the same.
I.

Following the steep decline of males from undergraduate biology in the late 1970s and 1980s, and the steady—but plateaued—production of female baccalaureates over the same time period, bachelor’s degree trends in the biological sciences—for both genders—exploded in the 1990s.¹ To say participation boomeranged would be an understatement—over a ten-year span beginning in 1989, biology became the fastest growing undergraduate field in the country. Both numerically and by percent growth, the biological sciences outpaced and outgrew every other major undergraduate category in the United States.² More men and women pursued bachelor’s degrees in the biological sciences than ever before, and except for a brief five-year period at the turn of the millennium, this explosive growth continues today. As reported in the most recent publication of the Digest of Education Statistics by the Department of Education, the number of bachelor’s degrees awarded in the biological sciences has grown 150 percent in just over twenty years—from 36,068 degrees in 1989, to 90,003 bachelor’s degrees in 2011.³

What follows in this chapter is an exploration of why—why the impressive and sudden shift in bachelor’s degrees in the biological sciences? Why, for a field which declined and stagnated throughout the 1980s, a boom and a rush a decade later. What event and/or series of events precipitated the sudden growth for females, and the

¹ In this chapter, I use the terms “biology” and “biological sciences” interchangeably to refer to the constellation of related majors identified by the National Center for Education Statistics as the “biological and biomedical sciences.” See Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 456-69.
² Ibid., 494-516.
³ Ibid., 496. Note: To put biology’s growth in perspective, consider its surge in comparison to undergraduate engineering. In 1989, engineering as a category awarded 86,000 bachelor’s degrees—almost 50,000 more degrees than the biological sciences. Today, that large difference is all but erased; in 2011, engineering conferred 93,117 bachelor’s degrees, while biology conferred 90,003 degrees—a present day difference of only 3,114 degrees.
resurgence for males? Simply put, what changed? This is the focus of the present essay—understanding the what and the why of biology’s turnaround in the 1990s.

![Figure 3.1: Biological/Biomedical bachelor's degrees by gender, years 1970-2011. Source: Digest of Education Statistics 2012, pp. 496.](image)

**Looking at the Data**

Figure 3.1 shows the number of U.S. baccalaureates awarded in the biological sciences between the years 1970 and 2011. As can be clearly seen, following the Vietnam War era and the declining and stagnating trends of the 1980s, the number of baccalaureates awarded in biology began a fast upward period of acceleration. In fact, over a ten-year period, the biological sciences became the fastest growing undergraduate category in the country, jumping from 36,000 degrees in 1989 (18,022 degrees to females, and 17,935 degrees to males) to over 65,000 degrees in 1998 (36,072 degrees for
females, and 29,511 degrees for males). In terms of percentages, biology baccalaureates increased from 3.5 percent of total undergraduate degrees in 1989 to 5.5 percent of total bachelor’s degrees in 1998—female baccalaureates increased from 3.4 percent to 5.5 percent of total female bachelor’s degrees, while male degrees increased from 3.7 to 5.7 percent of total male degrees (see Figure 3.2).⁴

![Graph showing percentage of bachelor's degrees earned in the biological sciences by gender, years 1980-2011.](image)

Figure 3.2: Percentage of bachelor's degrees earned in the biological sciences by gender, years 1980-2011. Source: Digest of Education Statistics 2012, p. 448 & p. 496.

In comparison to other majors, biology’s baccalaureate growth exceeded all other undergraduate categories. As displayed in Table 3.1, between 1989 and 1998 its 83 percent growth surpassed trends in psychology (51 percent increase in bachelor's degrees), the visual and performing arts (36 percent increase), the umbrella of social science majors (16 percent increase), as well as every other STEM category in American

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⁴ Ibid., 494-516.
higher education—biology trends dwarfed those in the physical sciences (13 percent growth), computer science (-9 percent growth), engineering (-13 percent growth), and mathematics (-17 percent growth). And apart from a five-year hiccup between 1999 and 2004, biology's growth continues to this day. In the past years, biology—again—outpaced almost all other undergraduate major categories. Between 2004 and 2011, the number of bachelor’s degrees awarded in biology swelled to all-time record highs, from 62,624 degrees in 2004 to 90,003 degrees in 2011, a growth rate of 44 percent—second only to the health professions.5

### Table 3.1: Baccalaureate snapshots, years 1989 and 1998

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Biology</td>
<td>36,068</td>
<td>65,917</td>
<td>29,849</td>
<td>83%</td>
</tr>
<tr>
<td>Health Prof</td>
<td>59,850</td>
<td>86,843</td>
<td>26,993</td>
<td>45%</td>
</tr>
<tr>
<td>Psychology</td>
<td>49,083</td>
<td>74,107</td>
<td>25,024</td>
<td>51%</td>
</tr>
<tr>
<td>Social Sciences</td>
<td>108,157</td>
<td>125,010</td>
<td>16,853</td>
<td>16%</td>
</tr>
<tr>
<td>Visual/Perf. Arts</td>
<td>38,420</td>
<td>52,077</td>
<td>13,657</td>
<td>36%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>13,492</td>
<td>23,276</td>
<td>9,784</td>
<td>73%</td>
</tr>
<tr>
<td>Education</td>
<td>96,740</td>
<td>105,833</td>
<td>9,093</td>
<td>9%</td>
</tr>
<tr>
<td>Public Admin</td>
<td>13,162</td>
<td>20,649</td>
<td>7,487</td>
<td>57%</td>
</tr>
<tr>
<td>English</td>
<td>41,786</td>
<td>49,016</td>
<td>7,230</td>
<td>17%</td>
</tr>
<tr>
<td>Foreign Language</td>
<td>12,403</td>
<td>15,279</td>
<td>2,876</td>
<td>23%</td>
</tr>
<tr>
<td>Physical Sciences</td>
<td>17,179</td>
<td>19,454</td>
<td>2,275</td>
<td>13%</td>
</tr>
<tr>
<td>Communications</td>
<td>48,889</td>
<td>50,263</td>
<td>1,374</td>
<td>3%</td>
</tr>
<tr>
<td>Architecture</td>
<td>9,150</td>
<td>7,652</td>
<td>-1,498</td>
<td>-16%</td>
</tr>
<tr>
<td>Math</td>
<td>15,017</td>
<td>12,401</td>
<td>-2,616</td>
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<tr>
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<td>27,829</td>
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<tr>
<td>Engineering</td>
<td>85,982</td>
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<td>-13%</td>
</tr>
<tr>
<td>Business</td>
<td>246,262</td>
<td>232,079</td>
<td>-14,183</td>
<td>-6%</td>
</tr>
</tbody>
</table>


**Female Baccalaureate Trends**

The phenomenal growth of the biological sciences can also be easily seen through

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5 Ibid.
examination of female trends in select undergraduate STEM areas. In 1986, the number of bachelor’s degrees earned by women in biology, engineering, and computer science were not dissimilar. In fact, from a contemporary perspective, the number of female graduates in each field is surprisingly comparable. In 1986, of the more than 46,000 baccalaureates earned by women in these three fields combined, four out of every ten were earned in biology, while three of every ten degrees were earned in computer science and engineering, respectively. In terms of raw numbers, these percentages translate to 18,370 female baccalaureates in the biological sciences, 15,129 bachelor’s degrees in computer science, and 13,072 bachelor’s degrees in engineering in 1986. As displayed in Figure 3.3, the 5,298-degree difference overall between degrees earned by women in the three fields now pales in comparison to contemporary figures. In the most recent data, female bachelor’s degrees in biology now number over 53,000 degrees—53,111 degrees (a 189 percent increase since 1986). Female bachelor’s degrees in engineering and computer science, however, remain around or below their 1986 numbers—in 2011, 16,017 bachelor’s degrees were awarded to women in engineering, and 7,594 bachelor’s degrees were awarded in computer science. In other words, of the 76,722 baccalaureates earned by women in the three fields combined, seven out of every ten degrees were earned in the biological sciences.6

Unlike the previous chapter which hinged on institutional and governmental policies incentivizing males toward the biological sciences, and the sudden and drastic decline from the major at war’s end, the narrative of this present essay will not be as tidy as the impact and repercussions of a policymaker’s signature or lack thereof. Rather, we will learn of an undergraduate field consubstantial with the ebbs and flows of an

6 Ibid. See Tables 345, 349, & 351.
emerging industry. We will discover a newfound atmosphere surrounding the biological sciences, a newfound context for the field sparked by the excitement and profitability inherent in the promises of its new technologies. We will discover a transition in the field from academic endeavor and the pursuit of basic research to intellectual property protection and commercial sector. And we will learn of business models and growing pains, booms and busts, venture capitalists and IPOs, and the allure of tremendous profit coupled with social utility.

Figure 3.3: Female baccalaureate trends in the biological sciences, engineering, and computer science, years 1986-2011. *Source: Digest of Education Statistics 2012, p. 496, p. 500, and 502.*

In this essay, we will follow biology’s rise at the end of the twentieth century—as an applied science and technology base, as well as an undergraduate major. From decline and stagnation in the 1980s to its modern-day popularity, we will explore the what and the why of undergraduate biology’s turnaround. That is, we will come to understand the
trajectory and progression of genetic engineering and biotechnology.

II.

By now the story is well known. In November 1973, the Cohen/Boyer group of Stanford and UC San Francisco, respectively, published the paper “Construction of Biologically Functional Bacterial Plasmids In Vitro.” For the first time, their paper outlined a “universally effective method for making recombinant DNA”—a milestone for a field only in its fourth decade. Thirty-five years earlier the neologism ‘molecular biology’ was coined by mathematician Warren Weaver in his role as Rockefeller Foundation Director of the Division of Natural Sciences. What was then used to label newfound applications of physics and chemistry techniques to experimental biology would soon evolve into the search of life’s underlying template. To that point, the significance of deoxyribonucleic acid—that is, DNA—remained unrealized. First discovered by Friedrich Miescher in 1869, the full importance of the molecule as the basis of life wasn’t fully discovered until the 1940s and 1950s. It had been prior postulated DNA to be monotonous, to be a reformulation of more elementary units; Nobel Prize awardee Max Delbrück once baptized this fundamental molecule as

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12 Morange, A History of Molecular Biology, 34.
“stupid.”13 Long thought too simple to be of any importance, DNA was overlooked in favor of proteins as the basic building blocks of genetics.14 Fifteen years and a paradigm shift later, DNA emerged as the “key to the code of life,”15 rescuing genetics from misdirected hypotheses long the forerunner of thought.16

In 1944, Oswald Avery and associates, in what is now an asterisked experiment, successfully identified DNA to be the hereditary material of life.17 Asterisked not because of wrongdoing or mistaken outcomes, but because their results were ahead of their time, too novel for a young discipline stuck in yesterday’s paradigm. For the first time, Avery et al. provided “rigorous proof that the gene is DNA and not protein”18—that DNA is the sole “carrier of genetic information”19—a landmark finding in hindsight, but an under-appreciated discovery in the immediate years to come. As written by Professor and Molecular Biologist Gunther Stent, six years after its initial publication contemporary geneticists still overlooked the importance of Avery and his associates:

A convincing demonstration of the lack of appreciation of Avery's discovery is provided by the 1950 golden jubilee of genetics symposium ‘Genetics in the 20th Century.’ In the proceedings of that symposium some of the most eminent geneticists published essays that surveyed the progress of the first 50 years of

14 Choudhuri, "The Path from Nuclein to Human Genome: A Brief History of DNA with a Note on Human Genome Sequencing and Its Impact on Future Research in Biology," 361.

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genetics and assessed its status at that time. Only one of the 26 essayists saw fit to make more than a passing reference to Avery's discovery, then six years old.  

In the decades to follow, history books have since recognized Avery’s seminal contributions to the field of genetics. He is a scientist “whom Nobel officials publicly regret having excluded from the Nobel roster”  

Avery’s discovery in 1944 of DNA as carrier of heredity,” the Nobel Foundation stated, “represents one of the most important achievements in genetics, and it is to be regretted that he did not receive the Nobel Prize.” Eminent biologist, Erwin Chargaff, similarly added, “the great names in the biology of the last hundred years are Darwin, Mendel, and Avery.”  

In 1952, Alfred Hershey and Martha Chase’s famous transduction experiment confirmed Avery et al.’s findings, and a field now thirsty for revolution jumped on the DNA bandwagon. “The general impact of the Hershey-Chase experiment was immediate and dramatic,” Gunther Stent would write. “DNA was suddenly in and protein was out, as far as thinking about the nature of the gene was concerned.” While generally considered empirically weaker than the results of Avery and associates, Hershey and Chase were credited as fore figures of molecular biology, with Hershey being awarded a share of the Nobel Prize in 1969.

In 1953, a year after Hershey and Chase’s experiment, Watson and Crick’s

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25 Stent, "Prematurity and Uniqueness in Scientific Discovery," 86.
discovery of the underlying structure of DNA—the now famous three-dimensional twisted ladder configuration of the double helix—ignited the ‘DNA revolution,’ and marked the official start of molecular biology as now known. In years to come, the discovery would be heralded as “genius,”27 “the defining scientific icon of the age,” and “the most celebrated scientific discovery of the twentieth century.”28 At that time, the immediate importance of the achievement was not lost on either scientist. To the then 23-year-old James Watson, Crick’s immediate and boisterous elation of their accomplishment would result in discomfort and squeamishness: “I felt slightly queasy when at lunch Francis winged into the Eagle [pub] to tell everyone within hearing distance that we had found the secret of life.”29 To that point, the mechanism of heredity and inheritance remained an unknown—that is, how DNA transferred information; “how genes replicated themselves and transmitted information from parents to offspring.”30 Watson and Crick’s discovery of the double helix so elegantly answered these questions, and more. Their model “made understandable, even to a child, how the genetic information…perpetuated throughout the generations by the pulling apart of the two strands and subsequent synthesis of complementary ones.”31 But the double helix also extrapolated the lineage of molecular biology and genetics back to the age of Darwin, providing even stronger roots and soaring wings for the mechanisms of evolution, variation, and mutation. “Darwin knocked mankind off his pinnacle,” geneticist Steve Jones once wrote. “DNA grinds his face into the biological mud.”32

28 Davies, Cracking the Genome: Inside the Race to Unlock Human DNA, 2. 
30 Ibid., ix. 
31 Hausmann, To Grasp the Essence of Life: A History of Molecular Biology, 90. 
32 Watson, The Double Helix: A Personal Account of the Discovery of the Structure of DNA, xii.
In 1962 Watson and Crick won the Nobel Prize for their work, and the double helix—whose image first appeared in the duo’s 1953 *Nature* article—has since become “the most reproduced image from any science at any period.” The “Mona Lisa of modern science,” its discovery has been called “one of the greatest moments in the history of science and humanity.” Editorialized by renowned evolutionary biologist Ernst Mayr in his seminal 1982 book, *The Growth of Biological Thought*:

The discovery of the double helix of DNA and of its code was a breakthrough of the first order. It clarified once and for all some of the most confused areas of biology and led to the posing of clear-cut new questions, some of which are now along the current frontiers of biology.

The frontiers of biology Mayr notes above, as now recognized, bring us back to Cohen and Boyer. Twenty years after Watson and Crick’s landmark discovery, Stanley Cohen and Herb Boyer propelled molecular biology into a new era—beyond the confines of university laboratories and the academic pursuit of knowledge, to the fickle world of start-ups, venture capitalism, and the promise of commercial profit. Their path from basic research and laboratory work, to patented invention and intellectual property protection, to Boyer’s commercial pursuits and the founding of Genentech—“a first generation biotechnology company”—became a prototype, a model, a springboard for others to

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36 *Christ to Coke: How Image Becomes Icon*, 279.
38 It would be inappropriate to ignore the substantial contributions of Rosalind Franklin in this short history. The author encourages readers unaware of her story to explore her work and learn of the profound impact her research has had in the identification of the underlying structure of DNA.
follow. And boy did they ever. A watershed in the history of the field, as captured by science historian Sally Smith Hughes, Cohen and Boyer’s path, and the founding of Genentech “inspired a new industrial sector, transforming the biomedical and commercial landscapes ever after.”

III.

Biotechnology was born in California, but it was conceived in Waikiki. There, famously, while attending a conference on the island, Cohen and Boyer first discussed the prospects of merging their research. A handshake in a Hawaiian deli sealed the deal, and in January 1973, their collaboration began in earnest at their universities in the San Francisco Bay Area. By mid-year—a shockingly brief amount of time for such ventures—Cohen and Boyer successfully completed “one of the most influential sets of experiments in biology.” Editorialized by Jeremy Rifkin, the duo had “performed a feat in the world of living matter that some biotech analysts believe rivals the importance of harnessing fire.”

What Cohen and Boyer accomplished was the development of a pioneering technique for synthetically cloning DNA in a laboratory—a process which has since been called “arguably the defining technique of modern molecular biology.” Using a genetic version of cut-and-paste, Cohen and Boyer invented a process in which foreign DNA

could artificially be implanted into bacteria and replicated. Bacteria are popular biology laboratory components due to the simplicity of their makeup and rapid reproductive processes. Nicely summarized by *Time* magazine in a cover story on Boyer: “During normal bacterial reproduction, the cell simply divides, passing exactly the same genetic information on to each daughter cell. Thus they are natural clones, genetically identical to their single parent.”45

Harnessing bacteria’s natural replication processes, Cohen and Boyer—using plasmids as biological vehicles—essentially invented genetic engineering’s version of a photocopier. They injected foreign DNA (in their case, from a toad) into bacteria; the altered bacteria—now acting essentially as man-made host cells but retaining their natural replication capabilities—reproduced, creating exact identical clones of the integrated bacteria/toad composite. Outlined in *Time*:

As the bacteria replicated, the transplanted DNA [were] copied down to the last step on the spiral staircase. Any product ordered up by the inserted genes—the antiviral agent interferon, for instance, or perhaps an enzyme to break down oil molecules—[could] also be made in the offspring. And in abundance: dividing once every 20 minutes, the original bacterium would undergo a population explosion. In 24 hours, a single bug could result in billions of bugs, all of them churning out the desired product.46

Characterized in the acclaimed 1998 book, *The Biotech Century*, Cohen and Boyer’s pioneering technique for synthetically cloning genes remains one of the “most

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46 Ibid., 59.
dramatic technological tool[s] to date in the growing biotechnological arsenal.” Their invention of a “simple and efficient method for selecting specific genes from any imaginable organism and accurately reproducing the genetic material in pure and unlimited quantity” would, as described in Nature, “rock[] the world of science,” and form the basis of genetic engineering and the biotechnology industry as now known. “That moment was elation,” Cohen would state. For Boyer, the outcome would bring tears to his eyes:

The [DNA] bands were lined up [on the gel] and you could just look at them and you knew…[that DNA recombination and cloning] had been successful….I was just ecstatic….I remember going home and showing a photograph [of the gel] to my wife….You know, I looked at that thing until early in the morning….When I saw it…I knew that you could do just about anything….I was really moved by it. I had tears welling up in my eyes because it was sort of a cloudy vision of what was to come.

What was to come was the commercial future of molecular biology. Cohen and Boyer’s experiments established the feasibility of mass-producing synthetic DNA and other biological products, and the commercial potential of such technologies became immediately obvious. Reported in a May 1974 New York Times article, applications to medicine and agriculture were abound. Molecular biologist and Nobel Laureate Joshua Lederberg would state of Cohen and Boyer’s work: “It may completely change the

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47 Rifkin, The Biotech Century, 12.
49 Genentech: The Beginnings of Biotech, 16.
50 Ibid.
pharmaceutical industry’s approach to making biological elements such as insulin and antibiotics.”53 Opportunities in agriculture were similarly prevalent—he headlines such as “Biotechnology Boom Reaches Agriculture” in Science and “Agriculture and Supply Attract Biotech Start-Ups” in Nature’s biotechnology subsidiary, Bio/Technology (now titled Nature Biotechnology) littered the field in the years to come.54

As a result, in November 1974, one year after initial publication of their first experiment, Stanford University and the University of California—with Cohen and Boyer listed as inventors—filed an application to the United States Patent and Trademark Office to patent the duo’s pioneering techniques. Now known as recombinant DNA technology, what was initially envisioned by both universities to be a routine patent process evolved into a six-year stalemate. Caught between a patent system unprepared for a new world of scientific advancements and a landmark Supreme Court decision eight years in the making, Cohen and Boyer’s application remained in limbo until December 1980. Only then, after a years-long debate regarding the scope and limitations of what exactly is and is not patentable (e.g., living organisms)—and the potential implications for future society should its scope broaden—would Cohen, Boyer and their universities discover their patent fate. Scientific history had been made, but the outcome of a new crop of patent applications—born from advancements in genetic engineering only previously imagined in fantasy novels and science fiction movies—would prove far greater to future industry, society-at-large, and the American economy.

