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GRAND VALLEY STATE UNIVERSITY

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Message from Nancy M. Giardina

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We are proud to present the thirteenth volume of the Grand Valley State University McNair Scholars Journal. It is the culmination of intensive research conducted by our student scholars and their faculty mentors through our Ronald E. McNair Scholars Program.

The Ronald E. McNair Scholars Program, now in its 15th year here at Grand Valley State University, provides an opportunity for students and faculty to apply much of what is learned within the classroom by engaging, outside the classroom, in research activities in a particular area of scholarly interest. These research activities provide a journey through the challenges and affirmations of scholarly work and better prepare students for graduate study and the pursuit of a doctoral degree.

Thank you to the faculty mentors who have worked so closely with our McNair Scholars to propel their research skills towards the next level of educational challenges.

Congratulations to the nine McNair Scholars whose research is presented here. Your journey and the challenges you have met during this scholarly activity speak to your talents and persistence in pursuing both your educational and life goals. Thank you for sharing your talents with the university community and continuing the spirit of this program.

Finally, thank you to all the people behind the scenes that work to sustain this program and produce this journal. Your work is valued as well.

Nancy M. Giardina, Ed.D.
Assistant Vice President for Academic Affairs

GRAND VALLEY STATE UNIVERSITY

"Before you can make a dream come true, you must first have one." - *Ronald E. McNair, Ph.D.*

Ronald Erwin McNair was born October 21, 1950, in Lake City, South Carolina, to Carl and Pearl McNair. He attended North Carolina A&T State University where he gradated Magna Cum Laude with a B.S. degree in physics in 1971. McNair then enrolled in the prestigious Massachusetts Institute of Technology. In 1976, at the age of 26, he earned his Ph.D. in physics.

McNair soon became a recognized expert in laser physics while working as a staff physicist with Hughes Research Laboratory. He was selected by NASA for the space shuttle program in 1978 and was a mission specialist aboard the 1984 flight of the USS Challenger space shuttle.

After his death in the USS Challenger space shuttle accident in January 1986, members of Congress provided funding for the Ronald E. McNair Post-Baccalaureate Achievement Program. The goal is to encourage low-income, first generation students, as well as students who are traditionally underrepresented in graduate schools, to expand their opportunities by pursuing graduate studies.

Ronald E. McNair Post-Baccalaureate Achievement Program

The Purpose
The McNair Scholars Program is designed to prepare highly talented undergraduates to pursue doctoral degrees and to increase the number of individuals (from the target groups) on college and university faculties.

Who are McNair Scholars?
The McNair Scholars are highly talented undergraduate students who are from families with no previous college graduate, low-income background or groups underrepresented at the graduate level for doctoral studies. The program accepts students from all disciplines.

Program Services
The McNair Scholars are matched with faculty research mentors. They receive academic counseling, mentoring, advising, and GRE preparation. In addition to the above services, the McNair Scholars have opportunities to attend research seminars, conduct research, and present their finding orally or written via poster presentations. In the first semester of their senior year, the scholars receive assistance with the graduate school application process.

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Table of Contents | 2009 McNair Scholars

Reflections of Whiteness: The Origins, Progression, and Maintenance of White Supremacy as a Cultural, Political, and Economic Force in American Institutions

Marcus Bell
McNair Scholar

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Abstract

Despite the prevailing national discourse that implicates race as an outdated phenomenon, ongoing social science data identifies race as very predictive in determining life outcomes. Over the last 40 years the emergence of "whiteness studies" has sought to redefine racism from individual actions of bigoted persons to institutional systems of privilege and disadvantage. While there have been a number of studies detailing the failures of reconstruction to embrace an equal citizenry fully, and also a number of studies detailing the eventual assimilation of European immigrants, few studies have sought to connect both into one simultaneous entity. Using historiography and historical comparison methodologies, this research examines primary and secondary data sources in order to illustrate how racism, factionalism, and violence doomed radical reconstruction and cemented white hegemony into American culture through its various institutions. It also examines the bloody decades following reconstruction and the early 20th century transformation of the category "white" from an ethnicity to a race, thus creating the badge of whiteness and securing its privileges for generations to come.

Introduction

In contemporary America, to be white is to be considered American. The normalcy of whiteness, the category that all others are compared to, is accompanied by a set of systematic privileges that advantages those of the dominant race at the disadvantage of all others (Bonilla-Silva, 2006). From education to life expectancy, from criminal justice to political representation, white hegemony permeates every institution in American society, and African Americans are typically at the opposite end of the spectrum (Brown, 2003). While white hegemony is the life force of America's institutions, white supremacy or white domination is what allows it to go unchallenged (Leonardo, 2009).

Despite the continuing levels of residential and school segregation, the vastly unequal levels of school funding, the increasing achievement gap between black and white students at all levels of education, the differences of accumulated wealth, the higher rates of black incarceration, the higher rates of blacks living in poverty, and the ongoing discrimination in healthcare, medicine, and employment, racism is largely seen as a thing of the past, only relevant on the periphery of American society. In fact, the most common form of racism accepted by the general public is "reverse racism," the notion that being white in America is to be disadvantaged, while being a member of a minority group comes with its advantages. Author Tim Wise (2008) writes, "Interestingly, whites often deny the importance of racism in determining the life chances of blacks, even as they give voice to beliefs that are themselves evidence of the very racial prejudice they deny" (p. 40). He continues: "In one of the more respected opinion surveys from the 1990s, six in ten whites said that discrimination was less important in determining the position of blacks in society than the 'fact' that blacks 'just don't have the have the motivation or willpower to pull themselves up out of poverty.'" In other words, whites could extol their belief in negative stereotypes while simultaneously denying any salience of racial discrimination.

Social scientists and historians of color turned a critical eye towards the white majority in the early 19th century with the works of Frederick Douglas and David Walker. Just as in the 1800s, scholars of the 20th century such as W.E.B Du Bois, James Baldwin, and later in the century Thandeka, Malcolm X, Toni Morrison, and Ralph Ellison, due to their marginalized status, were generally overlooked and disregarded as nothing more than fodder from "the African American left" (Roediger, 2007, p. xvi). For example, powerful insights by Du Bois (1903), such as "The opposition to negro education was at first bitter, and showed itself in ashes, insult, and blood; for the south believed an educated negro to be a dangerous negro" (p. 29), or perhaps even more profound: "to be a poor man is hard, but to be a poor race in the land of dollars is the very bottom of hardships" (p. 12), were dismissed as unimportant complaints from an inferior being. When Malcolm X (1965), a man considered to be a "black radical," spoke to crowds of thousands of black folk, proclaiming things such as "Brothers and sisters, the white man has brainwashed us black people to fasten our gaze upon a blond haired, blue eyed Jesus! We're worshiping a Jesus who doesn't even look like us!" (p. 263), he was considered dangerous, and his words of truth were considered to be that of a raving lunatic.

The first work on race relations that detailed the haunting, often violent opposition to full black inclusion in American society, and was actually taken seriously was *An American Dilemma* by Gunnar Myrdal in 1944. Myrdal was a Swedish sociologist who was funded by the Carnegie Foundation because of his intellectual ability and moral objectivity. In a sweeping indictment of American injustice and racial inequality, Myrdal concluded that the "dilemma" of which he spoke was not that of black inferiority, but that of white superiority: A superiority that was founded on a social, not biological basis, and was perpetuated by continuing levels of racism, both overt and ingrained in institutions. He wrote:

> There is no doubt that the overwhelming majority of white Americans desire that there be as few Negroes as possible in America. If the Negroes could be eliminated from America or greatly decreased in numbers, this would meet the whites' approval—provided that it could be accomplished by means which are also approved. Correspondingly, an increase of the proportion of Negroes in the American population is commonly looked upon as undesirable. (p. 47)

Concluding his accusation of white supremacy, Myrdal noted, "White prejudice and discrimination keep the negro in low standards in living, health, education, manners and morals. This, in its turn, gives support to white prejudice. White prejudice and Negro standards thus virtually 'cause' each other" (p. 193). While initially accepted and at first considered a classic, *An American Dilemma* was eventually overshadowed by World War II and the more militant offerings of the civil rights movement. However, in the late 20th century, Myrdal's work once again found its way to prominence in the new wave of studies aimed at identifying institutional discrimination, a new wave that would come to be known as "whiteness studies."

Contemporary Inequalitwies

Of course, times change, and the American Civil Rights movement achieved significant progress towards racial quality. Consequently, a plethora of erudite professionals, including sociologists to historians to political scientists, have come to the forefront in an attempt to tackle racial discrimination in its now mostly covert, post-civil rights manifestation. Studies examining white privilege and the various mechanisms of maintaining it have illuminated new ways of not only looking at racism today, but also new ways of looking at history in general. In its path of analysis, whiteness studies leaves no American institution uncovered. For example, in his 2009 book titled *Race, Whiteness, and Education*, Zeus Leonardo, speaking of the bipartisan legislation and political acceptance of No Child Left Behind (NCLB), wrote: "Insofar as NCLB is guided by an ideology of whiteness, it depends on the continuation of racial differences as part of a logical, rather than social, outcome. In other words, ostensibly giving public schools a chance to show progress, NCLB gives whiteness the right to declare students of color failures under a presumed to be fair system" (p. 136). Commenting on the roles that schools play in African American communities, and the conservative "free market, competition solution," Jerome E. Morris noted:

> Low income, predominantly black communities especially need stable institutions, and for many urban communities, schools can serve this function. This has to be taken into consideration when policy makers conceptualize choice models that transfer African American students away from their communities. Although it is important to increase choices for parents who do not want their kids to attend the city's school, if city schools are not viewed as viable choices for African American students, it could have dire effects on the roles that schools play in predominantly black communities. (p. 147)

Whiteness allows school reform to treat a gunshot wound with a Band-Aid. Legislation that provides choice for relatively few of the students who are forced to attend condemned schools does nothing to solve the problem of the condemned school. With the penalties of failure associated with NCLB, poorer schools that serve predominantly students of color are only getting poorer.