IV.

After 1974, Cohen and Boyer’s collaboration ended and their paths diverged. Cohen dabbled in commercial pursuits to a degree, but his life’s work remained academic. He remains at Stanford University to this day. Boyer, on the other hand, capitalized on the commercial profit of his and Cohen’s recombinant DNA techniques. In the years to come, biotechnology became a darling of Wall Street, and Boyer’s commercial pursuits a major player in its growth. Foreshadowing the excitement surrounding biology and biotechnology in the next decades, Boyer in many ways modeled a new path for future and budding biologists—a path pregnant with opportunities for tremendous profit and even greater social utility—that is, the profit of scientific discovery, the allure of the “millionaire-scientist,” and the promise of healing mankind’s greatest ills.

In April 1976, with venture capitalist Bob Swanson, Herb Boyer co-founded Genentech. Constructed in scope and in name upon the promise of genetic engineering technologies, Genentech became the first of many companies seeking to capitalize on the promise of biology’s recent advancements. Boyer had previously considered the commercial applications of recombinant DNA while working with Cohen, but lacked the business and financial acumen to progress forward and take action: “I had these little seeds of thought, fantasy more than anything. But I had no idea how you would start a

55 Hughes, *Genentech: The Beginnings of Biotech*.
56 See Krimsky, “The Profit of Scientific Discovery and Its Normative Implications.”
57 Detailed by Sally Smith Hughes, Genentech is “a contraction of genetic engineering technology” and, she continued, "a vast improvement over Swanson’s improbably suggestion of ‘HerBob.’" See Hughes, *Genentech: The Beginnings of Biotech*, 41.
company and where you would go, what you would do.\textsuperscript{59} Then entered Bob Swanson. All of 28-years old, he too sought action in the fantasy of biotechnology. Laid off months earlier by venture capital partnership, Kleiner & Perkins, Swanson cold-called Boyer. A ten-minute meeting became an hours-long conversation, and with $500 apiece for legal fees, beers in a tavern turned into a partnership. Using Cohen and Boyer’s recombinant DNA techniques, the two set their sights on the hormone insulin as the company’s initial focus.\textsuperscript{60} Its prevalence in pharmaceutical applications and the existence of an established patient base, coupled with opportunities for improvement over existing insulin sources made the hormone an ideal first candidate. Outlined by Sally Smith Hughes:

Used in diabetes treatment since the 1920s, the hormone [insulin] extracted from pigs and cows was an essential staple of medical practice, yet on occasion caused allergic reactions in human recipients. The thinking was that human insulin, as a natural product of the human body, would not present such problems.\textsuperscript{61}

Two and a half years later, in a September 1978 press conference, Swanson, Boyer and their now small team announced to the world their insulin results. For the first time in history, synthetic human insulin had been manufactured in a laboratory. Reported in Science News:

Human insulin has been produced at last by genetically engineered bacteria in a California laboratory—an achievement that catapults recombinant DNA technology into the major leagues of the drug industry. Immediately following the report of the research success, Eli Lilly and Co. announced an agreement with Genentech, Inc., a two-year-old research firm in San Francisco that sponsored and

\textsuperscript{59} Genentech: The Beginnings of Biotech, 36.
\textsuperscript{60} For further discussion, see ibid., 29-48.
\textsuperscript{61} Ibid., 37.
participated in the research. Lilly is the major supplier of animal insulin now taken daily by about a million diabetics.\textsuperscript{62} Genentech would claim their laboratory results to be the “most significant advance in diabetes treatment since the use of animal insulin began in 1920.”\textsuperscript{63} More importantly, the use of recombinant DNA to leapfrog existing therapies, as noted above, helped cement biotechnology’s place as a major player in the future of pharmaceuticals. Support for recombinant DNA in terms of government funding had greatly accelerated, and Genentech's results added further credibility to the technology's lofty promise of new cures and therapies to biology’s most unsympathetic disorders.\textsuperscript{64} Described by Hughes:

The firm’s stunning synthesis of a major drug and its pathbreaking partnership with Lilly riveted the pharmaceutical sector’s attention. As \textit{Science News} asserted, achieving human insulin “catapults recombinant DNA technology into the major leagues of the drug industry.”\textsuperscript{65}

“Biotechnology—both as a scientific art and commercial entity” a U.S. Congress Office of Technology Assessment (OTA) report stated, “has…resulted in research and development (R&D) that may lead to commercialization of products that can dramatically improve human and animal health, the food supply, and the quality of the environment.”\textsuperscript{66} Put even more simply by OTA in a related report, “Biotechnology can change the way we live.”\textsuperscript{67}

The era of biotechnology had arrived, and with it a new industry hoping to

\textsuperscript{63} Ibid., 196.
\textsuperscript{64} \textit{Genentech: The Beginnings of Biotech}, 104-05.
\textsuperscript{65} Ibid., 105.
capitalize on the frontiers of scientific discovery. But perhaps equally important to this particular story, for those involved the money was *extraordinary*. By 1981, compared to his salary as a professor, Boyer became the poster child of the millionaire-scientist dream:

Five years after Boyer became involved with Genentech, his personal stock in the company was valued at about $40 million in a volatile biotech securities market. His university salary at the time was $50,000. The lure of rapid financial success ran through the field of biology like an infectious virus.  

To put these figures in perspective, adjusting for inflation in 2015 dollars, Boyer’s salary jumped from $130,000 to just over $104 million.  

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Only twenty short years after Watson and Crick, the frontiers of biotechnology were discovered, and the fruits of all its treasures seemingly reachable. El Dorado, Camelot, Atlantis—biology’s search for life’s holy grail began in earnest in the 1970s and 1980s, and the excitement and growing pains of an industry still in its adolescent years permeated society. In the next years, Wall Street became as important to the field’s trajectory as the classroom and laboratory. And the allure of both profit and social utility attracted droves of undergraduates—male and female—in the 1990s. In the ten years between 1989 and 1998, biology became the fastest growing major in the country, a stark departure from the previous decade’s stagnation and decline.

What changed? The prospects and appeal of biology changed. From commercially

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ho hum to commercially remarkable, it is the resultant excitement surrounding the field’s revolution which set the stage for biology’s next act. In only ten years, the combination of technological advancements, coupled with key policy reformations, spurred a rush to the biology bandwagon. The influx of money, the birth of a new industry—it is this context and the trickling down to undergraduate choices which informs the sudden surge in degree trends starting in 1989. In the next section, we will learn of technology outpacing regulations, and regulatory bodies playing catch-up to inventions unforeseen. We will learn of a landmark Supreme Court decision, and a resultant shift in patent policies of the United States Patent and Trademark Office. Combined, these events fully opened the doors to molecular biology’s commercial viability. And we will learn of a cyclic bubble, glistening with promise, and its eventual burst—a pattern which would foreshadow the ups and downs of the industry in the years to come.

V.

Cohen and Boyer first published their results in 1973, Genentech was founded in 1976, but the true awakening of biotechnology didn’t truly occur until June 1980. That year, in a landmark 5-4 ruling eight years in the making, the Supreme Court paved the way for industry to fully capitalize on genetic engineering’s rapid ascension and its promise of tremendous profit. To that point in United States history, virtually all patents awarded by the United States Patent and Trademark Office were for inventions related to physical machines and/or technologies and/or utilities: nicely summarized by Gary Watson, up until 1980, “chemical, mechanical and electrical inventions comprised the
bulk of patented subjects.” But the Supreme Court’s landmark ruling in *Diamond v. Chakrabarty* added another piece to the portfolio of patentable entities—a departure from traditional entities for sure, and a harbinger of the future to come: that is, the patentability of *living organisms*. Immediately recognized as an inflection point in U.S. patent law, and the commercial hinge point for genetic engineering and biotechnology as both are now known, the outcome of *Diamond v. Chakrabarty* marked the unofficial start of molecular biology’s industrial surge.71

In 1972, Ananda Chakrabarty—a young General Electric scientist in Schenectady, NY—filed a patent application related to his invention “of genetically engineered bacteria capable of breaking down multiple components of crude oil.”72 As summarized by the *American Business Law Journal*, Chakrabarty invented “a new bacterium with markedly different characteristics from any found in nature.”73 The environmental and economic promise of his new bacterium was vast.74 Five years earlier, the SS Torrey Canyon, the now infamous supertanker carrying 120,000 tons of crude oil, ran aground off the coast of South West England, spilling black oil into the Atlantic Ocean. The spill—the first instance for a supertanker of its class and size, and to that point in history, the worst in the history of the world—was labeled by the United Kingdom’s government and media as the country’s “greatest peacetime threat.”75 Managing the oil spill, quite literally, was an unprecedented task. A *New York Times* headline stated, “Risk of Oil

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Pollution in Sea is Baffling Problem” and “Industry Unprepared to Deal With Contamination Problem Hazard in Big-Tanker Disasters.” 76 A combination of chemical “detergents” and combustible materials including, as reported in Life magazine, “161,000 pounds of explosives, 16 rockets, 3,200 gallons of napalm and 9,800 gallons of kerosene” were used to combat the leakage. 77 The methods were expensive and ineffective, and management of the spill an unsatisfactory and daunting task—science historian Daniel Kevles would later state, “the world had no truly effective technology to accomplish the [clean up].” 78

Enter Chakrabarty’s bacterium. Building upon his postdoctoral work at the University of Illinois where he investigated various microbes capable of biodegrading organic materials, at General Electric Chakrabarty developed a strain of bacteria able to digest and degrade crude oil and Bunker C oil (Bunker C oil is “the thick, sticky residuum left after the removal from the crude of its commercially valuable part”). 79 He accomplished this by combining DNA material from four bacteria strains into one: as he stated in an interview in People magazine, “I simply shuffled genes, changing bacteria that already existed. It's like teaching your pet cat a few new tricks.” 80 The result would be a new, laboratory-made organism capable of digesting oil with an efficiency unmatched by other existing microbial solutions, and more elegant than the small arsenal of weapons used in the Torrey Canyon spill.

Until that point in history, patent applications referring to organisms or living

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77 Jim Hicks, "The Oily Flotsam That Fouled Fair England" Life April 14, 1967.
79 Ibid., 116.
systems were rejected outright—it had become the “longstanding practice of the USPTO [U.S. Patent and Trademark Office]...to refuse claims to living systems as not being patentable subject matter.” With the notable exception of Louis Pasteur’s 1873 patent for the treatment of yeast in the making of beer, of the millions of patents awarded in U.S. history, patent applications for living organisms, both organic and inorganic, were considered products of nature and, therefore, considered not patentable. As a result, Chakrabarty and General Electric’s application to the USPTO for his oil-eating bacteria—filed in June 1972—was rejected by its examiner a year later. Appealing the decision on the grounds his oil-eating bacterium was “not a product of nature,” but rather “the product of a microbiologist,” over the next seven years Chakrabarty’s patent application worked its way through the appeals process and the court system. A protest brief filed by General Electric in 1974 was rejected by the Board of Patent Appeals and Interferences in 1976. General Electric again appealed the decision, this time to the federal United States Court of Customs and Patent Appeals which in 1978 sided with Chakrabarty, reversing both the Patent examiner and the Board of Patent Appeals’ decisions. The court “held that the fact that the micro-organism was alive was without legal significance for the purposes of patent law.” In turn, Sidney Diamond, the Commissioner of Patents and Trademarks, appealed the Court’s decision to the Supreme Court, where the case was reviewed on March 17, 1980.

For the young biotech industry, the outcome of the Supreme Court’s ruling in

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82 Hughes, Genentech: The Beginnings of Biotech, 148.
84 At the time, the board conceded Chakrabarty's bacterium to be a man-made invention, but re-affirmed living products as not patentable.
*Chakrabarty v. Diamond* would, in many ways, dictate its commercial future. If the Court ruled the fruits of its laboratories to not be patentable, and thus limiting intellectual protection for biotechnology’s advancements, the field’s profitability would be grossly muted. Should the Supreme Court rule in favor of Chakrabarty, and remove obstacles to the industry’s already accelerating commercial potential, the field’s momentum—coupled with Wall Street’s bullish excitement—could potentially surge the field to the highs of its romanticized heights.  

The USPTO, already backlogged by “114 patent applications [for] living organisms, with an estimated fifty applications added per year”—including Cohen and Boyer’s—had suspended review of patent claims for microorganisms until after the Court’s intervention; in many ways the future scope of biotechnology hinged on the case’s outcome. Summarized by Kevles, “an adverse ruling by the Supreme Court at that point would throw the biotechnology industry into turmoil.”

On June 16, 1980, the Supreme Court announced its decision—it had ruled 5-4 in favor of Chakrabarty. Aptly summarized by Krimsky—with a single vote the Court had “transformed the social and legal matrix within which science and the nascent biotechnology industry operated.” The Court ruled Chakrabarty’s bacterium to be a product of his “human ingenuity” and the discovery to be not “nature’s handiwork, but his own.”

In his decision, Chief Justice Warren wrote:

> In choosing such expansive terms as “manufacture” and “composition of matter,” modified by the comprehensive “any,” Congress contemplated that the patent laws should be given wide scope, and the relevant legislative history also supports

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a broad construction. While laws of nature, physical phenomena, and abstract ideas are not patentable, respondent's claim is not to a hitherto unknown natural phenomenon, but to a nonnaturally occurring manufacture or composition of matter—a product of human ingenuity “having a distinctive name, character [and] use.”

The following day, the ruling was A1 news in major newspapers throughout the country. *The New York Times* announced “Science May Patent New Forms of Life” and “Decision Assists Industry in Bioengineering in a Variety of Projects.” The *Washington Post* stated “Laboratory Life Forms Patentable” and “High Court Rules, 5-4, Genetic Work Protected by Law.” The *Los Angeles Times* added “Scientists May Patent Life Made in Lab, Justices Rule.” The *Kansas City Times* declared “Supreme Court decision could boost gene research” and “Industry and university researchers are predicting an upsurge in genetic engineering work….” The next day, on June 18, *The New York Times* reported: “U.S. to Process 100 Applications for Patents on Living Organisms.”

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The implications of the Supreme Court’s ruling would be long-lasting. The ruling provided the already accelerating biotech industry a strong and even more attractive foothold in future society. It became a lightning rod, an “agent in the transformation of molecular biology from a predominantly academic discipline to one with pervasive

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91 Ibid.
practical applications and industry connections. “By establishing property rights over discoveries in biology,” Sheldon Krimsky wrote, the courts and the U.S. Patent Office turned scientific knowledge into an invention, thereby creating new opportunities for scientists to acquire wealth, establishing new incentives for product development, and, downstream, adding to the costs of consumer goods and medical care.

In the years to come, this would mean big discoveries and even bigger money; more press conferences and higher-profile headlines; and an overall context and excitement for biology and health. The practical implications of which would be the carryover, the permeation, the effervescence of biotechnology’s darling status on Wall Street and in the media. Like biology’s popularity among young males during the Vietnam years, undergraduates in the 1990s chose to back the same proverbial horse but for an entirely different set of reasons. Cancer, AIDS, Heart Disease, but also the Human Genome Project, gene therapy, and Dolly—an inescapable narrative of the ‘80s and ‘90s was biotechnology, both the advancements of the science, as well as its promise to humankind’s future. “[The twentieth century] was the century of physics and chemistry,” Nobel Laureate and Chemist Robert Curl would declare. “But it is clear that the next century will be the century of biology.”

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VI.

Riding the wave of momentum from the Supreme Court's landmark ruling, Boyer and Swanson—after five years of operating Genentech via venture capital backing and private investments—took their company public. To say Wall Street was primed for the era of biotechnology would be a gross understatement. On October 14, 1980, the date of Genentech’s IPO—the first IPO ever for a modern biotech company—market history was made. Within its first minute of trading, Genentech’s stock price soared 130 percent—from $35 per share to $80 per share. Peaking just below $90, Genentech’s stock price settled to $71 per share by the end of the day. Summarized by historian Susan Wright, “overnight the company’s value increased from about $75 million to over $500 million, and the company’s founders, Swanson and Boyer, became millionaires.” In fact, Swanson and Boyer became multimillionaires thirty five times over. Now 32 and 44 years old respectively, after one day of public trading their combined shares of Genentech stock were worth over $140 million. Adjusting for inflation, in 2014 their shares of Genentech stock would value just over $400 million.

For investors, Genentech's day one performance was sheer pandemonium. The Wall Street Journal described its IPO as “one of the most spectacular market debuts in recent history”:

100 Hughes, Genentech: The Beginnings of Biotech, 158.
104 United States Department of Labor, "Inflation Calculator: Bureau of Labor Statistics".
this." Similarly echoed by a leading stockbroker to *The New York Times*, “Nothing like this has ever happened as long as I can remember. There's not enough to go round.”

Top tier science periodical *Science* reported “Gene Splicing Company Wows Wall Street” and “Investors' frenzy to buy into the new genetic technology caused a historic day on the market.” And *Time* magazine recapped the entirety of the phenomenal affair, from unheard of investment methodologies based on promise rather than past revenues—“Veteran traders had never seen such commotion over an embryonic company, which had only 140 employees, sold no product to the public and showed a profit for just one year, at a rate of 2¢ per share”—to the incredible upside of such investments and biotechnology's potential to revolutionize entire industries and society at large:

But what promises, what dazzling things to come—a new alchemy that may one day turn the basest of creatures into genetic gold…. In the future, it may produce vaccines against hepatitis and malaria; miracle products like low-calorie sugar; hardy self-fertilizing food crops that could usher in a new “green revolution”; fuels, plastics and other industrial chemicals, out of civilization's wastes; mining and refining processes to relieve Malthusian anxieties about a future without sufficient raw materials.

The Supreme Court's ruling in *Chakrabarty v. Diamond* opened the floodgates to biotechnology’s commercialization, and Genentech reaped the incredible benefits from the excitement surrounding the nascent market it helped create. In doing so, as lead

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106 Metz, "New Genentech Issue Trades Wildly as Investors Seek Latest High-Flier."
108 Wade, "Gene Splicing Company Wows Wall Street."
biotech investor Jim McCamant would write, it “galvanized venture capitalists, investment banks, and biotech scientists alike”\(^\text{110}\):

The dot-com phenomenon has since inured investors to this kind of opening-day activity, but in 1980 Genentech's performance was remarkable, setting a record for the largest first-day advance for an IPO. It was an unprecedented debut, one that sent the capital markets a memorable message: Investors were ready to buy into biotechnology companies, even ones that were years away from generating earnings.\(^\text{111}\)

The expectation for biotechnology and “genetic engineering [to become] the cornerstone of a future billion dollar industry” was widespread among investors.\(^\text{112}\)

Following Genentech’s success, in the months to come biotechnology’s initial wave of companies capitalized on the sector's first boom.\(^\text{113}\) In January 1981, Amgen—now a Fortune 500 company—raised $19 million in its first round of venture financing: Jim McCamant would comment, “a very large sum [of money] for an early round.”\(^\text{114}\) Two months later pioneering biotech firm Cetus went public. Its IPO “grossed $120 million”: $85 million more than Genentech, and “at the time the biggest industrial IPO in US corporate history.”\(^\text{115}\) Cetus's IPO, in fact, raised more capital than another booming industry’s then-rising star: “The size of the Cetus offering,” The New York Times reported, “broke a record set last October when Apple Computer, the manufacturer of

\(^{111}\) Ibid., 23.
\(^{114}\) Ibid.
home computers, raised $101.2 million in its initial stock offering.”

Two more biotechnology companies would go public in 1981, eight companies would go public in 1982, and twenty-two companies in 1983. As a whole, the industry was taking off, and its friendly relationship with Wall Street would become as instrumental to its success as the pioneering products it sought to produce—“If biotechnology was born by technological advances in genetic engineering,” biotech analyst Robert Kupor stated matter-of-factly, “Wall Street was its midwife.”

Kupor continued:

Wall Street is an indefatigable engine when it scents profits, and it worked with a vengeance during biotechnology’s gestational years of 1980 to 1986. The numbers speak for themselves. During the peak period of 1982 to 1986 alone, fifty-four biotechnology companies of all types ‘went public’ by selling $800 million of common stock to investors. During this same period, the more mature and more successful companies additionally consummated second and even third rounds of stock offering—thirty-four rounds in all, grossing $630 million. These more mature companies also raised approximately $400 million in research and development limited partnerships to fund individual products, as well approximately $200 million from bond issues. Simultaneously, another billion dollars of ‘venture capital’ funds flooded into new start-up firms, which hoped to go public in the future, in nearly 300 transactions. Overall, $300 billion was

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116 Cole, "Genentech, New Issue, up Sharply."
funneled into the industry during this five-year period alone.\textsuperscript{118}

In lockstep with such overwhelming market results and the industry’s seemingly limitless potential for future profit came a natural increase in hype and media attention. As biotechnology made way into the mainstream, coverage of the industry followed suit. In \textit{The New York Times}, for example, the number of biotechnology articles published during the 1980s increased cyclically throughout the decade.\textsuperscript{119} In 1981, at the start of its industrial growth, an article on the new and exciting science was published in the paper on average once every ten days. In 1984, despite biotechnology’s first market slump, \textit{The New York Times’} coverage of the field peaked again, and a new article was published on average once every seven days. In 1988, following yet another market boom in 1986-1987, the paper’s biotechnology coverage increased to its highest rate of the decade: in 1988 a new biotechnology article was published in \textit{The New York Times} every four days.\textsuperscript{120} A similar analysis of the \textit{Washington Post} found its coverage followed suit, increasing in frequency by 100 percent between the mid and the late-1980s\textsuperscript{121}—much of which focused on the technology’s most noteworthy and attractive components. Described by communications researchers Matthew Nisbet and Bruce Lewenstein, “Researchers found \textit{Washington Post} coverage through the 1980s was dominated by frames of progress and economic prospect, with dominant themes including health-related applications, basic research, and industry development.”\textsuperscript{122}

Longer and more in-depth profiles of the industry increasingly littered newsstands

\textsuperscript{118} Ibid., 262.
\textsuperscript{120} Ibid.
throughout the decade as well. Three days after Cetus's IPO, the cover of *Time* magazine depicted the smiling face of biotechnology’s poster child, Herb Boyer, under the headline: “Shaping Life in the Lab: The Boom in Genetic Engineering.” In a nine-page cover story, the magazine outlined the field's surge, from 1970’s discoveries and the science’s commercialization, to its immediate implications and financial incentives for molecular biologists. In doing so, it correctly foreshadowed the undergraduate biology boom to come:

Whatever gene splicing ultimately does in business, it has already created rich opportunities for biologists, long the poor cousins of science. Genentech Co-Founder Boyer has become a millionaire many times over, at least on paper…. To create the organisms that may turn those paper profits into real revenue, biologists with the prerequisite gene-manipulating skills are being recruited at a furious pace. Young scientists, the ink barely dry on their Ph.D.s, are being offered $30,000 a year, plus a little stock. Senior researchers are getting large chunks of the new companies. Others are fattening their relatively modest academic salaries by serving as part-time consultants to the new companies at fees of $1,000 or more a day.  

In 1983, famed and influential publishing house, Nature Publishing Group, published the first issue of *Bio/Technology* (now titled *Nature Biotechnology*). An offshoot to *Nature*, the specialized journal sought to focus on the flood of interest for biotechnology and genetic engineering beyond what its parent journal could adequately publish. Its genesis and fruition provided the young industry further credibility and

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123 Golden, "Shaping Life in the Lab."
124 Ibid., 52.
validation. The publication continues to this day.

In January 1984, *BusinessWeek* ran a cover story declaring, “Biotech Comes of Age” and “More Than 100 Gene-Splicing Companies Launch a Barrage of Products.” Laced throughout the piece were bullish predictions of the technology’s growing importance and future opportunities for incredible profit:

“The fundamental question—‘Is the technology real?’—has been settled: There is no doubt gene-splicing can produce useful products,” points out Janice M. LeCocq, a biotechnology analyst for Montgomery Securities in San Francisco. Most experts are now convinced that sales from biotechnology will increase dramatically over the next decade. Congress’ Office of Technology Assessment (OTA), for example, predicts that sometime before the turn of the century, annual sales of chemicals and drugs that are produced by gene-splicing could top the $15 billion mark. And sales of products growing out of gene-splicing will come from virtually every area of manufacturing.125

And in June 1987, *Changing Times* magazine (now titled *Kiplinger’s Personal Finance*) ran the cover story “Super Stocks for Tomorrow” with a one word, all capitalized, page-filling subtitle: “BIOTECH”126.

The word on Wall Street these days is that tons of money will be made from concoctions like t-PA, IL-2, Auriculin and factor VIII. Those are a few of the early products of biotechnology, the science that promises to revolutionize health care, agriculture and a host of other endeavors. Along the way, biotech will make some people rich.

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The upward vector of biotechnology—its scientific genesis in the 1970s, its prodigious and historic market debut, its tremendous investment portfolio, its mediagenic posture, and its already tangible and futuristic promise—the totality of its impact and aura in the 1980s would be cause for a new and exciting atmosphere for the industry in particular, and biology and health in general. New frontiers and advancements coupled with glowing media coverage and Wall Street excitement firmly etched the science’s pulse into the consciousness of society. The practical ramifications of which would be a newfound incentive toward the field, and a clear opportunity—for anyone interested—to satisfy both one’s conscience and wallet at the same time.

Between 1989 and 1998, the biological sciences became the fastest growing undergraduate major in higher education. Females and males alike entered the science faster and more often than any other major in the United States. Biology departments swelled to record highs, mushrooming from 36,068 graduates in 1989, to 65,917 graduates in 1998—an 89 percent increase, and a growth rate of 3,000 baccalaureates per year. Then, suddenly, in 1999, its growth stopped, and its ten-year boom over.

What follows next is a direct look at baccalaureate trends in the biological sciences throughout the 1990s. Bookending the major’s surge upward and contraction ten years later was the combination of market outlook and media opinion—favorable in the mid-to-late 1980s, and tepid ten years later.
VII.

Stemming from the convergence of industry potential, market status, and media reporting, the motivations underlying students’ new momentum toward the major can easily be understood through the natural and routine bandwagons which blossom in response to newly glamorous opportunities. Biotechnology’s bright future and healthy financial outlook—both as an industry, and for its players—satisfied this formula, and the technology’s dissemination and trickling down throughout media and culture made wagering on the field an exciting and natural proposition for many undergraduates. How 18- to 22-year-olds handicap their landscape of potential occupations and/or pursuits is perhaps an interesting investigation into an interesting creature, but in the mid- to late-1980s biotechnology became vogue, and it’s no surprise undergraduate enrollment in biology began reflecting society’s enchantment with the field. Biotechnology’s moment in the sun—its thriving, its glamour, and undergraduates wanting to capitalize on the industry’s ascension: this is the what and why informing undergraduate biology’s 1990s turnaround in this present essay.\textsuperscript{127}

\textbf{Biology’s Upward Surge: 1989 to 1998}

As an industry, biotechnology’s opening years were an overwhelming success. Its first market boom occurred in late-1980 and 1981, its second in 1983, and after a brief market hangover in 1984, it’s third in 1986.\textsuperscript{128} That year, building upon extremely well-publicized breakthroughs in biomedical research—breakthroughs which, as announced in a \textit{Fortune} cover story, “could cure cancer,” i.e., scientists “have discovered how to use a

\textsuperscript{127} Other arguments explaining biology’s ascension highlight the field’s influx of research dollars and the emergence of a new field of inquiry.

small group of substances…to control all cancers [emphasis added]”¹²⁹—the field swelled in valuation, enthusiasm, and hype. Excitement among researchers carried over to Wall Street, and biotechnology stocks peaked once again, surpassing previous records by a wide margin.¹³⁰ “Biotech Stocks Surge to Record Highs,” Bio/Technology declared in a January 1986 headline and reported, “The boom is back in biotech.”¹³¹ Science added “Hot Market for Biotech Stocks in 1986,” including the statistic: “[B]iotechnology companies have grossed more than $679 million from public stock offerings since December, more than 100 times the money invested in biotech stocks in the previous year.”¹³² And Chemical & Engineering News, a flagship publication of the American Chemical Society, reported “Biotechnology Stocks Outraced Stock Market in First Half,” and “[i]n the 12 months ending June 27, 1986, C&EN’s biotechnology stock index increased 180%.”¹³³

Unlike its previous two market booms—booms built upon a young, budding industry with seedling roots but grand potential—by mid-decade the permanence of biotechnology as an industry, its increasing solidification as a major player moving forward in health, agriculture, and beyond became a more concrete proposition. Already in 1986, as announced in a July issue of U.S. News & World Report, 700 American companies—big and small—engaged in biotechnology pursuits.¹³⁴ Only three years later, 500+ more companies joined the fold, and biotech as an industry surpassed 1,200

companies in the United States alone. Over the same time period, applications to the United States Patent and Trademark Office seeking approval for biotechnology patents increased from four- to five-figures. In only three years, the USPTO’s backlog of patent applications for biotechnology-related products jumped from an already whopping 9,806 applications in 1986, to 15,399 applications in 1989. Discussed in the 1991 Report on National Biotechnology Policy chaired by then-Vice President Dan Quayle, and conducted by the President’s Council on Competitiveness, attempts by the USPTO to improve its biotech backlog would result in the planned “hiring [of] 270 new patent examiners over the next five years in the biotechnology area along with improv[ed] training for examiners”—“Clearly,” the Council wrote, “increased [patent] resources will be needed in the biotechnology field as the industry continues to grow….” Federal support and spending on biotechnology also followed suit throughout the decade, doubling over a span of six years. In 1983, federal spending on research and development in biotechnology totaled just over $1.5 billion—compared to the United States space program, in 1983 federal support of biotech R&D already equaled one-fifth of the yearly costs necessary to operate the entirety of NASA. Three years later, in 1986, federal spending for biotech R&D increased to $2.16 billion—now almost one third of NASA’s total expenditures. And by 1988 federal biotech spending on research and

135 G. Steven Burrill and Ernst & Young High Technology Group, Biotech 90: Into the Next Decade (New York: Mary Ann Liebert, Inc., 1989).
137 Ibid., 6.
140 Office of Management and Budget, "Historical Tables, Budget of the United States Government, Fiscal Year 2015." See Table 4.1.
development surpassed the $3 billion mark.\textsuperscript{141}

News reports heralding the benefits of biotechnology to the United States economy and job market, and opportunities for employment within the industry also became more mainstream throughout the decade. In March 1986, \textit{The New York Times} reported the biotechnology sector to have “already created 5,000 to 10,000 new jobs” with more on the way: “Job opportunities will begin to expand as the companies move into production,” Peter Feinstein, a vice president of Biogen, told the paper. \textit{The New York Times} continued:

In the early years, biotechnology was almost entirely a research enterprise and company staffs were made up largely of scientists and highly trained research technicians. But Mr. Feinstein and others in the field said staffs were likely to broaden to include technicians in drug production, purification and processing.\textsuperscript{142}

Four months later, a July 1986 article in \textit{Bio/Technology} discussed the growing opportunities in industry for biology graduates—both at the present and for the foreseeable future. Based on a Center for Occupational Research and Development report entitled \textit{Education for Biotechnology}, the journal declared, “Students Look to Biotechnician Careers as the Ladder to Success.”\textsuperscript{143} Highlighting results from the study, the article outlined forthcoming opportunities and the growing need for graduates proficient in the techniques of biological experimentation with coursework in genetic engineering. “[H]istorically,” the article reported, “as technologies emerge from experimental laboratories and mature toward production, the number of required

\textsuperscript{141} The President's Council on Competitiveness, "Report on National Biotechnology Policy," 6.
\textsuperscript{143} Arthur Klausner, "Students Look to Biotechnician Careers as the Ladder to Success," \textit{Bio/Technology} 4, no. 7 (1986).
technicians increases.” The article continued, “Fastest growth is predicted in the East, where the number of biotechnicians could rise 251 percent in 10 years. In the West, biotechnician positions are expected to increase a healthy 121 percent....”¹⁴⁴

In April 1987, Bio/Technology also published an in-depth article on the growing influence of the industry on university curricula. Under the all-capitalized headline, “Undergraduate Education in Biotechnology,” the article reported on the direct adaptation of college programs to the biotechnology marketplace.¹⁴⁵ The State University of New York at Fredonia, for example, offered a Bachelor of Science degree in recombinant gene technology. Major courses included “recombinant gene technology (with laboratory), immunology and serology (with lab), and the molecular biology of disease.”¹⁴⁶ Worcester Polytechnic Institute in Massachusetts similarly offered a B.S. in biotechnology. As boasted in the article, “sixteen of the department’s 18 courses include[d] a laboratory [component].”¹⁴⁷ And Cedar Crest College in Allentown, Pennsylvania—a small, private liberal arts women’s college—offered a bachelor’s degree in genetic engineering technology. Major courses included “microbiology, cell biology, genetics, prokaryotic molecular genetics with recombinant DNA laboratory, eukaryotic molecular genetics with recombinant DNA lab, DNA sequencing lab, and monoclonal antibody technology.”¹⁴⁸ In addition to the above programs, the article reported the incredible employability of graduates in biotechnology, and indicated the need for one million workers in the industry’s future—“can this system meet the demands of mature

¹⁴⁴ Ibid., 601.
¹⁴⁶ Ibid., 347.
¹⁴⁷ Ibid., 348.
¹⁴⁸ Ibid., 347.
biotechnology industries, predicted to employ up to a million workers?"\textsuperscript{149}

From its first boom to its third, biotechnology transitioned from avant-garde to mainstream—still cutting edge, still incredibly glamorous, but now with strong roots in various aspects of society. By 1986 public awareness of biotechnology—its narrative, its promise, its science—had spread to a majority of America. A survey conducted by the Congressional Office of Technology Assessment found two-thirds of the United States public hopeful regarding the technology. Stated in the report: “[A] two-thirds majority of the public (66 percent) says it thinks that genetic engineering will make life better for all people.”\textsuperscript{150} Similarly, the Congressional Office found only “a quarter of the public (24 percent) report[ing] they have heard or read ‘almost nothing’ about genetic engineering”\textsuperscript{151}—“an even casual content analysis of newspapers and news magazines,” the report stated, “clearly reveals that the American people are being exposed to information about biotechnology, biology, and genetics on a frequent basis.”\textsuperscript{152} Coupled with recent and well-publicized advancements in cancer research, its record market surge, growing employment opportunities and newly tailored university majors, in 1986 the atmosphere and influence of biotechnology in American society would serve as a tipping point for undergraduate participation in the biological and biomedical sciences.\textsuperscript{153} Undergraduate participation began reflecting biotechnology’s growing presence in the country, and the upswing in student enrollment in the science a natural and anticipated outcome. Biotechnology’s glamour and lucrative appeal, and the spillover to biology and

\textsuperscript{149} Ibid.
\textsuperscript{151} Ibid., 45.
\textsuperscript{152} Ibid.
\textsuperscript{153} This directly corresponds to biology’s baccalaureate increase in 1990. After bottoming out in 1989, biology baccalaureates hinged upward in 1990 in lockstep with biotechnology’s 1986 market boom.
health in general became major themes in both society and higher education throughout the next decade. As a result, between 1989 and 1998 the biological sciences became the fastest growing major category in the country—more bachelor’s degrees were earned in the biological sciences in the decade than any other major category. In raw numbers, female degrees increased 18,184 degrees, while male degrees increased 11,665 degrees. In percentage of total baccalaureates, female biology graduates increased 2.1 percentage points (from 3.4 percent of the female graduating class in 1989, to 5.5 percent in 1998), while males increased 2.0 percentage points (from 3.7 percent to 5.7 percent, respectively).\textsuperscript{154}

**Biology’s Downward Turn: 1999 to 2004**

Then, between the early and mid-1990s, biotechnology’s darling status fizzled. For stakeholders the decade-long promise and hype of revolution transitioned to frustration and discontent, and the psychological letdown of the field perpetually being on the verge of incredible impact, but not fulfilling its lofty promise, sullied biotechnology’s narrative in the eyes of Wall Street as we will see below. Since Genentech’s IPO, positive market psychology had been central to biotechnology’s success—the incredible amount of capital invested in the industry was due not to profit, but rather the promise of profit. In the mid-1990s, the industry’s overall lack of market success led to the depreciation of both its stocks and public perception, and the resultant skittishness of Wall Street toward the field ultimately trickled to mainstream society and undergraduate enrollment.

As early as 1991, headlines in the *Los Angeles Times* announced, “The Unfilled Promise of Biotech ‘Cures’”—“the promised embarrassment of riches” the newspaper

\textsuperscript{154} Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)."
wrote of biotechnology’s anticipated consumer market boom, “has yielded more embarrassment than riches”\textsuperscript{155}—and “Rocky Road for Biotech Firms”:

Biotech stocks were sizzling this year, but these days it seems they’re burning investors.

The stock market’s recent nosedive was triggered in part by a ripple of sudden queasiness over the astronomic appreciation of the stocks of biotechnology companies—the vast majority of which have produced neither profit nor product.\textsuperscript{156}

That same year, adding fuel to the fire, \textit{Science} highlighted the impending biotech bottleneck in the U.S. Food and Drug Administration, and the regulatory barrier potentially limiting the industry’s profitability and impact in consumer markets in the future:

Yet patients may have to wait far longer than the biotech enthusiasts suggest before they reap the benefits of those new drugs. In fact, at the moment the biotech industry could be on the verge of becoming a regulatory victim of its own research and development successes.

Even as they publicly tout the good times just ahead, industry insiders openly worry that the FDA is falling behind in its ability to review and approve medicines quickly. Indeed, the management firm of Booz, Allen & Hamilton concluded the agency needed another 100 to 180 scientists in the next few years to handle its growing workload. Yet FDA officials point out that their staff is actually down from a high in 1979.


\textsuperscript{156} "Rocky Road for Biotech Firms," ibid., November 26, 1991, D9.
And the problems aren't due only to the volume of new products in the pipeline. They're also due to the fact that many second-and third-generation biotech products are much more complex scientifically than their earlier counterparts. Early biotech drugs were usually well-understood substances, such as insulin and other hormones, that function as therapeutic agents just as they do naturally. But many of the new agents...may work as drugs in ways that are far different from their natural functions. And their effects as drugs aren't well understood. As a result, the FDA is struggling to approve more drugs whose reviews are more complex. Yet there is little hope the FDA will get the money it needs to do the job. Therefore, it could be that the biotech industry—just as it hits its stride—is about to run into a stumbling block.\(^{157}\)

In 1992, biotechnology’s fall from grace continued. The *New York Times* described the year in biotechnology as one “in which the misses obscured the hits.”\(^ {158}\) Under the headline “Looking Beyond the Bloodletting in Biotechnology,” the paper reported, “the industry was beset by financial turmoil, the denial of regulatory approval for two once-promising drugs and rising concern about health-care costs.” The *Times* further added, “[o]ver the entire 12 months, the Federal Government approved only two new biotech drugs.”\(^ {159}\) And the *Wall Street Journal* acknowledged: “Many biotechnology companies have few, if any, products and no earnings. What they do have are lots of press releases.”\(^ {160}\)


\(^{159}\) Ibid.