In terms of wealth accumulation, Thomas M. Shapiro (2004) found that in 1999, 26% of all white children grow up in asset-poor households, compared to 52% of black children who share the same fate. For every white kid growing up in an asset-poor household, there are two black kids doing the same—a statistic that is even more disturbing when we consider the fact that African Americans only make up 13% of the population, while whites comprise upwards to 70%. Shapiro also noted that the average African American family has only 10 cents of accumulated wealth for every one dollar the average white family has, a ratio that holds constant even when the comparison controls for educational attainment, size of family, and annual income. These findings are consistent with U.S. Census data that showed in 1991 the median net worth of white households was $44,408, compared to $4,604 for black households. In 2004 the U.S. Census showed the median net worth of white households was $121,000, compared to $19,000 for black households (U.S. Bureau of the Census 1991, 2004). The two primary reasons for these gross inequities in wealth between black and white households are equity arising from home property values and intergen-

erational transfers.

While technically applicable to whites and free blacks (over 90% benefited whites), the Homestead Act of 1862 made over 270 million acres of land available for virtually nothing. Today, over 40 million whites are direct descendents of those benefiting from the Homestead Act, and over 15 million still live on the land in question. Furthermore, the Federal Housing Administration (FHA), part of the National Housing Act of 1934, lent over 120 billion dollars in government backed home equity to Americans. What is troubling about this is the fact that, for the first 30 years of its existence, the FHA, through restrictive covenants and district redlining, systematically operated in an all white fashion, and almost completely barred blacks from receiving any of these funds (Katznelson, 2005, p. 48). The FHA, along with the G.I. Bill and various other parts of The New Deal, is credited with creating the American middle class. Millions of middle class whites owe their lives to these programs that in retrospect constitute "affirmative action for whites."

A recent study found that the "baby boomer" generation is in the process of inheriting over seven trillion dollars in assets from their parents and grandparents (Wise, 2008, p. 240). Considering the baby boomer generation started in the late 1940s and early 1950s, the assets that their parents and grandparents accumulated were done so in a time of American history in which racism in all of its manifestations was generally accepted, and blacks faced open discrimination. Looking back, sociologists and historians agree that America at the close of the 19th century and the start of the 20th century operated in a racial caste system, and the constitutional rights of blacks were violated in all of America's institutions. While much of this took place 50-150 years ago, the opportunities provided and the wealth passed down have had an impact on every subsequent generation, and they still impact the economic landscape today. Coupled with the benefits accrued from the Homestead Act and FHA discrimination, there are substantial levels of wealth inequality between white and black families.

In terms of crime, referencing the now infamous Baldus study, a study examining over 2000 murder cases between 1973 and 1979 that resulted in death penalty sentences, Randal Kennedy (1997) observed that "among the variables that might plausibly influence capital sentencing—age, level of education, criminal record, military record, method of killing, motive for killing, relationship of defendant to the victim, strength of evidence, and so forth—the race of the victim emerged as the most consistent and powerful factor" (p. 329). Coming under criticism, Baldus subjected the data to 230 non-racial variables in order to control for anything that might have influenced the results, and still concluded that in the state of Georgia, the odds of being condemned to death were 4.3 times higher for defendents who were convicted of killing a white victim than those who killed a black victim (Baldus, 1979). Findings like these give footing to the pervasive feelings of helplessness and insecurity blacks feel in regards to police and the criminal justice system in general. They also suggest a psychological and material defense of whiteness: psychologically in the sense of security and confidence whites may have in the neutrality and application of the criminal justice system, and physically, in the literal increased likelihood of being put to death for having a white victim.

Furthermore, Kennedy (1997) asserts that "Alongside racially biased police brutality, the specter of wrongful convictions at trials tainted by bigotry has long haunted the collective conscious of African Americans. In addition, racially biased miscarriages of justice have strongly influenced American culture, particularly African American culture" (p. 24). It is also hard to ignore the positive correlation between the increase in black incarceration and the national war on drugs. In *Whitewashing Race: The Myth of a Colorblind Society*, Michael Brown (2003) found that "between the mid 1980's and the mid 1990's, the number of black men sentenced to prison for drug offenses increased by more than 700%, and the fastest growing segment of the prison population was black women, incarcerated mainly for nonviolent crimes" (p. 135). It would be reckless and irresponsible to deny the high prevalence of street crime perpetrated by African Americans (indeed most critiques of whiteness to date make this claim), but it is equally reckless, and perhaps even more irresponsible, to turn a blind eye to the salience of racial discrimination in all facets of the criminal justice system, from racial profiling to jury nullification to the application of the death penalty. For that matter, preoccupation with street crime neglects the far larger losses incurred through corporate crime and willful mismanagement for personal gain, all perpetrated by white executives. From 2001-2009, Enron, Arthur Andersen, Tyco, WorldCom, Global Crossings, AIG, Lehman Brothers, Bear-Stearns, and numerous smaller players accounted for nearly two trillion dollars in criminal and negligent losses, compared to about 108 billion dollars in street crime losses for the same period (FBI Crime Statistics and Analysis, www.fbi.gov).

The influence of whiteness invades areas of contemporary society other than education, criminal justice, and wealth accumulation. It also exacerbates inequalities in healthcare, employment, and political representation. With regards to disparities in healthcare, as Michael Brown (2003) noted, "Disparities that often mean life itself," in 2003 the National Cancer Institute (NCI) reported that cancer deaths are increasing much faster among blacks than whites, sometimes 20 to 100 times faster (p. 25). The NCI also noted that even though breast cancer is more prevalent among white women, black women are more likely to die from the disease. Furthermore, infant mortality, a condition that the medical profession agrees could easily be reduced with better medical care for the mother and child, is over twice as high for blacks than it is for whites (U.S. Department of Health and Human Services, 2003). In this sense, racial inequality not only has a powerful impact on the quality of life one lives, but on life itself. On average, whites not only enjoy a higher quality of life than blacks, but they are also more likely to live, as indicated by lower infant mortality rate and longer life expectancies.

With regards to employment, from less than high school to advanced degree, whites earn more than blacks annually. What is more telling, however, is that the white-black annual income gap increases with educational attainment. The gap is the smallest for whites and blacks who do not possess a high school diploma, and highest for whites and blacks who possess an advanced education degree (U.S. Bureau of the Census, Educational Attainment in the United States, 2003). In addition to these numbers, according to the Statistical Abstracts of the United States, a table provided by the U.S. Census that measured unemployment rates from 1980 to 2004, regardless of economic stability or instability, regardless of the decline in low skilled manufacturing jobs, and regardless of the exponential increase in educational attainment by black men and women, the national unemployment rate has for blacks remained stable at two to two and a half times higher than the national unemployment rate for whites (U.S. Bureau of the Census, Bureau of Labor Statistics 2004). These findings illustrate the employment hegemony that whites enjoy and are indicative of the inequalities that are present in other institutions as well. When the economy is doing well, whites will fare better than blacks. When the economy is doing poorly, whites will fare better than blacks. On average, it does not matter if we are comparing Ph.D. holders or high school drop outs, when it comes to employment, whites will fare better than blacks.

The apparatus that perpetuates these systemic inequalities in the age of individualism is as complex as it is profound. First, any analysis of the persistence of racial inequality has to discuss the re-segregating of America's neighborhoods and schools. In 1966 Thomas Pettigrew, an African American historian, noted, "Residential segregation has proved to be the most resistant to change of all realms—perhaps because it is so critical to racial change in general" (pp. 112-113).

While these studies empirically demonstrate salient racial inequality, it is important to note that contemporary inequalities in housing, education, employment, healthcare, wealth, and politics have historical roots and can all be traced backed to a missed opportunity for full racial inclusion following the Civil War.

The Present through the Past

In the four decades following the war that emancipated the slaves, newly freedmen and northern blacks saw the United States Government act on their behalf for racial equality for a brief moment in history during radical reconstruction, only to have any social, economic, and political gains taken away from them in the form of race riots, black codes, poll taxes, lynchings, and eventually Jim Crow laws. The early 20th century saw the assimilation of European immigrants such as Greeks, Irish, Jews, Poles, and Italians into the category of white, a designation that was previously out of reach to those considered higher than blacks, but lower than whites. This was a watershed moment in American history because it enabled racial discrimination to identify American citizens easily in dichotomous white and nonwhite terms. In a country that places privilege on white skin, easily identifying who is white and who is not has a powerful effect on where one can live, go to school, gain employment, watch a movie, or even receive medical treatment.

This is what I wish to examine. The failure of reconstruction not only meant the re-enslavement of African Americans in all but name, but it also opened the door to Jim Crow indoctrination, indefensible acts of violence against blacks, and the disenfranchisement of blacks, all of which doomed future generations of blacks to a disempowered existence of poverty, segregation, and poor educational and occupational opportunities. Coupled with their acceptance as white, European immigrants who previously faced discrimination now enjoyed institutional advantages that set in motion the rise of white supremacy along readily determined racial lines that encoded racism in institutional processes and cultural standards. While overt racism would continue, the new white supremacy established a new racism in the subtleties of standardized forms, procedures, alleged objective assessment, and the intricacies of individual perception.

Conceptualization of the Current Problem

The institutionalization of white supremacy into American society was synonymous with an intertwining of otherwise contradictive notions. That is, white supremacy not only originated in but was strengthened by the American ideals of democracy and independence. Democracy and discrimination are polar opposites, yet the existence of slavery within a country that fancies itself the land of opportunity, a country that promises the right to life, liberty, and the pursuit of happiness, indicates who is entitled to said opportunities, and who is not. As Joel Olson (2004) notes, "Reflecting American society at large, the discipline has generally treated race prior to, or outside the political realm. This pre-political conception of race tends to separate racial inequality out from democratic ideals, which makes it difficult to recognize the ways in which race and democracy are interconnected" (p. XII). He continues, "Logically, absolute equality and privilege conflict. When equality is reserved for some, however, it can coexist with privilege" (p. XVI). This is the essence of white supremacy: the existence of racial privilege within a democracy, the existence of unearned rewards accrued through race within a meritocracy, the existence of racial advantage in a country that alleges equal opportunity for all.

After the end of Civil War, and the official emancipation of all African slaves, white supremacy was implemented through four distinct mechanisms: social and economic apartheid, biological determinism, cultural apathy, and racial terrorism. Social and economic apartheid refers to the separate institutions of economy that were reserved for whites and blacks. This included employment, schools, criminal justice, politics, and social life. Biological determinism refers to the science of racial superiority; the notion that whites were genetically superior to blacks and that it could be proven scientifically. Cultural apathy refers to the north and its own vices as they pertained to race following the Compromise of 1877. These vices included their own social policies and behaviors that discriminated against blacks and an indifference to the racial terror that blacks experienced in the south. Finally, racial terrorism refers to the unprecedented and largely unpunished violence aimed at blacks at the hands of whites in the south. This violence, coupled with political, cultural, and economic inequality, was intended to relegate African Americans to second class citizens, but citizens nonetheless.

Social and economic apartheid, cultural apathy, biological determinism, and racial terrorism all occurred in a dialectical matrix. There was no chronological or linear process, one did not cause the other, and they often happened in conjunction with one another. The amalgamation of all four, however, effectively created a racial hierarchy within the walls of a democracy and laid the ground work for white supremacy for generations to come.

My use of the term "white supremacy" also warrants a little clarification. In America, largely because of its openly racist past, white supremacy is generally accepted as overt, public displays of racial discrimination. White supremacy is equated with the Ku Klux Klan, Neo-Nazis, and hate groups who openly tout the legitimacy of white superiority and the inferiority of all other races. With this conceptualization in mind, it would be easy to interpret my use of the

term "white supremacy" as outdated, or an indictment of America as a nation that openly discriminates against blacks in a hostile manner reminiscent of the antebellum slave state or the Jim Crow south. My conceptualization, however, for the purposes of this project, treats white supremacy as the systemic advantages conferred to whites on the basis of their skin color. These privileges come in many forms and impact many institutions. They are often times subtle in their practice, but their consequences are no less destructive than the racial oppression faced by African Americans throughout America's ugly racial history. It is precisely because of its subtlety that contemporary white racial privilege is largely considered a thing of the past, and America is now in a so-called post-racial era. Overt and public racial discrimination of America's past created white privilege, and the general indifference to its salient manifestation allows white privilege to continue today.

To be clear, white supremacy is the institutional practices that advantage whites at the disadvantage of other races. White supremacy is privilege within a democracy. White supremacy is the legacy of accumulated wealth and the ability to be considered the norm to which all other colors are compared. White supremacy allows whites to be taken as individuals, and not be a representative of their race.

Methods

To illustrate how white supremacy came to be, I analyze a 60 year period from the end of the Civil War in 1865 to the early 20th century case of United States v. Bhagat Singh Thind, which essentially led to the assimilation of all European immigrants. The overall method is historical-comparative with statistical augmentation, all from secondary sources. I intend to reconstruct the economic and cultural origins and development of white supremacy in the United States and its impact on the present. My literature review includes studies conducted on family wealth, whiteness, meritocracy, education, residential segregation, and employment, as well as historical studies of salient time periods: the pre-and post Civil War period and the first 25 years of the 20th century. I also will be looking at primary historical documents such as the U.S. Constitution, Supreme Court legislation, and quotations from prominent political figures throughout American history. This review incorporates all types of sources: journal articles, census data, primary historical documents, and secondary studies. I will conclude my analysis by bridging connections between past and present, illustrating various ways which historical inequalities and racial oppression benefits whites today in the realm of education, employment, housing, and wealth accumulation. These bridges, in conjunction with contemporary forms of white racial privilege, combine to maintain a constant and even strengthening presence of white supremacy in the American landscape.

The components of legitimizing white supremacy—social and economic apartheid, biological determinism, cultural apathy, and racial terrorism—all happened within the context of radical reconstruction and the 40-50 years following the end of radical reconstruction in 1877. This context is marked by four watershed moments: The creation of the Freedmen's Bureau in 1865, the Compromise of 1877, the 1896 United States Supreme Court decision in Plessey v. Ferguson, and the 1923 United States Supreme Court Decision in The United States v. Bhagat Singh Thind. While other moments during this time period, including the passing of the 13th, 14th, and 15th Amendments to the Constitution, southern elections, Supreme Court decisions, passed legislations, race riots, and northern resistance, were very influential in the institutionalization of white supremacy, the four aforementioned moments warrant additional explanation because of their lasting legacy in solidifying racial privilege.

Reconstruction

While the Emancipation Proclamation (occurring in two parts) was issued in late 1962 and early 1963, perhaps a more symbolic day for the hundreds of thousands of "technically" freed slaves was April 9, 1965. On this day, the much heralded General Robert E. Lee surrendered the Confederate Army of Northern Virginia to Lieutenant General Ulysses S. Grant, marking the official end of the bloodiest war ever to take place on American soil. It was one thing for the slaves to be told that they were now free by President Lincoln, but it was another thing altogether to see the fight to preserve the institution of slavery come to an end. The Confederate Army had been defeated, and the shackles and chains that had held the slave in bondage for so long were finally to be removed. The whips and lashes that had for centuries penetrated the skin and spilled the blood of servants were finally to be put away. With the Union persevering, newly freed slaves and northern blacks alike saw a genuine opportunity for America finally to live up to its ideals and truly become the land of equality and opportunity, where blacks and whites could lift their heads as brothers and sisters of a dignified and unified land. Sadly, it was not to be.

Social and Economic Apartheid

Initially, the promise of reconstruction and the possibility of racial equality seemed not only attainable, but inevitable. The Freedmen's Bureau was created in 1865 and was established to help the newly freed slaves, previous freedmen, and even poor whites. Through the various policies of the Freedman's Bureau, blacks were able to build schools, participate in politics, and get elected to office. The benefits and rights conferred to blacks were relatively small, but given the previous status of slaves, blacks had at least some reason to believe that things were changing for the better. The south had other plans, however.

First, with the election of ex-Confederate soldiers and former slave holders, policies signed into law upheld the institution of slavery in all but name. A series of laws referred to as "black codes" kept the freedmen disenfranchised, subjected them to violence with little to no protection under the law, and punished them for rudimentary infractions or "vagrancy laws," by which the only way the penalty could be mitigated was by paying a hefty fine (which the vast majority of ex-slaves could not afford) or becoming indentured servants for a specified amount of time (Foner, 1984). These "codes" were designed to preserve the southern way of life; to maintain a physical and a status distance between the nearly four million newly freed slaves who resided in the south, a system of social and economic apartheid was put into practice.

To understand how an institution as vicious and inherently unequal as slavery could exist in a land that espoused equality, one must understand the origins of prejudice. Ideally, democracy and racial subordination are contradictory to one another, so for them both to exist in the same country at the same time, subordinated groups had to be seen as less than human. Prejudice allowed whites to see African slaves as the product of an inferior race, therefore not afforded the rights and protections guaranteed by the United States Constitution. America was never meant to be a nation for anyone other than whites, therefore democracy and the subordination of the slave was not contradictory, but rather the natural order of things. Joel Olson (2004) writes, "Notwithstanding some soul searching by a few genteel slave holding intellectuals like Jefferson and Madison in the late eighteenth and early 19th centuries, there is little evidence of an American dilemma.... The democratic, egalitarian, and libertarian ideals were reconciled with slavery and genocide by restricting the definition of humanity to whites" (p. xvi). Examples of this sentiment are expressed in statements made by elected officials such as Governor B.F. Perry of South Carolina, who stated, "the government of my state is a white man's government and intended for white men only," and Governor R. M. Patton of Alabama, who proclaimed, "In the future, as had been the case in the past, the state affairs of Alabama must be guided and controlled by the superior intelligence of the white man" (Franklin, 1961, p. 51). An ex-Confederate officer elected to the Louisiana legislature agreed. In reference to newly freed slaves and education, he cautioned, "I am not in favor of positively imposing upon any legislature the unqualified and imperative duty of educating any but the superior race of man—the white race" (p. 46).