In 1993, two months after his inauguration, President Bill Clinton outlined a health-care reform proposal seeking, in part, to control the cost of prescription drugs—or, in the words of Vice President Gore, “stop drug over-charges and excessive profiteering.”¹⁶¹ For investors, the news meant even further apprehension for biotech investment. The impact was notable—the Wall Street Journal declared, “Bloodbath in Biotech…”¹⁶²; the New York Times asked “Another biotech selloff and again the question: Is this the bottom?”¹⁶³; and Science added, “Biotech Sails into Heavy Financial Seas”:

At the heart of the apprehension generated by price controls is one fear: If controls were in place, a biotech company would be unable to shower its investors with profits from a blockbuster new drug. “Price controls on new drugs have the potential of killing the industry,” says the downbeat Raab [Genentech CEO]. The reason is that while biotech firms have lots of promising new drugs in the pipeline, they don't have many products on the market. Therefore, they have to tap investors constantly to keep their books balanced. And if the investors constantly see returns that—due to price controls—seem minuscule compared to what they're used to, they're going to look elsewhere for their profits.¹⁶⁴

By 1994, attitudes toward biotechnology soured completely. “Seventy percent of [biotech] companies need to go out of business,” one investment analyst stated to a

prominent business periodical.\textsuperscript{165} Another asked of the biotech industry, “When the hell do we get earnings?”\textsuperscript{166} A front page \textit{BusinessWeek} cover story boomed: “BIOTECH: Why It Hasn’t Paid Off” and “An Industry Crowded With Players Faces an Ugly Reckoning.” The seven-page spread detailed the industry’s drought, and the negative perceptions and bearish attitudes toward the science:

The industry is still peddling dreams, and it did raise $4.7 billion in public and private capital in the 12 months ended last June. But investors are getting leery, and the money flow is drying up. Except for a handful of top-tier companies with proven products, biotech stocks have plunged: The Amex Biotech Index is off more than 505 from its zenith in 1992. Ernst & Young estimates that only 50\% of all biotech hopefuls have enough money to last 24 months, and most of those are still years from having a product. After a giddy run in the early ‘90s, “the market is disillusioned” with biotech, declares Karen Firestone, who manages Fidelity Investments’ $500 million Select Biotechnology Fund. From Wall Street’s perspective, “the technology hasn’t worked, and the likelihood of success is lower.”

After a decade as the highest-flying of America’s high-tech industries, biotech faces a reckoning—and it’s going to be ugly.\textsuperscript{167}

By mid-decade, Wall Street’s leeriness spread to undergraduate enrollment, and four years later in 1999 undergraduate biology’s decade-long baccalaureate increase came to an end. Between 1998 and 2004, the percentage of students earning


\textsuperscript{167} Carey, "Biotech: An Industry Crowded with Players Faces an Ugly Reckoning," 84.
baccalaureates in the biological sciences decreased from an eighteen year high of 5.6 percent in 1998, to 4.5 percent in 2004—a 1.1 percentage point decrease. The percentage of females earning baccalaureates in the biological sciences—as a ratio of the total female graduating class—decreased slightly from 5.5 percent in 1998 to 4.8 percent in 2004 (a 0.7 percentage point decrease), while male percentages decreased from 5.7 percent to 4.0 percent, respectively (a 1.7 percentage point decrease).\(^{168}\) Biotechnology’s moment in the sun spurred incredible excitement on Wall Street in the 1980s, but the industry’s failure to meet the unrealistic expectations placed upon its products—both inherited and self-perpetuated—resulted in discontent and negative attitudes in the 1990s. The shepherd boy who cried wolf too many times received disbelief and skepticism. By the mid-1990s, so too did biotechnology’s unfulfilled promise. As a result, between 1999 and 2004, undergraduate trends reflected society’s growing impatience with the industry, ending the major’s upward baccalaureate climb between 1989 and 1998.

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Between 1989 and 1998, in response to biotechnology’s incredible narrative, females and males flocked to undergraduate biology in record numbers. For ten years the biological sciences was the fastest growing major category in the country. However, a mid-1990s skittishness toward the industry resulted in a brief period of stagnation and decline in undergraduate biology baccalaureates between 1999 and 2004. Then in 2004, in correlation with the June 2000 announcement of the Human Genome being cracked—reported on the front page of the New York Times, “Genetic Code of Human Life is Cracked by Scientists,” officially marking the start of the genomics age—biology baccalaureates began another

\(^{168}\) Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)."
upward climb. Between 2004 and 2011 biology baccalaureates increased from 62,624 degrees to 90,003 degrees. The proportion of female baccalaureates in biology increased from 4.8 percent in 2004 to 5.4 percent in 2011, while the proportion of male baccalaureates increased from 4.0 percent to 5.0 percent, respectively.
Chapter 4: Engineering, 1976–1985
I.

Perhaps no STEM field has evolved more directly in contrast to the biological sciences over the past thirty years than undergraduate engineering. While biology as a major has successfully shed its male slant,1 and has swelled into an attractive option for females and males alike, engineering has remained consistently one-sided. Since 1985, males earned no fewer than 80 percent of all engineering degrees awarded in the United States in any given year. In terms of raw numbers, males earned at least 45,000 more engineering degrees than their female counterparts every year for the past thirty years. In comparison to undergraduate biology which now graduates six females to every four males—in 2011, as reported in the most recent Digest of Education Statistics published by the U.S. Department of Education, women earned 59 percent of all bachelor’s degrees awarded in the biological sciences2—the consistency of engineering’s disproportionate participation over the past three decades is all the more noteworthy. Headlines such as “Women still finding bias in engineering”3 in 1988; “Inequities force many women out of engineering, study discovers”4 in 1994; “Engineering: It's still a man's world”5 in 2001; and most recently “Uncivil work environment pushing women out of the engineering field”6 in 2014 document the field’s bias throughout the decades.

Explanations seeking to unravel why this is so—why undergraduate engineering remains consistently imbalanced in light of biology’s evolution—often focus on the

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2 Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 496.
discipline’s image as a male bastion, the lack of female role models and mentors in engineering, an imbalance in the counsel and encouragement given to males and females toward the major, and—as some have controversially cited—sex differences between females and males. In a meta-analysis conducted by psychologists from the University of Illinois at Urbana–Champaign and Iowa State University, researchers—upon integrating the results across 108 vocational interest inventories from a total of 503,188 respondents—concluded “men prefer working with things and women prefer working with people.” As the authors detail:

We synthesized evidence from interest inventories over four decades and found large sex differences in vocational interests, with men preferring working with things and women preferring working with people. These sex differences are remarkably consistent across age and over time, providing an exception to the generalization that only small sex differences exist. Second, this study provides a systematic review of the sex differences in the STEM interests that has not previously appeared in the literature. The pattern of sex differences in the STEM interests revealed by the present study closely resembles the composition of men and women in corresponding occupations and contributes to the understanding of the gender disparity in the STEM fields. The results suggest that the relatively low numbers of women in some fields of science and engineering may result from women’s preference for people-oriented careers over things-oriented careers.  

10 Ibid., 880.
Together, the veracity, the verisimilitude of the above explanations provide a portrait of undergraduate engineering and the seemingly substantial barriers handicapping the field. The tenacity and doggedness with which these items remain prevalent in light of biology’s progression point—as many have argued—to institutional miscalibrations and/or society’s inability to fully overcome its implicit biases. Despite large and mainstream efforts to reform, reshape, remodel the field’s narrative and appeal to females, the persistence of barriers in undergraduate engineering remains a very frustrating and disappointing reality.

In this chapter, we will dissect a time period in undergraduate engineering when women were able to overcome the historical, social, and institutional ceilings limiting participation. In fact, we will explore a decade in which engineering baccalaureates skyrocketed upward for both genders: between 1976 and 1985, female baccalaureates in engineering increased an astonishing 770 percent, while male baccalaureates in engineering increased 86 percent. In doing so, the goal of the present chapter is not to discount the reality of present-day gender differences or overlook institutional shortcomings, but rather to understand the collection of factors which combined thirty years ago to drive participation to the major as never before (or since). For women, majoring in engineering became a much more comfortable proposition in the mid-1970s and mid-1980s—from a virtual non-option to a legitimate major choice. For males, engineering participation reached an all-time high—men earned more engineering bachelor’s degrees in the mid-1980s than at any other point in the American twentieth or twenty-first century. Understanding why this was so—understanding the factors which combined to dramatically increase participation for both sexes, but particularly for

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11 Including the frenetic Space Race a decade earlier.
women—is the next necessary step to further comprehend and decipher the limitations which have stubbornly restricted undergraduate engineering participation over the past thirty years.

**Looking at the data**

![Graph showing engineering degrees by gender from 1970 to 2011](image)


Figure 4.1 shows the number of U.S. baccalaureates awarded in engineering between the years 1970 and 2011. Before biology’s recent surge, a surge which in many ways continues to this day—“[The twentieth century] was the century of physics and chemistry,” Nobel laureate and chemist, Robert Curl professed, “[b]ut it is clear that the next century will be the century of biology”—the predominant STEM major of choice was engineering. Between the mid-1970s and mid-1980s males and females flocked to the major in record numbers. Following a very brief period of decline in male participation between 1973 and 1976, the number of engineering baccalaureates for both

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12 In this chapter, I use the terms “engineering” to refer to the constellation of related majors identified by the National Center for Education Statistics as the “engineering and engineering technologies.” For further elaboration, see Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 456-69.
sexes turned sharply upward in 1977, accelerating over the next years to levels previously unseen. In fact, between the years 1976 and 1985 engineering became the second fastest growing major in the country—second only to business in numerical growth, second only to computer science in percent growth. In total, engineering baccalaureates increased 108 percent, doubling from 46,676 bachelor’s degrees in 1976, to 97,099 degrees in 1985.\footnote{Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 502.}

Its growth, as displayed in Table 4.1, outpaced trends in biology (-29 percent growth in bachelor’s degrees), the health professions (21 percent growth), the physical sciences (10 percent growth), the social sciences (-27 percent growth), and education (-43 percent growth).\footnote{Ibid., 494-516.}

**Table 4.1: Baccalaureate snapshots, years 1976 and 1985**

<table>
<thead>
<tr>
<th>Major</th>
<th>Baccalaureates 1976</th>
<th>Baccalaureates 1985</th>
<th>Numerical Growth</th>
<th>Percent Growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer Science</td>
<td>5,652</td>
<td>42,337</td>
<td>36,685</td>
<td>649.1%</td>
</tr>
<tr>
<td>Engineering</td>
<td>46,676</td>
<td>97,099</td>
<td>50,423</td>
<td>108.0%</td>
</tr>
<tr>
<td>Communications</td>
<td>21,282</td>
<td>42,102</td>
<td>20,820</td>
<td>97.8%</td>
</tr>
<tr>
<td>Business</td>
<td>143,171</td>
<td>236,700</td>
<td>93,529</td>
<td>65.3%</td>
</tr>
<tr>
<td>Health Prof</td>
<td>53,885</td>
<td>65,331</td>
<td>11,446</td>
<td>21.2%</td>
</tr>
<tr>
<td>Physical Sciences</td>
<td>21,458</td>
<td>23,694</td>
<td>2,236</td>
<td>10.4%</td>
</tr>
<tr>
<td>Architecture</td>
<td>9,146</td>
<td>9,119</td>
<td>-27</td>
<td>-0.3%</td>
</tr>
<tr>
<td>Math</td>
<td>15,984</td>
<td>15,099</td>
<td>-975</td>
<td>-6.1%</td>
</tr>
<tr>
<td>Agriculture</td>
<td>19,402</td>
<td>18,107</td>
<td>-1,295</td>
<td>-6.7%</td>
</tr>
<tr>
<td>Visual/Perf. Arts</td>
<td>42,138</td>
<td>38,285</td>
<td>-3,853</td>
<td>-9.1%</td>
</tr>
<tr>
<td>Psychology</td>
<td>50,278</td>
<td>39,900</td>
<td>-10,378</td>
<td>-20.6%</td>
</tr>
<tr>
<td>English</td>
<td>41,452</td>
<td>32,686</td>
<td>-8,766</td>
<td>-21.1%</td>
</tr>
<tr>
<td>Public Admin</td>
<td>15,440</td>
<td>11,754</td>
<td>-3,686</td>
<td>-23.9%</td>
</tr>
<tr>
<td>Social Sciences</td>
<td>126,396</td>
<td>91,750</td>
<td>-34,646</td>
<td>-27.4%</td>
</tr>
<tr>
<td>Biology</td>
<td>54,154</td>
<td>38,354</td>
<td>-15,800</td>
<td>-29.2%</td>
</tr>
<tr>
<td>Foreign Language</td>
<td>17,068</td>
<td>11,436</td>
<td>-5,632</td>
<td>-33.0%</td>
</tr>
<tr>
<td>Education</td>
<td>154,437</td>
<td>88,078</td>
<td>-66,359</td>
<td>-43.0%</td>
</tr>
</tbody>
</table>

*Source: Digest of Education Statistics, pp. 494-516*
For women, engineering’s boom in the mid-1970s and mid-1980s brought a sharp increase in participation. Prior to 1975, undergraduate engineering had never graduated more than one thousand women in any given year. Over the next ten years, however, this changed significantly. Between 1976 and 1985 the number of bachelor’s degrees awarded to women in engineering *septupled*, growing from 1,492 baccalaureates in 1976 to an impressive 13,108 baccalaureates in 1985—an overall increase of 770 percent.16 As displayed in Figure 4.1 and Figure 4.2, this ten-year time period is the only instance of meaningful and noteworthy growth for women in undergraduate engineering over the past half century. At the start of the decade in 1976, female engineers accounted for 0.4 percent of the total female graduating class. By 1985, female engineers accounted for 2.6 percent of the total female graduating class—less than, but not grossly dissimilar to English and letters (4.3 percent), the visual and performing arts (4.8 percent), biology (3.7 percent), and computer science (2.9 percent); and more than the physical sciences (1.3 percent), mathematics (1.4 percent), and all foreign languages combined (1.7 percent).17,18 Since then, however, female engineering baccalaureates have flatlined.

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16 Ibid., 502.
17 Ibid., 494-516.
18 For comparison, female education baccalaureates accounted for 13.4 percent of the total female graduating class, while business baccalaureates accounted for 21.1 percent of the female class.
For males, bachelor’s degrees in engineering doubled between the mid-1970s and mid-1980s, from an already substantial 45,184 degrees in 1976, to an inflated 83,991 degrees in 1985—an overall growth of 86 percent. In fact, in the mid-1980s more males earned bachelor’s degrees in engineering than at any other point in American higher education history. In 1976, 8.9 percent of all male baccalaureates earned a bachelor’s degree in engineering. Ten years later in 1985 this figure mushroomed to 17.4 percent, with one of every six male graduates earning a bachelor’s degree in engineering. To put engineering’s numbers in perspective, in 1985 almost 4 percent of males earned bachelor’s degrees in biology, 26.4 percent of males earned degrees in business, 5.1 percent in computer science, 4.4 percent in education, 3.5 percent in the physical sciences, and 10.6 percent in the social sciences. Since 1985 however, like their female counterparts, male trends have declined. As displayed in Figure 4.3, following peak levels in the mid-1980s, the percentage of males earning bachelor’s degrees in

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![Figure 4.2: Percentage of female bachelor's degrees earned in engineering, years 1970-2011. Source: Digest of Education Statistics 2012, p. 448 and p. 502.](image)

20 Ibid., 494-516.
engineering decreased over the next ten-years, and has virtually leveled off since the turn of the millennium.

![Figure 4.3: Percentage of female bachelor's degrees earned in engineering, years 1970-2011. Source: Digest of Education Statistics 2012, p. 448 and p. 502.](image)

What causes an undergraduate major to jump from 45,000 degrees in 1976, to over 90,000 degrees a decade later? What causes an 100 percent increase in male baccalaureates, and an almost 800 percent increase in female baccalaureates? And, in year eleven, what causes an end to the major’s upward climb, and a reversal in participation for both genders? In this chapter, we will explore a revolution in the foundations of human technology. We will explore a series of miniaturizations which now rank among the very top of humankind’s achievements: according to *The Atlantic*, this set of technologies is the fourth most important innovation in the past five-thousand years of human development—below the printing press, electricity, and penicillin; but above the combustion engine, the internet, and the automobile. And we will learn of unique circumstances which galvanized the engineering profession in the 1970s and early

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1980s, and the large incentives which attracted students toward the major as never before—that is, an explosion in engineering jobs, and an abundance of high-paying salaries. In other words, we will come to intimately understand the proliferation and impact of the microchip, the semiconductor revolution, and the dawn of the computer age.

II.

Famously, the world’s first computer—as we know computers today—was ENIAC. An acronym for Electronic Numerical Integrator And Computer, ENIAC was commissioned during World War II by the United States Army’s Ballistic Research Laboratory—an antecedent in form and facility to the contemporary Army Research Laboratory in Aberdeen, Maryland—to bolster the country’s ongoing war effort. At that time, prior to the invention of smart weaponry and precision aiming technologies—technologies which have since become common in the modern arsenal—aiming data, for both large and small field artillery, was dependent upon the artilleryman, and the conditions under which he fired. Field artillery performance, even today, is reliant upon a variety of atmospheric conditions. Like a golf ball in a strong crosswind, or a projectile in an advanced physics problem, a number of ammunition-meteorologic relationships need to be taken into account to increase firing accuracy. Atmospheric factors such as air pressure, air temperature, and wind conditions; and ammunition-specific factors such as projectile weight, projectile temperature, and projectile wobble all can—and do—
influence a shell’s airborne path. Essentially, every firing order issued to a field artillery unit is a high-level motion and trajectory problem to be solved. And in World War II, without the aid of modern services and technologies to aid path calculations, and without the luxury of time in the battlefield to hand-solve differential equations, the Army relied upon hundreds of female mathematicians—literally human “computers”—to pre-calculate shell trajectory data and ballistic coefficients for each weapon/ammunition combination for use in standard and nonstandard conditions. The work was an essential component of the U.S. war effort—“a gun without a [trajectory] table is almost as useless as a computer without a program”—but it was also incredibly time-consuming and tedious. Detailed years later by Kathleen McNulty, who at the age of twenty-two was hired by the Army to calculate such trajectories, the work required an extraordinary amount of endurance and human patience:

Numerical integration is where you take, in this particular case,…the path of a bullet from the time it leaves the muzzle of the gun until it reaches the ground. It is a very complex equation; it has about fifteen multiplications and a square root and I don't know what else. You have to find out where the bullet is every 10th of a second from the time it leaves the muzzle of the gun, and you have to take into account all the things that are going to affect the path of the bullet. The very first things that affect the path of the bullet [are] the speed at which it shoots out of the gun [the muzzle velocity], the angle at which it is shot out of the gun, and the size. That's all incorporated in a function which they give you—a [ballistic] coefficient.

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22 As reported by historian Harry Wulforst, “Just a slight change in wind direction, a drop in temperature, or even a switch to another type of ammunition can draw a well-sighted gun off target” (1982, pp. 1-2).
24 Ibid.
As the bullet travels through the air, before it reaches its highest point, it is constantly being pressed down by gravity. It is also being acted upon by air pressure, even by the temperature. As the bullet reached a certain muzzle velocity—usually a declining muzzle velocity, because a typical muzzle velocity would be 2,800 feet per second—when it got down to the point of 1,110 fps, the speed of sound, then it wobbled terribly…. So, instead of computing now at a 10th of a second, you might have broken this down to 100th of a second to very carefully calculate this path as it went through there. Then what you had to do, when you finished the whole calculation, you interpolated the values to find out what was the very highest point and where it hit the ground.