The ideology of white supremacy and black subordination did not begin with slavery, and abolishment of slavery as an institution did little to change this. Throughout the south following the war, ex-Confederate officers and even soldiers were being elected in mass numbers. As one historian put it, "In the south, some connection with the rebel service seemed to be the best endorsement in the eyes of the people" (Franklin, 1961, p. 44). Seen as dedicating themselves to an honorable cause throughout the war, southern populations not only sought to reward ex-members of the Confederate army, but also elect those who were more inclined to preserve "home rule," a euphemism for black subjugation. In reference to these Confederate politicians, Franklin noted, "Militia colonels and cavalry captains found opportunities for service as members of the legislatures, as sheriffs, local judges, and the like. Whatever their views regarding reconstruction, the former confederates could look forward to an important role in the formulation and execution of postwar policies" (p. 45). It was simple; the rebuilding and restoration of the south after the Civil War was going to be in the hands of those who fought under the Confederate banner. These men were seen as the best chance of preserving the southern way of life, especially as it pertained to the Negro; they did not disappoint.

A number of southern states, including Louisiana, Alabama, Mississippi, Florida, Texas, and Georgia, within a year of the end to the Civil War, enacted their own various versions of policies, official and unofficial, that have come to be known as "black codes." "They recognized the right of Negros to hold property, to sue and be sued (as long as both parties were black), and to have legal marriages and offspring" (Franklin, 1961, p. 48). Freedman could handle no firearms or other weapons, and they were not allowed to possess or drink alcohol. Any Negros who intermarried with whites were guilty of a felony, punishable by a fine, long prison term, or long assignment to servitude. In some cities, blacks were not allowed to come within the limits of particular cities without expressed permission from an elected official. Blacks were allowed to sign contracts as laborers for whites who owned land; however, if the contract was deemed to be broken or unfulfilled by the Negro (which was mostly determined by the subjectivity of the white land owner), then a fine was to be paid, and/or prison or servitude was enforced. Many communities required the Negro to be off the street by a specified hour, while others had laws against the Negro using insulting gestures or exercising the function of minister of the Gospel without a license. Some states required blacks to possess papers at all times that demonstrated or proved that they were "lawfully employed," while other states prevented slaves from renting land in urban areas purposely in order to limit their economic opportunities (Foner, 1984). Blacks who desired to pursue a profession other than farmer or servant (which mirrored the responsibilities of plantation slavery) were required to pay an annual tax of 10 to 100 dollars depending on the state. Whites were not subjected to these kinds of taxes. This is something that Eric Foner described as a "severe blow to the free black community of the south, and to former slave artisans" (p. 93).

Apprenticeship laws also surfaced, which arguably caused the biggest uproar amongst newly freed slaves because they most resembled slavery. Apprenticeship laws required blacks under the age of 18 to work for planters without pay. "These laws allowed judges to bind to white employers black orphans and those whose parents were deemed unable to support them. The former owner usually had preference, and consent of the owner was not required" (Foner, 1984, p. 94). As one could imagine, after the abolition of slavery, there were a lot of what the powers could consider "orphans." Many children were torn apart from their families during slavery, and after the war ended, this fact was used to declare African American minors as orphans and essentially keep them as slaves. Even when families were reunited, whites could for any number of reasons declare the parents unfit, thus rendering their children orphans and confining them to forced, unpaid servitude.

These "codes" or laws, as they were seen by the white majority of the south, were not a return to slavery per se, but a way to maintain the southern way of life by ensuring the newly freed slaves devotion to their country. As one reporter at the time observed, "we acknowledge the overthrow of the special servitude of man to man, but seek to establish the general servitude of man to commonwealth" (Foner, 1984, p. 94). The south saw a massive increase in the punishment of petty crimes, crimes that almost exclusively applied to blacks. For example, laws in Georgia and Mississippi made the theft of a horse or mule a capital crime. South Carolina required blacks working in agriculture to present written authorization from their "masters" before selling produce. Laws emerged that prohibited blacks from hunting, fishing, and free grazing of livestock. As one Floridian legislature put it, "opposing the rights of blacks to hunt and fish was necessary because hunting and fishing allowed blacks to subsist while avoiding plantation labor" (p. 95). North Carolina made the intent to steal a capital crime, and "intent" was decided by white sheriffs, white judges, and even white citizens. Some states even made it illegal to own a dog; while some states allowed blacks to own dogs, they assessed taxes in order to do so. "Most of the laws employed such terms as 'master' and 'servant' and clearly

implied a distinction that consigned the Negro to a hopelessly inferior status" (Franklin, 1961, p. 49). John W. Burgess (1906) summed it up best when he observed that "Almost every act, word or gesture of the Negro, not consonant with good taste and good manners as well as good morals, was made a crime or misdemeanor, for which he could be first fined, and consigned to a condition of almost slavery for an indefinite time, if he could not pay the bill" (p. 46).

The south quickly established a racial pecking order. By electing ex-Confederate soldiers and officers to office, southern states were able to ensure separate institutions of work for blacks and whites, separate laws that were applicable to blacks and whites, and separate modes of punishment for laws that were broken. Socially, there was little interaction between blacks and whites, and many types of physical or spatial interaction were illegal for blacks and could land them in jail, or into a condition resembling slavery. The expedience to which this racial hierarchy was established troubled the north. The Civil War was still fresh in the minds of many northerners, so the southern attempt to maintain a form a racial slavery led to a backlash from the north, and southerners elected to Congress were not recognized when the 39th Congress convened in December 1865. Republicans, the progressive party of the time, outnumbered the Democrats 3 to 1, and with little to no resistance from President Johnson, the Republican members of Congress took over the responsibilities of reconstruction. This time period has come to be known as radical reconstruction.

Radical Reconstruction

The term "radical reconstruction" was coined by the faction of Republicans who wanted equal rights and protection under the law for all previous freedmen and newly freed slaves. The notion of blacks being equal to whites in the eyes of the law was indeed a radical ideology to have at the time, but it should be noted that even those who subscribed to this "radical" ideology never maintained that blacks were equal to whites, but rather in order for America to live up to its promise, blacks should have equal rights under the law. One of the leading campaigners for black suffrage, Thaddeus Stevens, once openly announced, "I have never held to the doctrine of negro equality in all things, but simply before the law" (Benedict, 1991, p. 55). Michael Benedict asserts, "Few Republicans during the war or reconstruction believed blacks to be the equal of whites. Republicans had insisted only that freedmen be secured equality in basic civil and (after some hesitation) political rights, not that they be conceded what was called at the time social equality." Most radical Republicans shared the similar sentiment that because blacks did indeed belong to an inferior race, it was all the more reason they should be protected by equal laws (Anderson & Moss Jr., 1991).

With this in mind, the proposals and actual policies that were enacted during radical reconstruction were designed to promote equal protection in the eyes of the Constitution, not to espouse the equal status of the white and black race. The inferior status of former African slaves was not challenged, not even by the radicals. So by contrast, white superiority or white supremacy was espoused by the very people who would be charged with reconstruction and the assimilation of nearly four million newly freed slaves. Even though the radicals were the best chance that former slaves had at receiving any sense of equality, it was never their intention to deny white superiority. White was superior, black was inferior, and thus white supremacy as an ideology saturated any recommendations, proposals, laws, policies, or Supreme Court decisions.

From the end of 1865 to the beginning of 1877, southern blacks saw their lives begin to change. Schools were built for colored children, and although these schools were often dilapidated and overcrowded, it was significant that the United States government was making an effort to educate Negro children. In the south, blacks were able to own land for the first time, and they were even able to rent it out, provided the people they rented to were also black. Southern blacks were able to work for wages for the first time, and even though their wages were far less than those of whites, they saw opportunity to create a life in their own image, to do things as they saw fit. Although white resistance was fierce and often times violent, the presence of Union troops helped to curtail the rise of southern violence and ensure the promise of radical reconstruction. Blacks understood this, and they took action. "Like emancipation, radical reconstruction inspired blacks with a millennial sense of living at the dawn of the new era.... Blacks found countless ways of pursuing aspirations for autonomy and equality, and seizing the opportunity to press for further change" (Foner, 1984, p. 124).

Perhaps the institution most affected by the newly found aspiration and confidence championed by freedmen was politics. Not only did blacks turn out to vote in incredible numbers, but they also sought to be elected to office themselves. "One plantation manager summed up the situation: You never saw a people more excited on the subject of politics than are the Negros of the south. They are perfectly wild" (Foner, 1984, p. 125). Blacks voted in overwhelming numbers, exercising their newly gained suffrage, and as a result many black politicians were voted into office. Former slaves and previously freed blacks still living in the south finally felt as though they had political representation. Even though the radical Republicans were legislatively fighting on behalf of blacks, they only were willing to fight for so much, and they could never understand the physical and psychological existence in legalized racial servitude.