Every four lines we had to check our computations by something called Simpson’s rule to prove that we were performing the functions correctly. All of this was done using numbers so that you kept constantly finding differences and correcting back.25

In total, the construction of a comprehensive set of trajectories for an individual weapon/ammunition combination—approximately 3,000 calculations overall26—took a team of two hundred ballisticians months to complete.27 Given wartime demands which at times exceeded forty trajectory tables per week, quickly into war the Army fell behind schedule.28 Maintaining pace with war’s breakneck pace became a physical impossibility for the ballisticians, and “[u]nder the circumstances,” computer historian Stan Augarten

27 James Jay Carafano, Wiki at War: Conflict in a Socially Networked World (College Station: Texas A&M University Press, 2012), 66.
28 Harry Wulforst, Breathrough to the Computer Age (New York: Charles Scribner's Sons, 1982), 60.
tells us, “the BRL [Ballistics Research Laboratory] was willing to do almost anything to alleviate the [wartime] crisis.” This included, he wrote, “spending half a million dollars for the construction of a revolutionary electronic calculator.”\textsuperscript{29} That revolutionary electronic calculator became the world’s first modern computer—ENIAC—and from the depths of mathematics drudgery and the imperative for ballistics calculations during war the computer age was born.

Up to that point in history, humankind had already made remarkable advancements in the computational ability of mechanical systems. Using complex combinations of gears, cranks, electromechanics, and human ingenuity, creators invented devices to mechanize and solve a wide range of engineering and industrial problems. Pascal’s mechanical calculator, Charles Babbage’s Analytical Engine, Herman Hollerith’s tabulating punch-card machine,\textsuperscript{30} Vannevar Bush’s differential analyzer—in the evolution of computation, these landmark devices form the fossil record to its pre-electronic past. Built upon innards more closely aligned with steampunk technologies than the digital machines we depend upon today, they operated through chain reactions of carefully aligned mechanical parts: rotating shafts, gear trains, motors, etc.—components we still find in lathes and bandsaws and other machine shop equipment, but not our advanced electronics. Historically dependent upon metal in motion, computation’s...

\textsuperscript{29} Augarten, \textit{Bit by Bit}, 110.

\textsuperscript{30} In 1884, twenty-four year old Herman Hollerith filed a patent for, as he wrote, the invention of “a certain new and useful Improvement in the Art of Compiling Statistics.” What he introduced to the world was a novel tabulating punch-card machine system, a system which could record and rapidly compile enormous amounts of data by sorting and counting holes punched in 3 by 8 inch card stock. For the first time, Hollerith’s system made it “possible to count, collate, and analyze information by machine”—what he had invented, in other words, was the “world’s first data processor” (Augarten, p. 70). Due to widespread interest in his machines from an array of government and commercial vendors, in December 1896 Hollerith founded and incorporated the Tabulating Machine Company, which upon merger with three companies in 1911 would operate under the name Computing Tabulating Recording Company. Later, in 1924, to reflect the company’s growing international presence, the Computing Tabulating Recording Company formally adopted its contemporary name, International Business Machines—IBM.
turning point—its transition towards its electronic future—was ENIAC. Unprecedented in its ambition and complexity, upon ENIAC’s completion in 1945 following thirty months of development—roughly 200,000 man-hours of engineering—it was the world’s largest and, more importantly, fastest electronic machine.\textsuperscript{31} Ten feet tall, one hundred feet long, three feet wide; built atop 17,000 vacuum tubes, 70,000 resistors, 10,000 capacitors, 6,000 switches\textsuperscript{32}—all connected via 500,000 hand-soldered joints\textsuperscript{33}: the miracle was not ENIAC’s design or conception or grand objective—the miracle was the electronic mammoth worked. Detailed in his seminal 1972 account, Herman H. Goldstine—Michigan math professor turned Army first lieutenant and wartime Ballistics Research Laboratory liaison to ENIAC—outlined the incredible odds stacked against the machine’s all electronic-design, and the pessimism of engineering experts toward the quote-unquote ‘impractical’ machine:

To gain some rough measure of the magnitude of the risks, we should realize that the proposed machine [contained] over 17,000 tubes of 16 different types operating at a fundamental clock rate of 100,000 pulses per second. This latter point means that the machine was a synchronous one, receiving its heart-beat from a clock which issued a signal every 10 microseconds. Thus, once every 10 microseconds an error would occur if a single one of the 17,000 tubes operated incorrectly; this means that in a second there were 1.7 billion chances of a failure occurring and in a day about $1.7 \times 10^{14}$ chances. Put in other words, the contemplated machine had to operate with a probability of malfunction of about 1

\textsuperscript{31} Augarten, \textit{Bit by Bit}, 110.
part in $10^{14}$ in order for it to run for 12 hours without error. Man had never made an instrument capable of operating with this degree of fidelity or reliability, and this is why the undertaking was so risky a one and the accomplishment so great.\footnote{McCartney, \textit{ENIAC: The Triumphs and Tragedies of the World's First Computer}, 102.}

For many scientists and engineers, ENIAC’s construction was seen as an extremely expensive “waste of time.”\footnote{Goldstine, \textit{The Computer: From Pascal to von Neumann}, 153.} Its 17,000 vacuum tube foundation was unprecedented, unfathomable—no machine had ever used more than 2,000 in operation\footnote{Robert Slater, \textit{Portraits in Silicon} (Cambridge: MIT Press, 1989), 123-24.}—and experts warned it “would not run for more than 30 seconds” without failing.\footnote{Ibid., 124.} Way too many components engineers noted, way too high a probability for error—ENIAC was a paradigm shift in the making, but few saw it that way prior to its unveiling. Then, in 1945, when it famously worked—when it solved a trajectory calculation in not three days, but twenty seconds; when it computed solutions one thousand times faster than its closest contemporary; when it allowed civilization, for the first time, to solve problems too complex for the human brain alone, problems previously viewed as \textit{unsolvable} by engineers and scientists\footnote{Bijay K. Jayaswal and Peter C. Patton, \textit{Design for Trustworthy Software: Tools, Techniques, and Methodology of Developing Robust Software} (Upper Saddle River, NJ: Prentice Hall, 2007), 463.}—it changed history forever.

Immediately the world grasped the machine’s significance. In a front-page article the \textit{New York Times} called ENIAC “a tool with which to begin to rebuild scientific affairs on new foundations,”\footnote{“Mathematical Brain Enlarges Man’s Horizon,” \textit{Philadelphia Inquirer}, February 15, 1946.} and described the device as “one of the war’s top secrets, an amazing machine which applies electronic speeds for the first time to mathematical tasks hitherto too difficult and cumbersome for solution.” The Associated Press stated ENIAC

\begin{footnotesize}
\begin{itemize}
\item[c] Ibid., 124.
\item[c] “Mathematical Brain Enlarges Man’s Horizon,” \textit{Philadelphia Inquirer}, February 15, 1946.
\end{itemize}
\end{footnotesize}
“opened the mathematical way to better living for every man [sic].”\textsuperscript{40} A headline in the \textit{New York Herald Tribune} reported “Electronic Brain Computes 100-Year Problem in 2 Hours.”\textsuperscript{41} \textit{Time} magazine reported “eniac [is] so flexible that its inventors have given up looking for problems it cannot handle.”\textsuperscript{42} And under the headline “Mathematical Brain Enlarges Man’s Horizon,” the \textit{Philadelphia Inquirer} wrote ENIAC “wipes out the boundaries hitherto imposed by time upon the limits of mortal thinking,” and “solves the unsolvable”:

A new epoch in the history of human thought began last night. The scope and area in which man’s brain can grasp, predict, control suddenly opened outward into the distance with revelation of secret construction during the war of a 30 ton mathematical brain that solves the unsolvable.”\textsuperscript{43}

For humankind, ENIAC symbolized the future to come. The most elaborate and sophisticated device ever invented,\textsuperscript{44} it extended civilization’s grasp farther than ever before. In 1893, Frederick Jackson Turner famously eulogized the closing of the American frontier, and its impact on the Americanization of its people.\textsuperscript{45} Fifty years later the frontier of the mind—the search and pursuit by humankind to streamline its most fatiguing intellectual work—came to a close with ENIAC. Four millennia after the abacus, three hundred years after the first mechanical calculator, the wilderness of humanity’s brainpower was settled. In one day ENIAC outperformed the work of 70,000

\begin{itemize}
  \item \textsuperscript{41} McCartney, \textit{ENIAC: The Triumphs and Tragedies of the World's First Computer}, 107.
  \item \textsuperscript{43} "Eniac," \textit{Time}, February 25, 1946, 92.
  \item \textsuperscript{44} At the time, of course.
  \item \textsuperscript{45} "Mathematical Brain Enlarges Man’s Horizon."
\end{itemize}
mathematicians.\textsuperscript{46} In two weeks, \textit{Popular Mechanics} reported, ENIAC “solved…calculations which would have required 100 man-years [sic] of trained mathematician’s] work.”\textsuperscript{47} The computer made an impossible possible, and it multiplied humankind’s expectation of itself—and the reservoir of its intellect—as never before.

Immediately upon the machine’s successful development in late 1945—two months before its filet-mignon-catered public unveiling—ENIAC completed its first high-level assignment—a “secret numerical simulation for the [War Department’s] yet-untested hydrogen bomb.”\textsuperscript{48} Described by Walter Isaacson in \textit{The Innovators}:

The secret assignment came from Los Alamos, the atomic weapons lab in New Mexico, where the Hungarian-born theoretical physicist Edward Teller had devised a proposal for a hydrogen bomb, dubbed “the Super,” in which a fission atomic device would be used to create a fusion reaction. To determine how this would work, the scientists needed to calculate what the force of the reactions would be at every ten-millionth of a second.

The nature of the problem was highly classified, but the mammoth equations were brought [to] ENIAC to crunch. It required almost a million punch cards to input the data…. ENIAC solved the equations, and in doing so showed that Teller’s design was flawed.\textsuperscript{49}

Three months later, in a March 1946 thank you letter to Army Major General Gladeon Barnes by Los Alamos’s Director, Norris Bradbury, the well-known physicist thanked the Major General for his scientists’ use of ENIAC. Bradbury praised the machine,

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\textsuperscript{47} Carafano, \textit{Wiki at War: Conflict in a Socially Networked World}, 67.
\textsuperscript{49} Slater, \textit{Portraits in Silicon}, 74.
\end{flushleft}
congratulated the Army for its incredible development of the breakthrough device, and relished the future to come:

The calculations which have already been performed on the ENIAC as well as those now being performed are of very great value to us…. The complexity of these problems is so great that it would have been almost impossible to arrive at any solution without the aid of the ENIAC. We are extremely fortunate in having had the use of the ENIAC for these exacting calculations.

I should like to also offer our congratulations for the successful development of so valuable an instrument…. It is clear that physics as well as other sciences will profit greatly from the development of such machines as the ENIAC.50

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In a world of mechanical devices and analog processes; of Sisyphean tasks and human manpower; of pencil, paper, and repetitiveness—ENIAC altered the course of computation, and the world, ever after. It demonstrated the vast possibilities such machines could—and would—have on society; it bore into existence what we now know to be the Information Age51; and in the years to come, it and its kin profoundly influenced the lives of all humanity. ENIAC was the first, and it established the influence computers could have on humankind’s pursuit of superhuman data. But it wouldn’t be the only. Faster, smaller, stronger were on the horizon. Led by laboratory developments in New Jersey, Texas, and the yet-to-be-named Silicon Valley, the computer’s evolution—and

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the future of society—would be built upon a series of paradigm shifts, of technological breakthroughs enabling new applications and new freedoms in both the practical and the possible. ENIAC’s invention foreshadowed the future to come, but the true democratization of the computer—and more importantly computer technology—throughout industry and society wouldn’t take place until the 1970s. It was then that the microchip, the semiconductor revolution—the fourth most important innovation in the past five millennia of human civilization—was born into the world. ENIAC was more than the sum of its 100,000 components, and three decades later the microchip was more than an innovation—it was the future foundation of modern society, the underpinning of the next industrial revolution. An irreversible component to modern civilization and our daily lives, it has been said “[m]icrochips account for the biggest change that has occurred in our culture in the past four decades.” Author Jeffrey Zygmont continued:

They amount to a new human capability that is so advantageous is has reordered our lifestyles. Already the change is so complete that it has burrowed down to the roots of our culture. It’s gone subterranean. It’s one of our foundations now, one of the unnoticed abilities that is bound so tightly into human experience that it shapes our ideas, determines our actions, and expands our expectations. Like the furnace in the basement, the clothes that fill the closet, the automobile waiting in the garage, it is so dependably present that it stays hidden inside our thoughts.\footnote{Gregory C. Farrington, "ENIAC: The Birth of the Information Age," \textit{Popular Science}, March 1996, 74-76.}

It is this transition between the birth of the computer age before the mid-twentieth Century and the semiconductor revolution decades later which prompted undergraduate engineering’s 1970s explosion. The transistor, the integrated circuit, the microprocessor:
the emergence and proliferation of microelectronics in the decades following ENIAC and their impact on America and beyond—a la a furnace in every basement one hundred times over—it is this which attracted males and females to the major as never before. The excitement, the promise of progress coupled with high-paying jobs—the computer age officially reached mainstream society in the mid-1970s, and the engineering major reaped the benefits. In the next section we’ll explore the milestone moments which led to the semiconductor revolution’s true proliferation, and the seminal inventions which set the stage for engineering’s incredible growth.

III.

ENIAC was a machine that reshaped the progress of science, of civilization—“a tool with which to begin to rebuild scientific affairs on new foundations.” It captured the imagination of researchers and business leaders and the public as a whole. And even before its final panel was screwed shut, plans to engineer more advanced computers were underway. Led by the development of EDSAC and BINAC in 1949; EDVAC in 1952; and the world’s first commercially mass-produced computer—forty-six units in all—Remington Rand’s UNIVAC I in 1951, ENIAC’s successors advanced the bleeding edge of machine power, the bleeding edge of technological prowess, and with UNIVAC I sparked the computer industry. Genius; remarkable; at the time, unrivaled—

53 Kennedy Jr., "Electronic Computer Flashes Answers, May Speed Engineering."
54 An acronym for Electronic Delay Storage Automatic Calculator
55 An acronym for Binary Automatic Computer
56 An acronym for Electronic Discrete Variable Automatic Computer
57 An acronym for Universal Automatic Computer
58 The first UNIVAC I was delivered to the U.S. Census Bureau “to tabulate part of the 1950 population census and the entire 1954 economic census” (United States Census Bureau). The fifth machine, ultimately
the world’s first wave of computers were also antiques in the making. Built atop the limitations of vacuum tubes, the trigger to the world’s next generation of machines, and the modern electronics industry as a whole, was pulled in the 1950’s with the development of the transistor. “Inventing the transistor meant the fulfillment of a dream,” technology historians Braun and Macdonald explained, “almost as good as inventing the

destined for the U.S. Atomic Energy Commission (Hally, 2005, p. 41), was highlighted on CBS as part of the network’s coverage of the 1952 presidential election between then-Republican candidate, General Dwight D. Eisenhower and Democratic candidate, Illinois Governor Adlai Stevenson. Historian Harry Wulforst captured the night:

Sustaining viewer interest during the tedious hours of reporting the vote, precinct by precinct and state by state, was a tough challenge for broadcasters. Break the monotony, said the publicists, by predicting the winner with an electronic computer and viewers will stay with you all night to see if the computer is right or wrong. This extra bit of show biz, which might possibly add some life to a slow-moving story, was enthusiastically endorsed by CBS management, but professional newscasters did not know whether to take the matter seriously or not. Their general uneasiness was evident in a response by Walter Cronkite (then chief Washington correspondent for CBS) to a question by Dorothy Fuldheim during an evening news broadcast by WEWS-TV in Cleveland, Ohio:

Dorothy Fuldheim: Tell me, Walter, what are you going to do to report this very historic election?

Walter Conkite: Well, this year we’ve got the same basic formula that we had before, which is, of course, straight reporting of how the returns are coming in. However, we do have a little gimmickry this year which I think is most interesting, and may turn out to be something more than gimmickry. We’re using an electronic brain which a division of Remington Rand has in Philadelphia.

Dorothy Fuldheim: What does it do?

Walter Cronkite: It’s going to predict the outcome of the election, hour by hour, based on returns at the same time periods on the election nights in 1944 and 1948. Scientists, whom we used to call long hairs, have been correlating the facts [for these predictions] for the past two or three months…. Actually, we’re not depending too much on this machine. It may be just a sideshow…and then again it may turn out to be a great value to some people. (Wulforst, 1982, pp. 163–164)

By 8:30 pm Eastern Standard Time, with almost 3.5 million votes reported (7 percent of the total vote) (Wulforst, 1982, p. 168), CBS’s UNIVAC I accurately forecasted a landslide victory for Eisenhower—the machine gave the General 100:1 odds of winning the presidency and predicted 43 states, 438 electoral votes, and 32.9 million popular votes in Eisenhower’s favor (Nagle, 1954). “When they went to 100:1,” Cronkite later stated in an interview, “I said, ‘well this damn thing doesn’t work.’…Anyone who thinks the odds are 100:1 can’t have their ear to the ground, electronically or otherwise” (Julyk, 2008, p. 41). In reality, UNIVAC’s forecast was accurate within a 1 percent margin of error—when all votes were counted, President Eisenhower took thirty-nine states, earned 442 electoral votes, and received 33.9 million popular votes, leading CBS commentator Edward Murrow to famously state, “The trouble with machines is people” (p. 170).
perpetuum mobile.” Walter Isaacson called the transistor “one of the most important discoveries of the twentieth century.” And George Trigg, longtime editor of the prestigious Physical Review Letters, wrote “[p]robably no single development of modern physical science has touched so many people’s lives so directly as has the transistor.”

The transistor was born in 1947 in Bell Telephone Laboratories in Murray Hill, New Jersey. Compared to the vacuum tube, which was previously championed in the New York Times as the backbone to the world’s “electronic miracles from radio and television to radar and giant computers,” the transistor was superior in every way. “[A] thousandth as large, a hundredth as heavy and requiring about a tenth the amount of electric power,” the match head-sized device was considered to be “bits of laboratory magic,” and the usher to a “new electronic age.” Newspaper headlines stated “Tiny Electric Unit Promises Wonders” and “Experts See ‘Transistor’ …as Basis of Giant New industry.” Time magazine anointed the transistor the “missing electronic link” and the “long-awaited short cut through the great glass jungle of the electronics age.”

Due to the transistor’s incredible size and reliability, for the first time new and cutting-edge technologies became a reality: the satellite, the behind-the-ear hearing aid, the

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60 Isaacson, The Innovators: How a Group of Hackers, Geniuses, and Geeks Created the Digital Revolution, 144.
64 “Transistor Device in 1st Public Test,” ibid., March 4, 1952.
69 “Transistor’s Progress,” Time 60, no. 23 (1952): 44.
pacemaker, famously the transistor and pocket radio, “the computers that launched
[human]kind into space”70— “[w]ithout the tiny transistor” the New York Times reported
in 1972 on the device’s twenty-fifth birthday, “it is highly unlikely that man would yet
have walked on the moon”71— city street lights with automatic on/off timers, transistor
paging devices for doctors and hospitals, guided missile and radar systems, and nothing
short of the modern electronics industry as we now know it. “The transistor…created the
modern electronics industry,”72 Peter Drucker wrote; Wikipedia co-founder Jimmy Wales
added, “[i]he invention of the transistor changed everything.”73

The transistor was publicly announced on June 30, 1948 at Bell Telephone
Laboratories— “This cylindrical object which I am holding up is a Transistor,” Bell
director of research, Ralph Bown, announced. He continued, “Although it is a ‘little bitty’
thing, it can—up to a power output of about 100 milliwatts and up to a frequency of
about 10 megacycles—do just about everything a vacuum tube can do, and some unique
things which a vacuum tube cannot do.”74 In 1951, the first batch of commercially
produced transistors—made with germanium—were manufactured in Allentown,
Pennsylvania by Western Electric Company.75 Assembled by hand by a predominantly
female assembly line, the company produced approximately 8,500 transistors each
month.76 In 1952, the Sonotona hearing aid—the first consumer product made with
transistors—became available for sale to the public.77 Discussed by Kenneth Berger in

74 Michael Riordan and Lillian Hoddeson, Crystal Fire: The Invention of the Transistor and the Birth of the
Information Age (New York: Norton, 1997), 164.
75 Braun and Macdonald, Revolution in Miniature, 54.
76 Ibid.
the “History and Development of Hearing Aids,” within three years transistors completely replaced vacuum tubes in hearing aid equipment. In 1953, Fortune magazine proclaimed “The Year of the Transistor”: “For nearly five years,” the magazine wrote, “the electronics industry has been living with a pea-sized time bomb called a transistor, a device that can replace vacuum tubes for many jobs. This is the explosive year when the transistor goes into volume production.” In 1954, Texas Instruments announced the development of the first silicon transistor, the future elemental namesake of California’s Bay Area, and the soon-to-be foundation of technology and the electronics industry as a whole. The same year, led by Transitron, Raytheon, RCA, General Electric, Philco, and Western Electric, U.S. manufacturers produced and shipped 1.3 million transistors totaling $5.1 million in sales. By the end of the decade, U.S. transistor output topped 130 million transistors and $300 million in sales, and by the mid-1960s almost 900 million transistors and $500 million in sales. In 1956, “for their investigations on semiconductors and the discovery of the transistor effect,” the Nobel Foundation awarded the Nobel Prize in Physics to the transistor’s three inventors—John Bardeen, Walter Brattain, and William Shockley of Bell Laboratories. For their work and contribution each received “a gold medal, a diploma and a share of the $38,633 prize money.” In 1957, Philco Corporation introduced “the first commercially available [all] transistORIZED

81 The Nobel Foundation, Nobel: The Man & His Prizes, 471. In 1951 John Bardeen left Bell Laboratories to become a professor at the University of Illinois at Urbana-Champaign. In 1955, William Shockley left Bell Laboratories to start Shockley Semiconductor Laboratory at Beckman Instruments, Inc.
82 "Nobel Prize in Physics Awarded to Transistor Inventors," Bell Labs Technical Journal 35, no. 6 (1956): i.
computer”—the Philco 2000. Marketed as revolutionary, “unsurpassed in capacity or performance,” and with minimum installation costs—“[s]avings of $100,000 or more on site preparation can be realized with a [Philco 2000] system”—the machine was installed in the command center of the North American Air Defense Command (NORAD) headquarters in the early 1960s. There, the Philco 2000 remained NORAD’s main computer system until it was famously—infamously—replaced two decades later.

In 1958, riding the transistor’s momentum and growing influence, the electronics industry surged higher than ever before. Marveled in Time magazine, “No postwar industry has grown faster than electronics, and no electronic devices have paid off more handsomely than semiconductors.” Time continued:

Wall Street is well aware of electronics’ rapid growth, pays as much as 40 and 50 times earnings for what it calls “Buck Rogers stocks.” Eager buyers this year boosted Texas Instruments from 26½ to 86, Raytheon from 22 to 62¼, Fairchild Camera from 18¼ to 64¾, General Transistor from 17 to 51. But to many Wall Streeters, even such high prices seem cheap when sales and earnings are zooming. Explains one broker: “Current earnings are already past history. If you want to participate in growth, you have to pay for it.”

In 1959, in Dallas, Texas, the transistor revolution ended. If the vacuum tube symbolized the electronics industry’s first generation, and the transistor its second, Texas Augarten, Bit by Bit, 298. The Philco 2000 was initially named the Transac S-2000.


In November 1979, when field testing replacement computer systems for the aging Philco 2000, a potential replacement system misinterpreted a simulation exercise as a real missile attack: The computer ordered the launching of interceptors, and a total of 10 supersonic fighters took off from bases in Canada and the United States. In the usual threat-response scenario, the next step calls for a retaliatory strike by B-52 bombers carrying missiles with nuclear warheads. Fortunately, the error was discovered in less than six minutes, and the B-52s were ordered to stand down. (“Of Interest,” 1980, p. 9)

Transistor Transition,” Time 72, no. 25 (1958): 60.
Instruments’ 1959 invention of the integrated circuit would come to represent the industry’s third.87 The transistor introduced society to the reality and promise of miniaturized electronics, and a world of technology previously inconceivable. In the 1960s, the integrated circuit revolutionized society again, and transported humankind a prefix downward to the era of microelectronics and the official start of the semiconductor revolution. “We are on the threshold of not just miniature electronics, but microelectronics”—the New York Times announced—“of devices built of circuits so unbelievably tiny that they can literally be passed through the eye of a needle.” With the integrated circuit, the paper continued, “[t]here is almost nothing electronic which can any longer be called a dream.”88 Time magazine stated the integrated circuit “represents a bigger advance over the transistor than the transistor did over the bulky vacuum tube.”89 And the president of the National Academy of Engineering, Dr. Robert M. White, asserted “[v]ery few things have changed the world as dramatically as the integrated circuit,” and “[t]he development of the integrated circuit was the single most important event that helped usher in the information age.”90

For all the transistor’s advantages, for all its benefits over the vacuum tube, the invention of the integrated chip was a necessary solution to a growing problem. The transistor made possible not only the diminution of electronics, but also increased the potential complexity and sophistication possible in electronics design. With vacuum tubes, engineers were constrained by heat and power limits—“there was no point in

89 "Beyond the Transistor," Time 83, no. 6 (1964): 91.
90 Jon Van, "Microchip Inventors Win Award," Chicago Tribune, October 5, 1989.
designing a machine that would melt to shards as soon as it was turned on.”91 “With the transistor,” journalist T.R. Reid explained in his book, The Chip, “those fundamental design limitations disappeared…. [D]esigners could draw up plans for exotic communications and computer circuits using 50,000 or 500,000 transistors and similar numbers of diodes, resistors, and capacitors”92—that is, at least in theory. In practice manufacturing complex circuits was still an engineering nightmare. Like their vacuum tube-based predecessors, transistor circuits were built manually by hand with solder and wire and printed circuit boards. For industry the process was time-consuming, expensive, unreliable—discussed in Scientific American, “some electrical connections were inevitably flawed, forcing engineers to design redundant wiring routes that only exacerbated [the problem].”93 The transistor professed revolution but delivered only refinement; engineers could “envision countless electrical products that would transform society, but could not make them”94; Robert Slater added, “there were too many parts and interconnections [to be made], they were too close together, the human hand just wasn’t capable of handling the work…..”95

In the 1960s, the invention of the integrated circuit changed everything. A paradigm shift in the development and manufacturing of electronics, the integrated circuit reshaped industry and the technological world ever after. A decade earlier the transistor promised the future; in the 1960s the integrated circuit delivered. Hailed as “the most

92 Ibid.
95 Slater, Portraits in Silicon, 167.
important moment since man [sic] emerged as a life form,\textsuperscript{96} the invention of the integrated circuit presented industry a new approach, a new epoch in production of electronics. Evangelized early in military and space applications,\textsuperscript{97} and headlines in the \textit{New York Times}—“The ‘Chip’ Revolutionizes Electronics,”\textsuperscript{98} and “Pinhead-Size Solid Circuits Spur Electronics Revolution”\textsuperscript{99}—industry quickly gravitated to the landmark device.\textsuperscript{100} Between 1963 and 1973, sales of integrated circuits rocketed 5,406 percent; the OECD characterized the growth as “phenomenal”:

\[\text{...[T]he growth of the [integrated circuit] industry has, by any measure, been phenomenal. From the 1950s onwards the entire electronics sector has persistently grown faster than GNP per capita in most OECD Member countries, this growth rate has been outstripped by the semiconductor sub-sector, and sales of integrated circuits, since their appearance in the early 1960s, have grown even faster. During the period 1963-1973 in the United States, GNP per capita grew by 70 per cent, the electronics market grew by 202 per cent, semiconductor sales grew by 331 per cent and sales of integrated circuits by 5,406 per cent—77 times faster than GNP per capita.}\textsuperscript{101}

The digital wristwatch; the in-ear hearing aid; the unprecedented pocket calculator; the third-generation of computers; the next-generation of appliances; car sensors; hospital

\textsuperscript{96} As quoted in Leslie Berlin, \textit{The Man Behind the Microchip} (New York: Oxford University Press, 2005), 5.
\textsuperscript{98} Leedham, "The ‘Chip’ Revolutionizes Electronics."
and medical equipment; the UPC barcode scanner; innumerable everyday technologies; and the future of tomorrow’s device’s—in the 1960s the integrated circuit was the torch of the bleeding edge; “The future of integrated electronics is the future of electronics itself,” Gordon Moore wrote in his seminal paper.\footnote{Gordon E. Moore, “Cramming More Components onto Integrated Circuits,” Electronics 38, no. 8 (1965): 114.} In 2000, The Wall Street Journal declared the integrated circuit “the defining invention of the postwar world.”\footnote{Michael S. Malone, "The Missing Nobelist," The Wall Street Journal, October 17, 2000.} The same year, “for his part in the invention of the integrated circuit,” the Nobel Foundation awarded a share of the Nobel Prize in Physics to the device’s inventor, Jack Kilby.\footnote{Robert Noyce is also recognized as an inventor of the integrated circuit. Due to his death in 1990, he was not awarded a share of the 2000 Nobel Prize in Physics.} For his work and contribution Kilby received a gold medal, a diploma, and $913,000 in prize money.\footnote{James Glanz, "3 Men Vital to the Internet Share Nobel Prize in Physics," New York Times, October 11, 2000.}

By the end of the 1960s—only ten years after its invention—the integrated circuit was praised “the vitamins of the entire industrial system.”\footnote{Christophe Lécuye, Making Silicon Valley: Innovation and the Growth of High Tech, 1930-1970 (Cambridge: The MIT Press, 2006), 292.} Likewise, Business Week—in a 1969 headline—described the device as “Where the action is in electronics.”\footnote{“Where the Action Is in Electronics,” Business Week, October 4, 1969.} The magazine highlighted the chip’s large revenue potential for semiconductor companies, new and old, and the healthy sellers market available to engineers and managers:

In the semiconductor industry, where frenzy, tumult, and excitement are the rule, 1969 stands as an especially critical milestone. It looms as the last year to start an integrated circuit operation—where today’s hottest action is—and make it big.
…Hordes of bright engineers and top managers are job-hopping in a quest for better pay and stock options, or deserting industry leaders to start their own [integrated circuit] shops.\(^{108}\) The same year, humanity’s greatest achievement showcased the pinhead-sized circuit on an extraterrestrial scale. In partnership with American sweat, determination, science and engineering prowess and ingenuity, the integrated circuit aided President Kennedy’s commitment to “land[] a man on the moon and return[] him safely to earth.”\(^{109}\) In July 1969, NASA, the Apollo program, the United States, and humankind as a whole—through Neil Armstrong, Buzz Aldrin, and Michael Collins—made history in a corner of the universe previously unknown. At its peak the Apollo program “consumed over half of all integrated circuits being manufactured.”\(^{110}\) Discussed in The Innovators by Walter Isaacson:

The seventy-five Apollo Guidance Computers that were built ended up containing five thousand microchips apiece, all identical…. The program beat Kennedy’s deadline by just a few months; in July 1969 Neil Armstrong set foot on the moon. By that time the Apollo program had bought more than a million microchips.\(^{111}\) In ten years the integrated circuit transformed the possible and cemented itself in the ether of industry and society. Enabled by the transistor, the chip went farther and with more ubiquity than possible of its discrete predecessor. Two years later, the industry’s

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\(^{108}\) Ibid., 86.
next milestone, standing atop the shoulders of the integrated circuit, revised civilization and transfigured humankind and its wares forever.

In 1971, in its third year, Intel Corporation invented the microprocessor. “The microprocessor,” author Michael Malone wrote point-blank, “is the most important invention of the twentieth century.”\(^\text{112}\) In a retrospective volume entitled *One Digital Day* with the subtitle *How the Microchip is Changing Our World*, Malone continued:

The microprocessor is helping inventors propel humanity into an era of change the likes of which we have never known. It is not merely an invention, but a metainvention which enables us to create yet other inventions. Thousands of new devices and products have been made possible by the existence of the microprocessor and by the embedded intelligence it offers despite infinitesimal demands for space or power.…

For hundreds of years, humankind has searched for the philosophers’ stone, the magical object that turns ordinary metal into gold. Who would have thought it would turn out to be a little sliver of crystal with etching on its surface?… [T]he microprocessor, in the space of a single generation, has evolved from a clever technical novelty to a tireless, almost invisible partner to humanity. Today, there is no place on, above or below earth that it has not reached.\(^\text{113}\)

The shepherd of industrial automation, the usher to the digital revolution—the microprocessor has been described as miraculous\(^\text{114}\); according to John Markoff of the *New York Times*, many view “the advent of the microprocessor as the dividing line


between two historical epochs: the industrial age and the information age.”

Gordon Moore called the device “one of the most revolutionary products in the history of [human]kind.” And President H.W. Bush—in honoring its inventors—added with pride, “The microchip…helped America change the world.” Defined as a ‘computer on a chip,’ with its injection virtually any appliance became programmable through software: the light switch, the hot water heater, the coffee maker, the toaster, the garage door opener, cell phones, printers, key fob systems, air conditioners, vending machines, ATMs, motion sensing devices; plus manufacturing equipment, transportation systems of every sort, communications systems, robotics, video gaming consoles, etc. The microprocessor infiltrated every corner of daily life; it is the physical courier to civilization’s digital existence. “This talk about the pervasiveness of advanced electronics”—a key semiconductor leader stated to the New York Times in 1976—“it’s all an understatement.” He continued “[t]he technology is going to move faster than we can be sensible in applying it.”

With the continued maturation of the integrated circuit and the birth of the microprocessor, the semiconductor industry soared. Between 1972 and 1984, factory sales of semiconductor components increased 1,050 percent. Shown in Figure 4.4, the semiconductor industry’s record 1972 profit of $1.5 billion sharply escalated to a record 1984 profit of $17 billion. The Washington Post announced, “Semiconductor Industry Growth is Spectacular”—“It has been a booming industry without parallel” the paper

wrote, and “[o]ver the past decade, the compound annual rate of productivity growth for
the U.S. semiconductor industry has been a spectacular 22.5 percent—and prices have
been reduced steadily.” Headlines in *The Wall Street Journal* similarly declared
“Semiconductor Sales Show Sharp Increase World-Wide,” and “Semiconductor
Demand Continues to Be High….” And the OECD, in a 1980 survey report,
acknowledged the combination of the integrated circuit and microprocessor as the
principle catalysts and growth agents to the industry as a whole:

> Although the integrated circuit segment, in terms of sales value, does not appear
to form a major part of the electronics sector, or even of the component industry,
its significance is unparalleled in terms of its frantic rate of technical change and
its phenomenal growth. Both of these factors are reflected throughout the
electronic capital goods and consumer sub-sectors. Indeed, throughout this sector
survey, the author has adopted the feeling shared by the vast majority of observers
of, and participants in, the electronics sector, that the technical change in the
manufacture and design of integrated circuitry is the principal technical factor
underlaying most of the technical changes taking place in the sector as a whole.
Therefore, despite the small relative size of the integrated circuit (ic) industry…it
receives a disproportionate amount of attention in this sector survey. It can also be
argued that ‘market’ figures for integrated circuits greatly underestimate the
importance of such components in the straightforward sense that the vast majority
of ic’s never reach the open market. Not only do electronic equipment
manufacturers also fabricate ic’s for use in their own equipment (IBM who sell no

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122 Charles J. Elia, "Semiconductor Demand Continues to Be High, Raising Hopes of Avoiding a Boom-
circuits are believed to be the world’s largest manufacturer of ic’s) but also most of the large firms who produce components manufacture electronic equipment, and thus use large numbers of their own ic’s which never reach the market.\(^{123}\)

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\text{Figure 4.4: Factory sales of semiconductor components, years 1957-1991. Source: Electronics Industry Association Yearbook, years 1969-1993.}
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Just as the Shinkansen today symbolizes modern Japan,\(^{124}\) and the luxury automobile German engineering, in the 1970s and early 1980s the semiconductor revolution penetrated the American narrative and showcased to the world the country’s technological leadership. Ten years earlier the Space Race was more than human exploration, in the 1890s steel was more than a celebrated industry, and starting in the 1970s microelectronics were more than flecks of electronic circuitry. For the country and


\(^{124}\) Christopher P. Hood, Shinkansen: From Bullet Train to Symbol of Modern Japan (New York: Routledge, 2006).
beyond the integrated chip and microprocessor industry was the next era of innovation. The highest of high technology, the heir apparent to the country’s future, the microchip symbolized the pinnacle of American engineering, and the excitement of the age oozed throughout society. Described today as the fourth most important innovation in five thousand years of human development,\(^{125}\) of course the semiconductor revolution resulted in an abundance of engineering jobs, and of course undergraduate baccalaureate trends followed suit. Starting in the 1970s, and lasting until the early 1980s, the vector of microelectronics pointed sky high, and the engineering majors reaped the benefits.

In the next chapter we will follow undergraduate engineering’s rise. Between 1976 and 1985 engineering graduation rates—for both females and males—surged skyward. Male engineering baccalaureates increased 86 percent, and female baccalaureates increased 770 percent. Then, after peaking mid-decade, baccalaureates for both genders began to fall. In the next section we will explore why.

\[\text{IV.}\]

Braun and Macdonald captured it perfectly—a *revolution in miniature*: “The scale of this innovation,” they wrote, “is matched by its impact. Whole new industries arose, new professions, new ways of production and new organizations.”\(^{126}\) What was mere fantasy during World War II became a reality thirty years later—the advent not of a singular intelligent machine, the computer as we know it, but the explosion and renaissance of entire sectors, entire product lines engulfed by a wave of new and modern

\(^{125}\) Fallows, "The 50 Greatest Breakthroughs since the Wheel."
electronics. “Microprocessors which form the heart of a microcomputer,” the OECD wrote in its survey report, “can be used in any situation which historically utilised some form of information processing technology, whether electronic, mechanical, pneumatic or hydraulic in nature.”\(^{127}\) The organization continued:

[Microprocessors] have already displaced mechanical parts in products such as cash registers, cameras, calculators and watches, as well as having transferred the process of information transmission in communication devices (teletypewriters, telephone exchanges). Microprocessors are also currently being used to control consumer products like washing machines and ovens, or parts of such products like car engines. Such traditional capital goods as machine tools, textile machinery and fork-lift trucks can be microprocessor controlled as well as whole systems such as chemical process control, automated assembly lines and railway signal networks.\(^{128}\)

The application of semiconductor components to virtually any imaginable ingredient of daily life, including the growing interdependence and “expansion of electronics into fields that ha[d] been hitherto nonelectronic in nature or even nonexistent,”\(^{129}\) and the resultant overhaul of entire industries in the 1970s and 1980s—the microchip has been credited as the foundation of the world’s “third industrial revolution”\(^{130}\)—is the history and circumstance informing undergraduate engineering’s baccalaureate growth. Like the first industrial revolution, circa the 1760s to 1820s, which introduced the factory system,

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\(^{128}\) Ibid.


steam power, and mechanized labor\textsuperscript{131}; and the second industrial revolution, circa the 1870s to 1910s, built atop electricity, the internal combustion engine, as well as revolutions in transportation (e.g., the railroad system, the automobile, the airplane) and communication (e.g., the telegraph, the telephone, and the radio)\textsuperscript{132}; the microprocessor was a turning point in the human experience, a paradigm shift in the foundation of technology, and the catalyst to an engineering explosion.