Racial Terrorism

Some important forms of racial domination occurred overtly. "At least two motifs would run through any biography of the United States: an enduring democratic heritage and a legacy of social domination along ethno-racial lines" (Hiers, 2007, p. 2). The social domination mentioned by Wes Hiers was the result of various policies, institutions, laws, and coercion that regarded African slaves as sub-human. The most visceral and visual aspect of these practices was the unbridled and largely unpunished violence aimed at people of African descent at the hands of whites. Public whippings, beatings, rapes, race riots, and most of all lynchings were the different forms of violence used to ensure black subjugation. "Thousands of lynchings in the decades before World War I gave menacing force to everyday reminders of white supremacy" (Sharfstein, 2003, p. 1486). The initial racial backlash against blacks following the end of the Civil War was at least partially blunted by the passing of civil rights legislation and the presence of Union troops. With election of Rutherford B. Hayes to the White House in 1876 and the Compromise of 1877, all Union troops were removed from southern states, hate groups such as the Ku Klux Klan rose to prominence, and the racial terrorism of blacks increased exponentially, leaving southern blacks in a state of constant fear for their lives.

While radical reconstruction was by no means successful in leveling the playing field between whites and newly freed slaves, it did make many strides. As Theresa Richardson (2000) writes:

> The 13th Amendment assured the right of all African American to freedom from involuntary servitude. The 14th Amendment assured the right to citizenship; and the 15th Amendment provided self-determination with right to vote. The dogma of race once unleashed, however, was not to be reined in easily. The purpose of reconstruction between 1865 and 1877, in the years of radical republicans, was to dis-empower the planter class aristocracy of the south. Slavery was abolished, schools were set up, former slaves acquired land, and the right to vote was briefly acquired along with the experience of holding an elected position. The aristocracy was temporarily displaced and the plantation economy destroyed. (p. 316)

The key word here is "temporarily." The presidential election in 1876 ended with a lot of ambiguity and controversy. The Democratic candidate, Samuel J. Tildan, won the popular vote and accumulated 184 Electoral College votes (at the time 185 votes were needed to win the Electoral College). Three southern states that were under Republican control during radical reconstruction, Florida, Louisiana, and South Carolina, all had their results disputed by both candidates. The campaign managers for Rutherford B. Hayes claimed victory in all three of these states, which led to a stalemate between the two candidates, as well as their supporters. "The ensuing deadlock proved irresolvable by traditional means and in one of the wisest pieces of statecraft ever evolved by an American Congress, an extraordinary electoral commission was created, composed of members of the Senate, House of Representatives, and Supreme Court" (Peskin, 1973, p. 63). Hayes was declared the winner of the election, and immediately the cacophony of outrage was direct and demanding. "The decision of the commission in favor of Hayes, in a strictly partisan eight to seven vote, so angered Democrats that many of them openly threatened revolution, while others in the House of Representatives began a filibuster to prevent Hayes' inauguration."

Hayes sought a compromise. In order to prevent the impending filibuster and be recognized as President of the United States, Hayes withdrew the military from southern states, thus officially ending reconstruction. Hayes also sought to establish a southern constituency that was not dependent on the Negro vote, and the only effective way to sway the majority of southern whites was to give them patronage to protect their "home rule."

Discussion

This study addresses an apparent paradox. If racism is still prevalent in contemporary America, and America as a nation believes that racism is unjust, then where is the national outcry? Why is there no movement to secure the equal distribution of opportunity and fairness in the realms of education, employment, housing, politics, and healthcare? Why is it that politicians do not stress the need to eradicate racial privilege, and why is there not an abundance of congressional legislation being proposed to secure a fair and just playing field for all Americans?

Furthermore, are young people really more tolerant when it comes to matters pertaining to race? Is reverse racism the only type of discrimination that really matters today? The answers to all of these questions are complex and contradictory depending upon whom is asked. No realistic party will dispute the concrete and malicious nature of racial oppression in the past, nor will they dispute the negative impact that past racial discrimination had on disadvantaging people of color following social change and reform. What is not so acknowledged are the advantages this very same oppression conferred to whites and its significance not only to contemporary inequality, but also to the way in which mainstream America interprets racism. No realistic observer can dispute the contemporary racial disparities between whites and people of color in areas like educational attainment, employment, income, healthcare, and national crime rates; what is not so clear is the cause of all these inequalities.

Conceptually, we have typically understood racism too narrowly. Some views treated racism as a matter of individual choice or prejudice, that particular individuals perpetrated discrimination or aggression against other individuals with the justification of racial superiority. The feelings underlying these actions, whether biological and/or cultural superiority, and the slurs that result from such attitudes, whether the more overtly malicious "nigger," and "coon," or the coded "Urban," and "ghetto," the notion of superiority and inferiority still remains. In terms of economics and politics, racism was viewed as an institution, both as slavery and later as enforced apartheid in the form of de jure segregation.

With slavery abolished and mandated segregation legally invalidated by the Supreme Court, the purely overt understanding of racism leads people to believe that racism is no longer relevant because it no longer exists. What mainstream America and even scholars of race and ethnicity often fail to realize is that segregation was not challenged for the sole purpose of integration; it was an attempt to undermine the contextual structure that made legal segregation possible and morally acceptable: white supremacy. In contrast to overt racism, the concept and practice of white supremacy, however, legitimate a perception of white superiority and non-white, especially black, inferiority as an essential truth—a truth that is self-evident and requires no rational proof. It is both an assumption and a feeling that can be encoded into individual perception, cultural values, and institutional function. Failing to understand, or refusing to recognize this distinction—that white supremacy can exist without significant malicious racism and can nevertheless contribute to inequality and oppression—confounds our collective ability to understand properly the persistence of racial inequality and subsequently to develop solutions.

Dual Legacies

The continuing salience of the narrow conception of racism that limits understanding to overt and malicious attitudes and practices results from what I call the dual legacies of racial oppression. The first legacy is institutional advantage. This refers to institutions of family, education, government, and business that function to serve the interests of some dominant group in order to perpetuate their dominance and simultaneous

inequality. This includes multiple forms of dominance, such as gender and class, as well as race. These and other forms also tend to intersect. The focus of this paper, however, is race.

The second of the dual legacies, and perhaps the more damaging of the two, is the outdated interpretation of racism. Scholars, politicians, law makers, police officers, conservatives, liberals, blacks, whites, indeed, the greater part of mainstream America, all tend to understand racism as a historical manifestation, started and completed in the past, that is no longer relevant. In this misunderstanding, racism is a thing of the past.

Institutional Advantage

The legacy of white supremacy permeates all facets of American society. Racial discrimination of the past cannot be separated from racial inequality today, because institutions that allow racial oppression to exist cannot be separated from the people who practice discrimination. People look at various institutions as being objective and neutral, therefore past racial inequality was a result of the actions of people living at the time. In this regard, America in the eyes of many people today is past its racial hierarchy because its contemporary citizenry openly extols the ideology of equality and inclusion. This paradigm allows for the institution that provided the contextual framework for racial oppression essentially to go un-scrutinized and evade its own culpability in the very racial oppression being characterized as no longer relevant.

The proposed "neutrality" of America at the institutional level was the breeding ground for genocide, slavery, imperialism, terrorism, and legal apartheid for almost 400 years. As these practices took place, time did not stand still, and neither did policy, legislation, opportunity, precedent, and wealth accumulation. Fortunes were made, wealth was accumulated, legends were born, and traditions were established all in a time when the great American spirit of competition was restricted to whites only. America grew to become the most powerful nation on earth, and its ideological scaffold was white supremacy. American industry skyrocketed, its economy flourished, and it did so under the veil of inherent white superiority. Employment opportunities were color coded, with the higher paying jobs being reserved for whites only, with the lower, menial jobs reserved for people of color. As the number of jobs grew, people of color were suddenly deemed qualified for jobs that were previously considered too sophisticated for them; jobs that were now vacated by whites who moved up the employment ladder. When the number of jobs fell, credentialing, or college degree requirements set in, and higher educational attainment became essential for quality employment. These forces combined to create a "last hired-first fired" reality for people of color; a reality that can still be felt in contemporary America.

Soldiers returning home from World War II were able to take advantage of the G.I. Bill and other forms of veterans assistance, allowing them to go college almost for free. The Federal Housing Administration provided hundreds of millions of dollars in home equity, and in concurrence with the GI. Bill, it is credited with creating the American middle class. For the first 25-30 years of their existence, these programs essentially operated in an all white fashion, virtually excluding all people of color. Urban renewal projects, district redlining, and restrictive covenants barred people of color from living in affluent, suburban neighborhoods, which in turn barred them from attending better funded schools with better trained faculty. For the first three decade following the end of World War II, the American middle class was not only created, but also flourished under the welfare state. Alongside the FHA preceding the Second World War, federal initiatives following the war, such as veterans' assistance programs and the G.I. Bill, provided literally millions of Americans, the vast majority of them white, with the opportunity to go to college, start businesses, relocate to better neighborhoods, and elevate their socioeconomic status. Ira Katznelson (2005) writes, "No other New Deal initiative had as great an impact on changing the country as the Selective Service Readjustment Act.... Even today, this legislation, which quickly came to be called the G.I. Bill of Rights, qualifies as the most wide-ranging set of social benefits ever offered by the federal government in a single, comprehensive initiative" (p. 113). Comprehensive, wide-ranging social benefits that were provided by the government, and without specific barriers mandated by race, were in practice able to operate in a predominantly all white fashion for the first 30 years of their existence.