Beginning in the early 1970s, as factory sales of semiconductor components rocketed upward (see Figure 4.4), demand for engineering graduates followed suit. In 1974, a \textit{Chicago Tribune} headline stated “Engineering Grads…on ‘Most Wanted’ Lists,” with the caption “Engineering students prepare for high pay offers”\textsuperscript{133}—“An electrical engineering senior graduating this December,” the paper reported, “has been offered a starting salary of $17,400 by a Chicago firm,” and “Another electrical engineering student graduating in May has reported an offer of $16,000….”\textsuperscript{134} The \textit{Los Angeles Times} declared, “Job Prospects for Engineers Rosy…”\textsuperscript{135}; the \textit{Wall Street Journal} announced, “Graduating engineers…will find themselves [among the] most in demand for jobs next spring”\textsuperscript{136}; and Dean Victor Lindquist of Northwestern University, in a newspaper interview stated, “For graduating engineering students, the job prospects are like a huge pot of gold at the end of a four-year rainbow.”\textsuperscript{137} In December 1974, the \textit{Boston Globe}

\begin{flushright}
\textsuperscript{131} See S. Lilley, \textit{Men, Machines and History: The Story of Tools and Machines in Relation to Social Progress} (London: Lawrence & Wishart, 1965), 87-112.
\textsuperscript{132} See ibid., 113-41.
\textsuperscript{134} For reference, the annual salary of a graduating senior from the class of 1975, after one year of full-time employment, averaged $7,600 (Snyder, Tan, & Hoffman, 2004, p. 464).
\end{flushright}
added “Jobs: Engineers to Do Best in '75,” and five months later, in the face of an oncoming U.S. recession, the Chicago Tribune announced “Engineers’ Bright Job Prospects Defy Economic Gloom.” In response to the powerful narrative, freshman enrollment in engineering increased—between 1973 and 1975, freshman enrollment in engineering grew 45 percent, from 51,925 students in 1973 to 75,343 students in 1975 (see Figure 4.5).\textsuperscript{138} Four years later, as the incoming classes of 1973 and 1975 became the graduating classes of 1977 and 1979, respectively, engineering baccalaureates began its decade-long surge. Between 1976 and 1979 engineering baccalaureates increased 35 percent—from the 1976 low of 46,676 degrees to 62,898 degrees in 1979.\textsuperscript{139}

\begin{figure}[h]
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\includegraphics[width=\textwidth]{figure4_5.png}
\caption{First year engineering enrollment, years 1967-1990. \textit{Source:} Engineering Manpower Commission reports in Engineering Education.}
\end{figure}

\textsuperscript{138} I recognize ‘freshman’ is not a gender neutral term. I reluctantly use the term to avoid any ambiguity regarding the population in question. Please note I use the term once and switch to ‘first year students’ thereafter.

\textsuperscript{139} Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 502.
In the first half of the 1970s the proliferation of the integrated circuit and microprocessor galvanized engineering both as a profession and as a major. More importantly, the semiconductor industry became the symbol of American might—the Washington Post stated point blank, the semiconductor industry is “America’s symbol of technological superiority”\(^\text{140}\)—and throughout the remainder of the 1970s, the influence and expectation of electronics and semiconductor components enraptured society. The New York Times reported engineers in Silicon Valley “are convinced they are revolutionaries and that their discoveries will affect the way Americans work, live and play within a decade.”\(^\text{141}\) Sociologist Trevor Jones, in Microelectronics and Society, wrote:

> The microprocessor (or ‘silicon chip’ or just plain ‘chip’) has attracted more attention than any other recent technological innovation: a veritable torrent of words on the subject has poured from the pens and mouths of journalists, trade unionists, socially-conscious technologists and scientists, politicians and even clergymen.\(^\text{142}\)

And, in a statement to the Boston Globe, the vice president of a technology-based consultant firm directly linked engineering’s explosion to the proliferation of electronics: “The reason why we’re [high technology] in a boom situation today, with no end in sight, is the new pervasiveness of electronics in society.”\(^\text{143}\)


\(^{141}\) McElheny, "Revolution in Silicon Valley."


Between 1975 and 1979, first year engineering enrollment increased another 28,000 students, and four years later baccalaureate trends continued to climb upward. Headlines in the *Los Angeles Times* reported “Demand for Engineers Fast Outgrowing Supply,” and, “They Can Pick And Choose: Jobs Outnumber Engineering Students”\(^{144}\) — “From Hawthorne to Hartford, from Dallas to Seattle,” the paper wrote, “aerospace, electronics, and other high-technology companies are engaged in a frenetic hiring campaign that holds high stakes for workers and industry alike.”\(^{145}\) The *New York Times* reported, “Engineers: Graduates in Demand”\(^{146}\) — “The stock market may be down and the economy may have bearish overtones, but there is a bull market for graduates who have majored in engineering,” and “[New Engineer magazine editor] thinks the demand for engineers in research and development will concentrate on those with electrical and electronics majors and those experienced in computer science.”\(^{147}\) The *Boston Globe* reported, “Everyone Wants Engineers.”\(^{148}\) And the *Chicago Tribune* announced, “Engineers Top Wanted List”\(^{149}\):

Job offers for engineering graduates are pouring in again this year, surpassing even last year’s record demand, the College Placement Council reports.

Employers have made 40 per cent more offers to prospective engineers at the bachelor’s degree level than they had last year at this time, when college

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\(^{147}\) Ibid.

\(^{148}\) Smith, "Everyone Wants Engineers: Jobs, Jobs Everywhere, and No Big Surge in the Labor Supply Is in the Offing."

\(^{149}\) "Engineers Top Wanted List," *Chicago Tribune*, April 1, 1979.
recruiting reaching its highest level since the last 1960s, the center said in a report for release this week.

For engineering departments in the early 1980s, the record influx of students and increasing demands for engineers became a double-edge sword. A headline in Science stated “Engineering Education Under Stress” with the subtitle “Undergraduate crush exacerbates shortage of faculty, resources…”—“At Iowa State University (ISU),” the journal reported,

incoming students intent on majoring in high-demand specialties in engineering and computer science are warned that it may take them 5 years rather than 4 to complete their undergraduate work. The caveat is a clear local sign of what nationally is being called the crisis in engineering education.

As in other universities around the country the oversubscribed majors are electrical engineering, computer engineering, and mechanical engineering....

The Los Angeles Times announced “A New Engineering Boom Creates Campus Problems,” and reported the University of Illinois at Urbana–Champaign “reduc[ed] [engineering] enrollment 20% to relieve pressure on overworked faculty members and crowded laboratories.” Under the headline “Professors Respond to Lure of Industry Salaries: Engineering Schools Facing Crisis,” the paper also highlighted the incredible imbalance in industry salaries versus the modest income of university engineering professors, and the lure for engineering professors to leave academia. Between 1977 and

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151 Ibid., 1479.
1982, the paper reported, “The number of full-time engineering professors has fallen by 2,500, or about 15%, in five years.” And under the headline “Bull Market For Engineers: Schools and Industry Compete for Baccalaureates and Ph.D.s,” *Time* magazine noted the dwindling faculty candidate pool and the competition between industry and academia for engineering PhDs:

[D]eans of U.S. engineering schools [find] themselves hopelessly outmatched in the intense competition for top talent in a soaring job market for engineers. Massachusetts Institute of Technology has been trying for four years to fill three vacant assistant professorships in the growing field of electrical engineering. The University of Illinois is desperately trying to recruit 30 more professors for an engineering staff that normally numbers 400. Nationally, the American Association of Engineering Societies reports that 2,000 college teaching jobs are going begging…. Faculty members are chosen from the pool of engineering Ph.D.s, and the pool is dwindling. In 1972 U.S. universities awarded 3,774 engineering Ph.D.s, as against 2,751 this year. More than a third of those went to foreign nationals, who are likely to take their skills back home after graduation.¹⁵⁴

Between 1979 and 1981, the bull market for engineers continued—in 1981 first year engineering enrollment reached 115,280 students (compared to 52,100 first year students in 1972). The *Los Angeles Times* announced “Job Offers Pour In for U.S. Engineering Graduates” and “Top Salaries Going to June Graduates in Engineering”¹⁵⁵—“The fattest paychecks at the end of the academic trail, up to $30,000 a year, await

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engineering graduates this year...”156 Under the headline “Engineering Grad Top Banana,” the Chicago Tribune reported, “Although engineering students accounted for only 7 per cent of the bachelor degree candidates in 1980-1981, competition for these graduates was so keen that engineering job offers totaled 65 per cent of all offers made by recruiters.”157 The Boston Globe declared, “Money Drawing More Students to Engineering,” and “Engineering Grads Paid the Highest.”158 And the New York Times stated, “Degrees in Engineering Bring Top Offers for ’81 Graduates.”159 Four years later, engineering’s incoming class of 1981 became its graduating class of 1985, and the major’s baccalaureate surge reached 97,099 degrees (compared to 46,676 degrees in 1976).160

Overall, in ten years engineering’s first year enrollment increased 122 percent, while engineering baccalaureates increased 108 percent. Between the mid-1970s and mid-1980s, male bachelor’s degrees reached an all-time high—from 45,184 degrees in 1976 to 83,991 degrees in 1985. As a ratio of the total male graduating class, male engineers increased from 8.9 percent in 1976, to 17.4 percent in 1985 (see Figure 4.1 and 4.3). For female engineers, bachelor’s degrees in engineering increased from 1,492 degrees in 1976 to 13,108 degrees in 1985.161 As a ratio of total female baccalaureates, female engineers increased from 0.4 percent of the total female graduating class—that is, for every 250 female graduates, only one earned a bachelor’s degree in engineering—to
2.6 percent in 1985—one female engineer for every 39 female graduates.\textsuperscript{162} As displayed in Figure 4.1 and Figure 4.2, the decade between 1976 and 1985 is the only time period of meaningful and noteworthy growth for women in undergraduate engineering over the past half century.

![Graph showing total engineering enrollment by select curricula, years 1977-1990.](image)

Figure 4.6: Total engineering enrollment by select curricula, years 1977-1990. Note: in 1975, the seven engineering curricula above accounted for 67.3 percent of total engineering enrollment; in 1986 the seven engineering curricula accounted for 77.2 percent of total engineering enrollment. Source: Engineering Manpower Commission reports in Engineering Education.

In terms of curricula, according to the Engineering Manpower Commission (since renamed Engineering Workforce Commission), between 1975 and 1985 electrical engineering’s total enrollment increased 60,441 students, while mechanical engineering’s enrollment increased 31,302 students, aerospace engineering increased 11,308 students, industrial engineering increased 8,913 students, chemical engineering increased 4,548 students, and civil engineering decreased 3,198 students (see Figure 4.6). Similarly,

\textsuperscript{162} Ibid., 448, 502.
between 1977 and 1985 computer engineering’s enrollment increased 13,804 students (1977 was the first year computer engineering’s enrollment was provided as an individual category in the enrollment/degree report by the Engineering Manpower Commission in *Engineering Education*). Likewise, in terms of percent of engineering enrollment, electrical engineering was the clear benefactor of engineering’s boom. Shown in Figure 4.7, its enrollment captured almost 10 percentage points more of engineering’s enrollment in 1986 than it did in 1977. Among the seven most popular engineering curricula, electrical engineering is the only one with a pronounced incline, a pronounced peak in the mid-1980s, and a subsequent decline thereafter.

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Figure 4.7: Engineering curricula as a proportion of total engineering enrollment, years 1977-1990. 
Source: Engineering Manpower Commission reports in Engineering Education.

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Beginning in the early 1980s, America’s longstanding position as world leader in the semiconductor sector came to an abrupt end. America invented ENIAC, America invented the transistor, America invented the integrated circuit, and America invented the microprocessor. But in the 1980s, U.S. command in electronics was lost to Japanese competition. For the country, the falling dominoes of soft markets and dwindling stock prices turned to layoffs and reduced operating costs, and as a result, the overwhelming and bullish narrative of high-paying jobs in engineering throughout the country came to an end. Beginning in the late 1970s, headlines in the New York Times acknowledged the

Now come signs that Japan is looking to add yet another scalp to its lengthening collection of industrial trophies—the $4.8 billion U.S. production of integrated circuits, the hottest and most highly competitive field of advanced industrial technology. The worldwide semiconductor market is expected to soar to $100 billion annually by the end of the century. Moreover, the industry's key product, the confetti-size sliver of silicon known as the microchip, is revolutionizing everything from giant computers to tiny home appliances, making possible a whole new generation of low-cost machines that can “think” and “talk”…. 

Japan is quietly trying to displace the U.S., where integrated circuits were developed early in the 1960s, as the world’s leading designer and producer of computer hardware. Already Japanese companies control nearly 25% of the world chip market. Japanese manufacturers have made serious inroads in the 16K RAM (for random access memory) chip, which is capable of containing 16,384 separate bits of information. Japanese producers now control 40% of that U.S. market.


The foreign challenge traces back to the 1973-75 recession, when orders for circuits plunged and the industry reacted by slashing capital spending in new plants and equipment by 52%. During 1979, however, demand for the chips surged as toymakers and electronics companies incorporated them into TV computer games and “smart toys” for tots. But domestic producers such as Intel, Advanced Micro Devices and Texas Instruments were unable to fill the orders. Japanese manufacturers quickly filled the gap.166

Soon, for American manufacturers the combination of low Japanese prices and high Japanese quality coupled with market and regulatory barriers were too much to overcome. As early as 1980, newspapers reported a $223 million U.S. semiconductor trade deficit with Japan,167 and in 1983 America’s worldwide trade surplus in electronics turned into an overall trade deficit (see Figure 4.8).168 Dwindling profits and shrinking stock prices became common—the New York Times reported “shares of semiconductor companies have dropped to their lowest levels in years and could be selling at bargain prices,”169 and “[i]nvestors who stuck with semiconductor stocks through a troubled first half in hopes that the industry would be in an uptrend by the second may find their judgment severely tested.”170 And Headlines announced, “Singing the Semiconductor

Blues,” “Forecast Gloomy for Semiconductors,” and “Beaten at Our Own Game.”


For engineers, the result of the above would be rounds of layoffs, furloughed jobs, and wage freezes. In March 1982 the *Los Angeles Times* announced “Sperry Plans New Layoffs at Irvine Unit” (“Sperry Corp. will lay off 250 engineers and researchers at its Irvine-based minicomputer facility…”)

the *Wall Street Journal* reported, “Texas Instruments Furloughs 2,700, Citing Soft Market”

and the *Boston Globe* announced, “750 Honeywell workers in Massachusetts found themselves looking for jobs.” Others

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added, “Semiconductor Firm Imposes Wage Freeze,” and “Slump Hits Bay State High-Tech.”¹⁷⁵ In May 1982 Texas Instruments announced more layoffs—via the Boston Globe, “Texas Instruments Cuts 425 Workers”¹⁷⁶; in June, semiconductor company GCA announced job cuts to its integrated circuit division—“GCA Corp. to Idle 175, Report Loss”¹⁷⁷; in July, the Wall Street Journal reported more Texas Instruments cuts—“Texas Instruments Inc. Lays Off Additional 125, Bringing Total to 7,000”¹⁷⁸; in August, National Semiconductor Corp. announced 1,000 job cuts¹⁷⁹; in September, Texas Instruments announced another 2,600 layoffs¹⁸⁰; in October, the Wall Street Journal reported, “Many Plant Closings Planned by National Semiconductor Corp.”¹⁸¹; and in November Intel enacted a one-year wage freeze—“Intel to Cut Salaries Up to 10%, Impose 1-Year Pay Freeze”¹⁸²—while Motorola adjusted employees’ work weeks to reduce operating costs—“48-Hour Work Week Started by Motorola.”¹⁸³

In the early 1980s the help wanted signs prominently recruiting engineers a few years earlier were replaced by pink slips. The United States’ semiconductor portfolio gave way to Japanese competition, and American manufacturers struggled to stay profitable. A headline in the New York Times conceded, “Why Japan Won the Chip Race,” stating point blank: “The battle for the latest generation of computer memory

¹⁷⁹ "Layoffs by National Semiconductor Total 1,000 in U.S.,” Wall Street Journal, August 9, 1982.
¹⁸² Marilyn Chase, "Intel to Cut Salaries up to 10%, Impose 1-Year Pay Freeze," ibid., November 18, 1982.
chips is over. Japan has won.”\textsuperscript{184} For undergraduates the symbolism of America’s lost leadership in the semiconductor revolution, and the reality of layoffs diminished engineering’s appeal, and enrollment and baccalaureate trends in the major quickly reacted to the market. As displayed in Figure 4.5, first-year enrollment crested in 1982, and proceeded to decline steadily throughout the remainder of the decade. Four years later, in 1986, engineering baccalaureates turned downward as well, marking the official end to engineering’s 1976 to 1985 surge.

Chapter 5: Interpretation of Results
This study represents one of the more detailed explorations of disaggregate female and male trends in undergraduate STEM over the past half-century. Using an explanatory history case study methodology, select trends were examined to better understand the types of historical mechanisms influencing baccalaureate outcomes in science, technology, engineering, and mathematics. Fifty years ago a gender gap characterized every STEM field. Today, this is no longer the case. However, explanations of why participation remains stalled in some STEM fields as opposed to others are not fully understood. While much has been written about the gender gap at an aggregate level, less attention has been given to understanding the sequencing and evolution of disaggregate female and male baccalaureate patterns within individual STEM fields. Therefore, it was the intent of this dissertation to offer historical accounts of significant female and male trends in undergraduate STEM. Doing so—I argued—would provide a deeper inroad into gender issues prevalent in STEM, and advance understandings of the disciplinary, cultural, and political barriers which remain invisibly intact in certain fields. Therefore, I asked the following research questions:

1. What mechanisms influenced the periods of increasing and decreasing patterns of participation characterizing select individual STEM fields in the last fifty years?

2. How do these underlying influences inform an explanatory framework of female and male participation in undergraduate STEM as a whole?

Concerns about gender and the underrepresentation of women in undergraduate STEM have increasingly become mainstream over the past half century, and countless theories and frameworks seeking to explain gender trends in science, technology,
engineering and mathematics have been offered by a variety of researchers. Some argued biological and innate differences accounted for the drastic divide.¹ Others acknowledged the combination of “chilly climates” and overtly masculine environments within STEM classrooms and departments have alienated and precluded female participation.² Eccles and Hoffman foregrounded socialization and cultural forces—women, they argued, pursue “studies emphasizing nurturing while men are encouraged in domains emphasizing quantitative reasoning.”³ And Polachek postulated economic reward expectations and life-cycle investments to underlie the undergraduate gender gap.⁴ 

To further explore trends in undergraduate STEM, and to examine focal periods in select fields, I used an explanatory history case study approach. Explanatory histories seek to gain a deeper understanding of a specific course of events, and present a theory of cause: a theory which “represents the researcher’s estimate of how one event or combination of events determined—entirely or at least partially—what happened later.”⁵ Three focal cases were selected for examination based on their significance to the aggregate gender gap. The first case was selected because it resulted in near female and male baccalaureate parity in an undergraduate STEM field. The second case was selected because it resulted in the first instance of female baccalaureate majority in an undergraduate STEM category in the past half century.⁶ And the third case was chosen for its importance to contemporary questions regarding the limited participation of females in undergraduate engineering. Overall, it was found each focal period of

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¹ Blickenstaff, "Women and Science Careers: Leaky Pipeline or Gender Filter?.
² Etzkowitz et al., "Athena Unbound: Barriers to Women in Academic Science and Engineering.
⁴ Polachek, "Sex Differences in College Major.
⁵ Thomas, Blending Qualitative and Quantitative Research Methods in Theses and Dissertations, 20.
⁶ Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)," 494-516.
baccalaureate growth and decline could be derived from either political, occupational, and/or public perception-related factors. In other words, in each case female and male pursuits in undergraduate STEM were tied to a collection of atmospheric conditions beyond the college or university, with a characteristic four-year delay in baccalaureate response. The combination of these factors, and their impact on undergraduate trends, can be summarized as collective *calculations of advantage.*

**Summary of Results**

In the first history we explored the one-sided decline of males from the biological sciences between the years 1976 to 1986. Motivated by a 1989 National Science Foundation profile report, female and male parity in the biological sciences was not the result of increasing female trends, but rather decreasing male trends. Stated in the report:

In 1986, fewer men and women earned baccalaureates in the biological sciences than in 1976. This downward trend was more pronounced for men: the number of baccalaureates awarded to men decreased by 44 percent compared to a 1-percent decline for women. Consequently, in 1986, the number of women baccalaureates almost equaled that of men.\(^7\)

Through an exploration of cultural and societal influences on student outcomes, it was found the evolution of deferment policies during the Vietnam War resulted in the incentivized participation of males in the biological sciences. Language from an internal Selective Service “Orientation Kit”—as reprinted in *Ramparts* magazine—explicitly acknowledged ‘channeling’ as an important component of the Selective Service System’s mission during Vietnam (i.e., “One of the major products of the Selective Service

\(^7\) National Science Foundation, "Profiles—Biological Sciences: Human Resources and Funding (NSF 89-318)," 31.
classification process is the channeling of manpower into many endeavors, occupations and activities that are in the national interest”8). In the 1960s, various deferment-related pathways were available to young men—marriage, parenthood, graduate school, etc. However, by 1969 the only deferment-related pathway (apart from ministerial options) was the successful pursuit of an occupation in a medical or health-related field. Using medical school and MCAT examinee data, we observed a growing relationship between the biological sciences and medical education; the biological sciences became a prominent pipeline for graduate training in health and medical fields. Then, in 1973, with the United States’ transition toward an all-volunteer military force—which brought an end to conscription policies and governmental incentives toward the biological sciences—male enrollment in the biological sciences decreased resulting in declining baccalaureate trends between 1976 and 1986.