Similar realities exist in education. Educational attainment dramatically rose throughout the 20th century, and for over 60 years racial segregation was legally enforced. The remaining forty years of the 20th century have been marred by de facto segregation, unequal school funding, unequal distribution of resources, and disparate levels of quality instruction. Preceding the landmark Brown v. The Board of Education Supreme Court ruling in 1954 that invalidated the separate but equal doctrine, schools in the south were forcibly segregated by race under the ruse that as long as the school systems were equal in the education they provided to children, it was perfectly democratic to separate them by race. In reality schools were anything but equal, as children of color were forced to attend schools that were lacking in every conceivable category that was conducive to a quality education. At the same time, the north was marred with de facto segregation, the type of segregation that is very prevalent today. Although not as direct or as obvious as Jim Crow segregation, "voluntary," or "natural" segregation is almost just as destructive as legal apartheid. For the better part of the century, Jim Crow provided white students with opportunities that were simply not available to black students. These opportunities, bolstered by racial discrimination in federal initiatives such as the G.I. Bill, extended to college and provided many options for upward social mobility. This social mobility comes in handy today when it comes to positioning young children for better educational opportunity. Parents can rely on family wealth, wealth that was accumulated in the era of open racial hostilities, to buy houses in better, more expensive neighborhoods, thus affording their children the chance to attend better schools. Some parents even can use family wealth to send their kids to expensive private schools; schools they otherwise would not have been able to afford (Johnson, 2006, p. 157). These practices do not mention race and are essentially uninfluenced by any government policy to date. Therefore they are not considered racist or contradictory in any way to the American promise of meritocracy, even though advantage and disadvantage are routinely inherited along racial lines. When taken together with the unequal allocution of schools funds, resources, and quality instruction, advantages made possible by past racial discrimination only serve to strengthen the influence of white supremacy in the American educational system, and students of color will disparately continue to inherent disadvantage in the land of equal opportunity.

While America pretends to be past its racial apex, survey data indicate that a sizeable percentage of whites still believe in negative racial stereotypes about blacks. Tim Wise (2008) writes, "In one of the more respected opinion surveys from the 1990's, six in ten whites said that discrimination was less important in determining the position of blacks in society than the 'fact' that blacks 'just don't have the have the motivation or willpower to pull themselves up out of poverty'" (p. 40). How many of the white respondents who openly admit to at least some negative stereotypes are in a position to hire, fire, or lend money to people of color? How can institutions be considered race-neutral when there is a strong likelihood that people operating within those institutions may hold a personal bias against others based on skin color? Furthermore, with the persistence of negative racial stereotypes, the changes that are needed at the institutional level will be considered reverse discrimination or welfare handouts to undeserving poor. The historical legacy of racial oppression essentially created the socioeconomic position of African Americans as a whole, and the ongoing struggles of African Americans in the areas of educational attainment, unemployment, crime rates, poverty, isolation, and general deprivation are used to justify having racial stereotypes. Surely problems within the black community cannot be fully attributed to past and present racial discrimination. Personal choices and decisions made by blacks themselves have to bear the brunt of the bleak reality many blacks find themselves in. With that being said, the contexts in which these personal choices are made are a consequence of institutional forces that advantage whites in the land of equal opportunity. With the acceptance of the United States as an actual meritocracy, systemic inequality and white hegemony will not be vilified for the role they play in the urban pathologies that are condemned so much and attributed to personal responsibility.

Racism as a Thing of the Past

To be sure, racism was slavery, and afterward, racism was enforced subjugation that left African Americans with no guaranteed rights before the law. Racism was a black body hanging from a tree while whites commemorated the occasion with food and drinks. Racism was men dressed in hooded sheets brandishing shotguns and burning down black schools and churches. Racism was schools, movie theatres, neighborhoods, drinking fountains, jails, beaches, and hospitals that all held the moniker "Whites Only." Many believe that civil rights legislation washed away these aggressive and repulsive symbols in the decades since the civil rights struggles of the 1960s.

This narrow interpretation, combined with actual progress in reducing racial discrimination and a burgeoning black middle class, can be directly attributed to the almost universally accepted notion among whites, including white progressives, that racial discrimination is simply not a major problem in contemporary America. Taking it one step further, because racism is considered to be so inconsequential, progressive policies aimed at leveling the playing field, programs like affirmative action, are experiencing severe backlash and have been overturned in a number of states. "Reverse discrimination," that is, racism that advantages minorities at the disadvantage of whites, is largely considered to be the only real illustration of racial discrimination today.

To be clear, slavery, lynching, the KKK, and American Apartheid were indeed examples of racism; however, the society that allows these atrocities to take place is just as racist, and it bears equal responsibility when addressing issues pertaining to race. It is not enough to look at black men being lynched or the KKK burning crosses on people's front lawns; we also have to look at the justice, or lack thereof, that was afforded to these victims through the nonexistent arrest and prosecution of their assailants. It is not enough to look at slavery and the Jim Crow south; scrutiny also must be given to the presence of a racial caste system within the borders of a country that champions equality, opportunity, and freedom. Until the conceptualization of racism is made to include structural and systemic inequalities, rather than simply overt individual actions, any analysis of the impact of contemporary racial inequality will be highly ambiguous at best.

Today, because of the absence of racial enslavement and formal apartheid, racism is looked upon as a relic of history and confined to the periphery of modern day society. Racism, once a pathology that caused a broad coalition of whites and blacks to band together, is now seen as an excuse for laziness and lack of personal responsibility. Blacks who speak against racism today are "looking for handouts," and whites who speak against racism are doing nothing but "encouraging indolence" or "haven't seen the way blacks live." It is true that America has come a long way in living up to its ideals of equality and inclusion. It is also true that younger generations are more tolerant than ever in terms of openness to people of different races. However, due to the narrow interpretation of what constitutes racism, even those who championed racial equity during the civil rights movement and even the most progressive of younger generations will still be apt to conclude that racism has for the most part been eradicated. Again, this can be evidenced by the growing backlash against affirmative action programs and the increasing rhetoric of reverse discrimination.

Confusing everyday racism or overt acts of bigotry, which can be perpetrated by any member of any race, with white supremacy or inherent institutional advantage, which racially speaking, can only be enjoyed by whites, is what allows fallacious notions of whites being disadvantaged in America to persist. This confusion also undermines ongoing attempts to remedy the racial hierarchy that currently exists in society. The progress that America has made on achieving racial equality must be acknowledged and even celebrated, but it cannot be mistaken for a completed objective.

The Continuing Salience of White Supremacy

A latent consequence of understanding racism as overt actions by individual actors is the perplexity of intentionality. The necessity of psychological bigotry as a precursor for any action or policy to be considered racist blinds people to the reality of subconscious stereotypes that lead well meaning people to act in ways that discriminate against blacks, and seemingly race neutral practices that advantage whites at the expense of blacks, poor people, and other people of color. This is a phenomenon which Barbara Trepagnier (2006) refers to as "silent racism" (p.1). She writes that "Silent racism—the racist thoughts, images, and assumptions in

the minds of white people, including those that by most accounts are 'not racist'—is dangerous precisely because it is perceived as harmless." She continues, "The silent racism in people's thoughts, images, and assumptions shapes their perspective of reality. And a perspective that is shaped by racist thoughts, images, and assumptions—no matter how subtle they are—will produce behavior that reflects racist thoughts, images, and assumptions." A brief overview of how de facto segregation is perpetuated in our new "colorblind," so called "post-racial" America illustrates this point. At the individual level, well meaning white parents who want better educational opportunities for their children migrate to "better" neighborhoods with "better" schools. Although "better" can be composed of many attributes, perhaps the most powerful indicator of a "better" neighborhood is a white neighborhood (Johnson, 2006). There is no doubt that many parents are indeed racially conscious when choosing which neighborhoods to live in and which schools to send their kids to. Other parents though, parents who by all conceivable measures would consider themselves anti-racist, simply want what is best for their children. Combined with the inability of many black parents to afford to live in more affluent neighborhoods, thus hindering their ability to send their children to better schools, residential and school segregation are steadily increasing, and in many geographical locations are near or have exceeded Jim Crow levels.

At the institutional level, residential and school segregation is just as destructive as they were when America stood against it as undemocratic and unconstitutional. With schools being funded primarily by property taxes, schools located in more affluent neighborhoods receive considerably more funding and resources than schools located in poorer neighborhoods. The schools with better resources tend to be located in suburban school districts. The suburban school districts are located in suburban neighborhoods, and these neighborhoods tend to be predominantly or sometimes all white. Additionally, with the federal mandate of annual school progress as outlined in the national school initiative No Child Left Behind, schools are being shut down, and teachers are losing their jobs. What this means for schools with limited resources that are more at risk of being shut down is that better trained and higher quality teachers are not willing to teach there. Teachers are not only looking for employment that provides more autonomy and better resources, but they also are looking for job security. This is not to say that all suburban schools are all white or all good, nor is it to say that all urban schools are all color and all bad; what it does say is that there is a strong correlation among race, class, and quality of educational opportunity. Current practices by individuals and current policies by institutions combine to create a disparate effect on white children and children of color. However, due to the lack of obvious prejudicial intent, the absence of legally enforced separation, and no overt mention of race, these practices are not considered racist, even though they overwhelmingly advantage whites and disadvantages minorities. This example illustrates the covert nature of white supremacy and how limited understandings of what constitutes racism hinder the possibility of remedying new forms of racial inequality.

Conclusion

Racial oppression is not a static phenomenon. Racism today is not the racism of the antebellum south. Racism of the 1890s was not the same racism of the 1990s. At one point in history, racism was the enslavement of the majority of all blacks living in America. While at a different point in American history blacks were free from servitude, they were officially and unofficially separated from whites through its various institutions. Although the manifestations were different, the aura of white supremacy was the cornerstone of both slavery and apartheid, and America gave solace to a racial hierarchy that for centuries was considered a natural right. In place of the aforementioned biological determinism, cultural superiority and work ethic are now given credit for the gulf of racial disparities between blacks and whites. Whether discussing the "natural birth right" of whites historically, or the perception of "superior values and work ethic" among whites today, with the exception of emancipation and the eradication of de jure segregation (de facto segregation is still prevalent and even increasing), America has not been held responsible for the role it played in establishing white supremacy and promoting racial inequality. The transformative quality of white supremacy hides its salience and almost completely exonerates America for the role it plays in permitting it to take place and perpetuating it across generations.

Today there is a term used to describe people who are at the bottom of the socioeconomic spectrum. The term is "underprivileged." This can be applied to poor people, minorities, women, or any group of people who are now, and have historically been exploited or discriminated against. Paraphrasing Tim Wise (2004), the passive voice of the term underprivileged implies that no one did anything. "It's as if one day someone said 'here is privilege and I'll be damned, there you are under it'" (p. 36). This addresses the overall structure of American society as it pertains to race. Speaking socially, culturally, politically, and economically, America was initially shaped and flourished under the banner of white supremacy. As a result, America has established generally accepted "race neutral" policies that inherently advantage whites but are not considered racist because these policies do not specifically mention race. Exacerbating the almost nonexistent national outcry about institutional racism is the covert way in which it operates and the contemporary interpretation of what actually constitutes racism. This interpretation can be directly attributed to the overt history of racial discrimination in America, and it is an interpretation that is faulty on the basis that it was never complete to begin with. Assessing racism solely focused on individuals, not institutions, it failed to account for people who made decisions based on factors not relating to race.

In our culture today, I argue that any actions that are made without cognitive animosity towards blacks or other people of color are not considered racist, no matter the impact it has on promoting racial inequality. We are biased to focus primarily on intent, and in particular, individual intent, and less on social forces and outcome. This reduces racism to willful expression of racist sentiments, regarded as particular to racist individuals who are dismissed as ignorant or fringe members of an otherwise progressive society. Such inept understandings of racism place a formidable hurdle in the quest for racial equality in America today. In order to perfect our "more perfect union," any research aimed at analyzing racial inequality or even racial disparities must start with history. Racial discrimination is not some archaic, insignificant blemish on America's resume of equal opportunity, and it should not be treated as such.

Tim Wise (2004) also writes, "the term underprivileged completely disregards the relative nature of the word under" (p. 64). This statement is as profound as it is succinct. People of all walks of life, conservative, liberal, poor, wealthy, white, black, etc., acknowledge the existence of people who are underprivileged, yet it is rarely if ever mentioned just who the underprivileged are "under" in comparison to. That is, there is no mention or analysis of anyone being over-privileged. Without any regard for ideologies, theories, and paradigms, it is inarguable that if something is considered "under," then by definition there has to be an "over." Whether the topic is race, class, gender, or sexuality, if one segment or portion of a particular demographic is underprivileged, then one part must be over-privileged. In the specific category of race, minorities, typically blacks and Hispanics, are considered to be under-privileged in the areas of educational opportunities, accumulated wealth, job opportunities, housing, political representation, and quality healthcare coverage. Their existence as members of an underprivileged class is almost universally accepted, even when the reasons for their membership are ferociously disputed. Conversely, since there is little mention of the over-privileged, possible reasons that bolster their life chances via the non-merit based availability of resources and opportunities not only go unexamined, but they are also taken as earned by the individuals who benefit from them. This not to say that all members of the over-privileged class do not work hard or do not take advantage of the opportunities available to them; it simply states that they are presented with unearned opportunities that are not readily available to members who are considered to be underprivileged. In the area of race, the over-privileged class refers to whites. The intersection of different forms of privilege, such as class, age, religion, and so on, all combine to create a segment of the population that is inherently advantaged by American democracy. However, in each subsection, whites are advantaged over blacks. In America, a poor white woman will surely be predisposed for worse life chances than middle or upper class white women, yet in all likelihood that same poor white woman will be predisposed for better life chances than a poor black woman. In a country that continually espouses race neutrality and equal opportunity, inherent advantages of any kind render these assertions obsolete.

After hundreds of years of racial bondage and oppression, following the Civil War, America had the opportunity to live up to its ideals. Equal opportunity, freedom, and justice for all were for the first time in American history something that was plausible in practice, rather than just rhetoric. Slavery was lawfully abolished, and the vicious war being waged that would ultimately determine the fate of millions of southern slaves and countless freedmen living in America had seemingly ended on the side of equality. White supremacy, however, was too strong to overcome. Immediately following the official surrender of the Confederate army, hoards of ex-Confederate officers, commanders, and supporters were voted into office throughout the south. They were elected into powerful positions of far reaching authority, such as mayor or governor, and they also were elected into more intimate, but no less powerful positions, such as sheriff or prosecutor. For former slaves living in the south, life in the post slavery era was eerily similar to life under institutional bondage. Emancipation brought freedom in name only, and for the first several years following the end of the Civil War, blacks living in the south were slaves in everything but name. White supremacy, already established by the very existence of racial slavery, continued to pervade American society at the individual and institutional level. White supremacy was not slavery, but it allowed slavery to exist. Therefore, the eradication of the American slave state did not mean the eradication of white supremacy; it only meant that it had to change forms.

Radical reconstruction was considered a coup for progressives who fought and died for racial equality. Blacks in the south, as well as the north, saw their rights increase exponentially. They were allowed to attend school, to vote, to own land, to be elected to office, and actually to earn a wage. Although the gains were significant, considering any form of freedom is better than no freedom at all, they were relatively small in comparison to the rights and opportunities enjoyed by whites (even poor whites), and the rights guaranteed to them by the Constitution. Even many of the most ardent supporters of racial equality, the radical Republicans, did not consider blacks to be equal to whites in an existential sense. On the one hand, there were people who outright considered blacks to be biologically inferior to whites, and who thought American society should reflect as much. On the other hand, there were people who also thought blacks were biologically inferior to whites, but it was precisely because of this inherent inferiority why they needed to be afforded equal protection under the law. In either case, blacks were considered inferior, and white supremacy continued to be the dominant ideology, even after emancipation, and even during radical reconstruction.

The end of radical reconstruction saw all of the progress that was made on behalf of blacks in America virtually wiped out. The rights bestowed upon newly freed slaves in the south were relatively small in comparison to full inclusion in a free society; nevertheless, they were important to the former slaves who saw them as a form of liberation. These relatively small gains were also big enough in that they frightened the whites to the point that they considered them a threat. Many blacks who were elected to office were immediately thrown out of office, and black citizens were ceremoniously disenfranchised. White supremacist hate groups such as the Ku Klux Klan sprang up all across the south, and violence against blacks, even in the north, increased by considerable margins. Black churches and schools were burned down, and mass lynchings exploded with the brutal murders of hundreds, perhaps thousands of blacks that took place in broad daylight without any chance to pose a defense for the crime they had been accused of committing. The level of unequal treatment experienced by blacks at the hands of whites was a more violent rendition of the treatment they experienced immediately following the end of the Civil War with the black codes. Only this time, there were no radical Republicans who would speak on behalf of the newly re-disenfranchised. This was largely due to the perception that reconstruction had progressed too slowly and been somewhat of a failure.

At the dawn of the 20th century, science and intellectuals joined the side of white supremacy. In the form of eugenics, notables such as Francis Galton, Karl Pearson (who introduced linear regression and correlation to the social sciences), Margaret Sanger, George Bernard Shaw, and Konrad Lorenz supported the notion of biological racial hierarchy, with "negroids" at the bottom. Proponents hoped to use science to breed a superior population. The rise of eugenics and the assertion of biological determinism rendered moot any notions of social equality. Separate standards of living, individu-

ally and institutionally, while already in existence, became indoctrinated into law at the close of the 19th century with "Separate but Equal Doctrine" set forth in Plessey v Ferguson.

The first two decades of the 20th century saw the assimilation of southern and eastern European immigrants, people who had previously been considered less than white, into the dominant culture. This created a united racial category of "white" and secured privileges by virtue of their "whiteness." With the ambiguity of who was to be considered white put to rest, white supremacy corresponded with the prosperity and growth of America as a country, a correspondence that indelibly infused white supremacy socially, politically, and economically into American culture and institutions. By the time America (forcibly) owned up to the obvious hypocrisy of a racial caste within a democracy, generations of whites had benefited from the overt white superiority that was ingrained in American institutions, while generations of people of color had been denied all that was promised to them by a Constitution that promised "Life, Liberty, and the Pursuit of Happiness." Even still, a truly inclusive democracy has not been realized.