In the second history we explored an increase in female and male baccalaureates in the biological sciences between 1989 and 1998. Notably, during that ten-year span the biological sciences were the fastest growing undergraduate category in the country, both numerically and in percent growth. Through an exploration of industrial and market psychology factors, it was found the 1970s birth and 1980s blossoming of biotechnology and genetic engineering as an industry, and the popular perception of biotechnology on Wall Street and in the media, spurred undergraduates toward the field. In 1980 a landmark Supreme Court decision, *Diamond v. Chakrabarty*, triggered the commercial awakening of genetic engineering. By mid-decade, after a string of highly publicized breakthroughs, excitement among researchers carried over to Wall Street, and biotechnology stocks soared. This positive atmosphere for biotechnology in research and

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8 "Channeling," 34.
on Wall Street trickled throughout American society and catalyzed a strong narrative for undergraduate participation in the biological and biomedical sciences. As a result undergraduate participation began reflecting biotechnology’s growing presence in the country, and beginning in the late 1980s male and female baccalaureates in biotechnology began to climb upward.

In the mid-1990s, however, poor market performance and the failure of biotechnology products to reach consumers en masse resulted in bearish Wall Street overtones and frustration with the field. The *Wall Street Journal* published, “Bloodbath in Biotech…”; *Science* declared “Biotech Sails into Heavy Financial Seas”; and a front page *Business Week* cover story teased, “Biotech: Why it Hasn’t Paid Off.” Biotech’s mid-1980s boom became biotech’s mid-1990s bust, and baccalaureate trends in the late 1990s began reflecting its diminishing public perception. Male baccalaureates in biology (as a proportion of total male baccalaureates) decreased 1.7 percentage points in six years—from 5.7 percent in 1998 to 4.0 percent in 2004; while the proportion of female baccalaureates in biology as a proportion of total female graduates decreased 0.6 percentage points—from 5.5 percent in 1998 to 4.8 percent in 2004.

In the final history we explored female and male baccalaureate trends in engineering, years 1976 to 1985. During this ten-year span engineering was the second fastest growing major in the country—second to business in numerical growth, second to computer science in percent growth. It was found the maturation of the integrated circuit and microprocessor, the advent of the semiconductor revolution, and the proliferation of microchips throughout industry and society resulted in an incredible demand for engineers. As reported in various newspaper articles throughout the decade, engineering
graduates received an incredible number of job offers—according to the College Placement Council, in 1981 engineering graduates receive 65 percent of all job offers extended to graduating students. In addition to the sheer number of available jobs, engineering graduates received the highest annual salaries compared to their peers. As a result, engineering enrollment soared, with electrical engineering the largest benefactor. According to the Engineering Manpower Commission, between 1975 and 1985, electrical engineering’s enrollment increased 60,441 students, while mechanical engineering’s enrollment increased 31,302 students, aerospace engineering increased 11,308 students, industrial engineering increased 8,913 students, chemical engineering increased 4,548 students, and civil engineering decreased 3,198 students. Similarly, between 1977 and 1985 computer engineering’s enrollment increased 13,804 students.

Then, beginning in the early-1980s, America lost its semiconductor lead to Japan. Price competition and unmatched advancements in quality led manufacturers to purchase semiconductor components from non-U.S. suppliers. Previously characterized as the symbol of American technology and technological superiority, America’s lost lead in the semiconductor industry resulted in electronics layoffs, furloughed workers, wage freezes, etc., and as a result, a downward pointing vector for engineering. In terms of undergraduate baccalaureates, for both males and females this downward pivot trickled down to engineering baccalaureates beginning in 1986.

**Discussion**

I began this study with two goals: first, to explain historical gender participation patterns in select undergraduate STEM fields in the last fifty years, which I achieved. Second, I sought to contribute to a more adequate and in-depth explanatory framework
modeling gender participation in STEM as a whole. In this section, I will apply and relate my findings to existing and contemporary understandings of undergraduate female and male STEM trends.

**Calculations of Advantage**

We’ve explored female and male trends in undergraduate STEM from three vantage points, and gained a robust understanding of the types of mechanisms which have influenced baccalaureate growth and decline. These mechanisms can be summarized as collective *calculations of advantage*.

In all three examples, we observed undergraduate fields swelling in enrollment in reaction to opportune narratives. Deferment opportunities during Vietnam incentivized a growing subset of males toward the biological sciences, and bullish job markets and overwhelming narratives in engineering (1976-1985) and the biological sciences (1989-1998) resulted in increasing female and male baccalaureates in both fields, respectively. Then, in the absence of advantageous narratives, each field declined. The removal of deferment opportunities dissuaded male students from the biological sciences, while bearish periods in biotechnology and the semiconductor industry negatively impacted baccalaureate trends in both.

The crucial observation—the connective tissue relating the three societal trends to undergraduate baccalaureate decisions—is the theorized personal valuation matrix informing students’ selections of majors. We postulate students’ valuation matrices to assign advantage—or lack thereof—to various pathways against a range of individually-distinctive determinants (e.g., personal values, life expectations, strengths, weaknesses, etc.). We assign the terminology *calculations of advantage* to describe the favorable
component within this undergraduate handicapping process. In the first history, opportunities to avoid war resulted in the positive evaluation of the biological sciences in the early 1970s.\textsuperscript{9} Likewise, bullish job markets, high-paying salaries, and/or positive market psychology resulted in a growing subset of students to view both the biological sciences and engineering very favorably. The resonation of all three societal influences on students’ valuations resulted in increasing calculations of advantage assessments for each respective area, and as a result, increases in enrollment and baccalaureates. Then, as societal and industrial influences shifted—in the cases of genetic engineering and the semiconductor revolution, negatively—student valuations waned, resulting in the perceived lack of advantages for the biological sciences and engineering, and thus a downward reversal in baccalaureate trends.

Through this framework we can also begin to explore the similarities and differences in baccalaureate growth between both genders. In the case of the biological sciences, years 1989 to 1998, the impact of biotechnology on female and male trends was uniform in outcome—that is, biotechnology’s advantages resonated equally with each gender. Both females and males started from similar initial baccalaureate levels in 1989, and as the decade progressed each gained an equivalent proportion of degrees as related to overall gender trends. In the case of engineering, years 1976 to 1985, both females and males flocked to engineering as never before, however the overall portrait of undergraduate engineering throughout the decade remained predominantly male. Males gained 38,807 degrees, while females gained 11,616 degrees.\textsuperscript{10} On the surface, this result provides little information regarding female inroads into a male-dominated field.

\textsuperscript{9} This characterization echoes what researchers in economics, higher education, and sociology have applied—without this level of detail—to student choice.
\textsuperscript{10} Snyder and Dillow, "Digest of Education Statistics 2012 (NCES 2014-015)."
However, when separating baccalaureate trends by gender, between 1976 and 1985 we found engineering to be the second fastest growing male major category in the country in terms of percent growth (second only to computer science), and the second fastest growing female major category in the country in terms of percent growth (again, second only to computer science).\textsuperscript{11} From this perspective, the semiconductor revolution resonated equally with females and males—that is, equivalently increasing ratios of males and females viewed engineering as being advantageous between 1976 and 1985 due to the same catalyst. This is an important distinction given contemporary research which often foregrounds issues of gender and gender discrimination, as oppose to occupational and/or opportunity-related influences. Through the lens of personal valuation matrices and calculations of advantage, we are provided a more nuanced vocabulary and more nuanced framework with which to explore gender and STEM beyond numerical notions of the gender gap. Female and male assessments of advantage toward engineering were proportionally equivalent between 1976 and 1985, as they were in the biological sciences between 1989 and 1998. Thus, we theorize in some historical periods of STEM growth the most important predictor of female and male trends not to be gender, but rather initial baccalaureate starting levels and prevalence of advantageous opportunities.

\textbf{Challenges to Existing Frameworks}

Compared to contemporary frameworks focused on issues of gender and undergraduate STEM at aggregate levels, the collection of histories in this volume provides a level of detail typically unmatched in most examinations of the gender gap. As a result, extending its results to existing research paradigms of gender and STEM is

\textsuperscript{11} Ibid.
warranted. Specifically, I will focus on application of its results to notions of ‘men and things, women and people’ paradigms. Su et al., in their meta-analysis of sex differences in vocational interests, stated:

Given women’s preference for people-oriented careers over things-oriented careers, women who pursue scientific careers tend to gravitate toward fields that allow for more opportunities to work with people, such as the biological and medical sciences, psychology, and other social sciences (Lubinski & Benbow, 2007).12

While recent trends in undergraduate STEM baccalaureates seemingly support this notion—biology is often highlighted as the exception to undergraduate STEM’s gender gap, and surface level characterizations of the field coupled with intrinsic female orientations toward people-centered curricula are often identified as explanatory factors—the historical analyses presented in this volume challenge this popular conclusion. Through the lens of this study, the recent popularity of the biological sciences can be viewed merely as a trend. Displayed in Figure 5.1, in 1986 female baccalaureates in the biological sciences, computer science, and engineering were not dissimilar. Since 1990, however, female trends in the biological sciences have increased significantly, while trends in engineering and computer sciences have stalled. Through the results of this dissertation, and the collectives finding of each individual case study, arguments citing inherent female tendencies toward the biological sciences appear simplistic. Rather, the prominent increase in biology baccalaureates are informed by industrial booms in genetic engineering and biotechnology. And calculations of advantage—and

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the subsequent lack thereof—explain not only increasing female and male baccalaureates in the biological sciences, but also periods of stagnation and/or decline.

![Graph showing female baccalaureate trends in the biological sciences, engineering, and computer science, years 1986-2011. Source: Digest of Education Statistics 2012, p. 496, p. 500, & p. 502.](image)

In addition, arguments citing female preferences toward the biological sciences—especially in comparison to males—are not accurate. Displayed in Figure 5.2 is the proportion of female and male baccalaureates earned in the biological sciences, respectively, since 1980. Only in 2000 did females eclipse males in gender ratio, and in recent years the difference has not been meaningful. Likewise, female trends in the biological sciences have not always increased. Between 1976 and 1986, female baccalaureates stagnated numerically, and decreased in percentage of female baccalaureates. More recently, female baccalaureates in the biological sciences declined in the wake of biotechnology’s 1990s slump. The proportion of female baccalaureates
awarded in the biological sciences decreased from 5.5 percent in 1998 to 4.8 percent in 2004. Thus, I conclude notions of female preference for the biological sciences—whether inherent or inherited—are both overly simplistic and misleading.

Figure 5.2: Percentage of female and male baccalaureates earned in the biological sciences by gender, years 1970-2011. Source: Digest of Education Statistics 2012, p. 448 & p. 496.

The Gender Gap

In each chapter of this dissertation, I’ve made the case undergraduate trends in STEM are bound to the happenings of society. That the peaks and valleys of undergraduate baccalaureates are not independent of the American landscape, but rather the outcome and byproduct of the American and global macrocosm. Through the lens of each individual chapter, as well as through the dissertation as a whole, we cannot help but view baccalaureate trends as the result of rich narratives and authentic opportunities; of
here and now movements and their impact on undergraduate choices; and, in a very real
sense, as the byproduct of whatever has captured America’s attention. While this seems
incongruent to contemporary notions of the gender gap (e.g., in two of my chapters I
focus on periods of parallel growth, rather than on periods of increasing female STEM
trends with respect to males), the results of this dissertation provide a realistic
expectation—a concrete pathway—for analyzing and understanding female and male
parity in STEM moving forward.

Two thirds of this dissertation focused on periods in which STEM fields were the
fastest growing or second fastest growing majors in the country. Between 1989 and 1998,
the biological sciences were the fastest growing area in American higher education, both
numerically and in terms of percent. Between 1976 and 1985, engineering was the second
fastest growing area in the country—second only to computer science (another STEM
major) in percent growth, and second only to business in numerical growth. Throughout
both periods in higher education, female and male baccalaureates in each area swelled in
number. For biology, women jumped from 18,070 degrees in 1989 (50.1 percent of
biology baccalaureates) to 36,803 degrees in 1998 (55.0 percent of biology
baccalaureates), and males increased from 17,998 degrees (49.9 percent) to 28,507
degrees (45.0 percent), respectively. In engineering, between 1976 and 1985 female
baccalaureates increased 770 percent—from 1,492 degrees (3.2 percent of engineering
baccalaureates) to 13,108 degrees (13.5 percent), and males increased from 45,184
degrees (96.8 percent) to 83,991 degrees ten years later (86.5 percent). With respect to
the gender gap, the takeaway from both of these periods is notable. After the emergence
of biotechnology as an industry and a surge in undergraduate participation, females
gained five percentage points on their male counterparts. After the start of the semiconductor revolution and its impact on undergraduate choices, females gained ten percentage points on their male counterparts. While each time period is characterized by parallel female and male numerical growth, in each decade we slowly see gender gap improvement in individual STEM fields. In each instance, the result is the figurative—and more importantly, literal—advancement of females in STEM. In other words, in each chapter the narrowing of the gender gap did not hinge on one-sided trends or the increasing participation of only one gender in a field. Rather, the gender gap was tied to female baccalaureates increasing at a faster rate than males regardless of male growth. As a result, in a very realistic sense, through this dissertation we can begin to visualize the narrowing of the gender gap through a series of progressive baccalaureate fits and spurts built atop the lockstep and incremental advancements of advantageous opportunities.

Implications for Further Research

This study represents one of the first attempts to explore select disaggregate female and male trends in individual undergraduate STEM disciplines using an explanatory history case study methodology. Clearly, additional examinations of disaggregate patterns—in addition to the three presented in this volume—would contribute to an even fuller understanding of the types of mechanisms informing female and male enrollment in STEM fields. The three histories contained in this dissertation provide a level of detail unmatched in most studies of gender and STEM. More histories would further add to researchers’ understandings of gender and STEM as well as the sequencing of gender trends within individual undergraduate STEM fields.
In addition, there are several unanswered questions from the three analyses presented in this volume which warrant further exploration. In the first focal history exploring male trends in the biological sciences during Vietnam, we observe a markedly different baccalaureate pattern between females and males in years 1976 to 1986—male trends declined 44 percent while female trends declined one percent. Between 1970 and 1976, however, surging male baccalaureates were mirrored by surging female baccalaureates (see Figure 5.2). While deferment and conscription policies explain both the rise and fall of male baccalaureates, an analysis of female participation in the biological sciences in the 1970s, using techniques similar to those in the three preceding chapters, would be beneficial. Potential counter arguments against the history outlined in Chapter Two on males and Vietnam could easily focus on the apparent parallel increase in male and female baccalaureates at the start of the 1970s. A fuller understanding of this time period with respect to female trends would provide further clarity to this lingering question.

Likewise, in the second history focused on biotechnology and baccalaureate trends in the biological sciences in the late 1990s, both female and male trends peak in 1998 (see Figure 5.2). In subsequent years, however, female trends decline at a slower rate than their male counterparts. Between 1998, the percent of male baccalaureates awarded in biology declined from 5.7 percent in 1998, to 4.0 percent in 2004 (a 1.7 percentage point decrease), while the proportion of female baccalaureates decreased from 5.5 percent in 1998 to 4.8 percent in 2004 (a 0.7 percentage point decrease). Why female trends declined at a slower rate than males in the biological sciences during this time period is a very fruitful area for further exploration. A thorough understanding of this
difference could inform overall understandings of female and male trends in aggregate-level STEM.

**Limitations**

There are two prominent limitations to this study which restrict the generalization of its results. First, while I’ve offered three historical arguments connecting a variety of social, technological, and/or political influences to enrollment patterns, and identified student calculations of advantage as a mechanism informing increasing and decreasing patterns in select STEM fields, more histories are needed to generalize results to female and male STEM trends as a whole. Due to the small number of historical case studies, caution is warranted when extending this study’s conclusions to other undergraduate STEM trends. Each history in this volume examined a period prominently marked by an increasing baccalaureate slope, a peak, and a clear downward decline. However, a majority of baccalaureate trends in undergraduate STEM do not conform to this pattern, and extending this study’s results to these periods is not justified at this time.

Second, each focal case study in this volume was constructed through an explanatory history methodology. Explanatory histories seek to establish an “estimate of how one event or combination of events determined.” As a result, each history represents a single theoretical account. Therefore, the results of this study are open to alternative theorizing by other researchers. I attempted in this study to demonstrate each population in question as agents interacting with the institutions of her and his world. And I attempted to derive outcomes (operationalized as increasing or decreasing baccalaureate trends) by informed understandings of American society, culture, and human nature. Alternative understandings of these forces, however, could result in

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13 Thomas, *Blending Qualitative and Quantitative Research Methods in Theses and Dissertations*, 20.
divergent accounts with different historical emphases. Therefore, caution is warranted when interpreting each history’s results.

Conclusion

This study provides a unique exploration of select disaggregate female and male trends in undergraduate STEM using an explanatory history case study methodology. Overall, it was found female and male trends in undergraduate STEM were informed by calculations of advantage, as based on assessments of potential social, political, technological, and/or monetary factors. In the cases of engineering, years 1976 to 1985, and the biological sciences, years 1989 to 1998, bullish job markets and glamorous public perceptions resulted in a growing subset of undergraduate students to view each field as being advantageous to future prosperity, thus resulting in an increase in baccalaureates. After cresting in public/industrial/economic perception, etc., bearish overtones surrounding both industries resulted in a growing subset of students to retreat from each major, respectively, and thus a decrease in baccalaureates. In the case of the biological sciences, years 1976 to 1986, it was found war avoidance behaviors during Vietnam and opportunities for deferment incentivized a growing subset of males toward the major. In 1973, with the enactment of an all-voluntary armed service force, the omission of incentives toward the biological sciences resulted again in a growing subset of students to retreat from the major.

In a sense, findings from across the histories speak to the intersection of two comfortable and accepted ideas. One, discrimination and bias against women exists in society, and this discrimination is displayed in the aggregate gender gap which is prominent in undergraduate STEM. Two, undergraduate trends are not independent of the
waxing and wanings of society nor do they exist in a vacuum. Rather, undergraduate trends are embedded within the culture, and the attention of the populace is reflected in undergraduate choices. Given the implications of this dissertation, the intersection of these two ideas—while individually accepted—results in a somewhat uncomfortable, yet hopeful, notion: that gender-based obstacles can be overcome by opportunity, and that there is evidence female and male undergraduates are willing to invest in STEM majors with remarkable upside regardless of historic influences. In other words, if incredible opportunities in American society present themselves, and if high-paying and glamorous jobs are accompanied by authentic narratives of prosperity and excitement, it appears forces of discrimination and bias will diminish in their wake.
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