While overt racial discrimination has been marginalized, the covert destructiveness of white supremacy still pervades society in every conceivable way. The people, albeit slowly, are becoming more tolerant, or at least confining their racist beliefs to private quarters, but the institutions that have always been infected with the disease of white supremacy still suffer from this malady. White supremacy was born with the founding of this country—it grew with the prosperity of this country—and if left unchecked, will continue to undermine all that is just within this country, and its citizens, both white and black alike, will suffer the consequences.

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Investigations in the Geometry of Polynomials

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Abstract

Because polynomial functions are completely determined by their roots, every property of a polynomial is affected when these roots change. Our research aims to further our understanding of how the distribution of a polynomial's roots affects specjfic characteristics of the function. We are especially interested in classifying which root distributions maximize or minimize certain properties. We employ recent results on polynomial root dragging and root motion to explore these issues further, including the attempt to explain why many properties are maximized by Bernstein polynomials. This paper will survey some important results and present our investigations into new problems and approaches.

1 Introduction

How do changes in the roots of a monic polynomial with all real zeros affect the other characteristics of the function? This is the question that drives our investigations in the geometry of polynomials. It is well known that a monic polynomial with all real zeros is uniquely determined by the placement of these zeros. That is, given any n roots, there is exactly one monic polynomial with all real zeros that passes through these roots. Therefore, every characteristic of a polynomial depends on the location of its roots, and even the slightest change in the root distribution will produce an entirely new polynomial. Many questions in this same field of study have been answered, and the beginning section of this paper will be focused on introducing some of these important results, along with the key concepts that were necessary for proving them. The goal of this paper is to contribute to the overall understanding that we possess of this relationship between a polynomial's roots and its other characteristics.

For the sake of convenience, and since any polynomial with all real zeros may be scaled to be monic with all roots in $[-1, 1]$, we have narrowed the focus of this paper to monic polynomials with all real zeros that live in the interval $[-1, 1]$. That is, we are interested in polynomials that can be written in the form

$$p(x) = \prod_{i=1}^{n} (x - r_i),$$

where n is the degree of the polynomial, and the r_i's are real numbers in $[-1, 1]$ that represent the roots. This provides us with some consistency and makes it sensible to compare properties from one polynomial to another.

Once we are able to compare polynomials and the properties that they possess, we may then ask a very natural question that is so common in mathematics: "What root location will make property X the most extreme?" This question of extremality has been the primary focus of our research, and it is in this spirit that we write this paper. There has been much work done in this field in recent years, and the results developed provide crucial perspectives and tools for our investigations. The Polynomial Root Dragging Theorem [1, 2] is one of the most influential theorems in our research, and we will illustrate how extremal problems in the geometry of polynomials may be thought of more intuitively from this perspective.

One intriguing question that has been given little attention arises when we notice the pronounced patterns found when analyzing problems dealing with maximality. A large portion of this paper will be dedicated to surveying some of the results that are available pertaining to these maximal problems. While the individual problems that we will outline have well-established proofs, we strive to offer what we believe to be a promising, yet undeveloped, general explanation for the "maximal polynomial" phenomenon. Along the way, we make some additional observations that are either new or underreported.

2 Fundamental Results

First and foremost, it is important to survey some fundamental theorems and concepts in the geometry of polynomials. This section is meant to clarify the sort of problems that this research is interested in answering, as well as give the reader a flavor for the different kinds of mathematics that are employed when investigating this kind of problem. Here, we outline some of these important theorems and extend a couple of them to prove new results. The results themselves, as well as the analytic approach used, will be highlighted, and important concepts will be defined appropriately.

As mentioned earlier, one of the most important results in this field is the Polynomial Root Dragging Theorem [1, 2],

as proven by Bruce Anderson. This theorem illustrates the effect that "dragging" any number of roots of a polynomial in a given direction has on the location of the critical numbers of the polynomial. The proof uses a concept known as the logarithmic derivative. As this concept appears frequently in the geometry of polynomials, and specifically in the proofs we outline in this paper, it is worth discussing in some detail before we present the theorem.

Definition 1. *The logarithmic derivative of a function $p(x)$ is the quantity*

$$\frac{p'(x)}{p(x)}.$$

This is called the logarithmic derivative because it is obtained by taking the derivative of the logarithm of a given polynomial p: $\frac{d}{dx}[\ln(p(x))] = \frac{p'(x)}{p(x)}$. For a given degree n monic polynomial $p(x) = \prod_{i=1}^{n}(x - r_i)$, with roots $r_1, r_2, \ldots, r_n$, the logarithmic derivative is

$$\frac{p'(x)}{p(x)} = \sum_{i=1}^{n} \frac{1}{(x - r_i)}.$$

This is a strictly decreasing, rational function with $n-1$ zeros, and it proves to be a very useful tool in multiple theorems throughout this paper.

Now we may introduce the Polynomial Root Dragging Theorem. As we will show, in response to dragging a polynomial's root(s) in a given direction, its critical numbers will move in the same direction as the roots that are dragged, or they will remain in place. Further, the critical numbers that move will move less than the root that is moved. Here, we prove this result for moving roots to the right. The proof can be easily altered to prove that the result is also true when we move roots to the left.

Theorem 1. *Let $p(x)$ be a polynomial of degree n with distinct real roots $r_1, r_2, \ldots, r_n$. Then as we "drag" some or all of the interior roots a distance at most ε to the right, the critical points will all follow to the right, and each of them will move less than ε units.*

Proof. Let $p(x)$ be a polynomial of degree n with distinct real roots $r_1, r_2, \ldots, r_n$. We will prove that as we "drag" some or all of the interior roots a distance at most ε to the right, the critical points will all follow to the right, and each of them will move less than ε units. Letting $p(x) = (x - r_1)(x - r_2)\cdots(x - r_n)$, we know that for any critical point c, $p'(c) = 0$. Since there are no repeated roots, we know that $p(c) \neq 0$. Therefore, we can take the opposite of the logarithmic derivative and obtain

$$-\frac{p'(c)}{p(c)} = \sum_{i=1}^{n} \frac{1}{r_i - c} = 0. \tag{1}$$

So equation (1) shows that c is an implicit function of the roots of $p(x)$. Implicit differentiation with respect to r_i gives

$$\frac{\partial}{\partial r_i}\left(\frac{1}{r_1 - c}\right) + \frac{\partial}{\partial r_i}\left(\frac{1}{r_2 - c}\right) + \cdots + \frac{\partial}{\partial r_i}\left(\frac{1}{r_i - c}\right) + \cdots + \frac{\partial}{\partial r_i}\left(\frac{1}{r_n - c}\right) = \frac{\partial}{\partial r_i}(0). \tag{2}$$

This yields

$$\left(\frac{1}{r_1 - c}\right)^2 \frac{\partial c}{\partial r_i} + \cdots + \left(\frac{1}{r_{i-1} - c}\right)^2 \frac{\partial c}{\partial r_i} + \left[\left(\frac{1}{r_i - c}\right)^2 \frac{\partial c}{\partial r_i} - \left(\frac{1}{r_i - c}\right)^2\right] + \left(\frac{1}{r_{i+1} - c}\right)^2 \frac{\partial c}{\partial r_i} + \cdots + \left(\frac{1}{r_n - c}\right)^2 \frac{\partial c}{\partial r_i} = 0. \tag{3}$$

From here, solving for $\frac{\partial c}{\partial r_i}$ leads us to see that

$$\frac{\partial c}{\partial r_i} = \frac{\left(\frac{1}{r_i - c}\right)^2}{\left(\frac{1}{r_1 - c}\right)^2 + \left(\frac{1}{r_2 - c}\right)^2 + \cdots + \left(\frac{1}{r_n - c}\right)^2}.$$

Clearly, $\frac{\partial c}{\partial r_i}$ is positive. Further, if we let $A \subset \{1, 2, \ldots, n\}$ with $|A| < n$ it follows that

$$0 < \sum_{i \in A} \frac{\partial c}{\partial r_i} < 1. \tag{4}$$

Since c depends on the roots, we can now consider what happens to c when we shift each of the interior roots r_i to the right by $\varepsilon_i \geq 0$, respectively. We can define a function f that represents the location of c after the roots have been moved as follows:

$$f(t) := c(r_1, r_2 + t\varepsilon_2, \ldots, r_{n-1} + t\varepsilon_{n-1}, r_n)$$

where t varies from 0 to 1. Then by the multivariable chain rule, we have

$$f'(t) = \sum_{2}^{n-1} \frac{\partial c}{\partial r_i}\frac{dr_i}{dt} = \sum_{2}^{n-1} \frac{\partial c}{\partial r_i}\varepsilon_i \leq \max(\varepsilon_i) \sum_{2}^{n-1} \frac{\partial c}{\partial r_i}.$$

By (4), we can conclude that

$$\max(\varepsilon_i) \sum_{2}^{n-1} \frac{\partial c}{\partial r_i} < \max(\varepsilon_i),$$

and thus $f'(t) < \max(\varepsilon_i)$. The mean value theorem states that for some ζ between 0 and 1, $f'(\zeta) = f(1) - f(0)$. Since we have shown that for all t between 0 and 1, $f'(t) < \max(\varepsilon_i)$, we can then conclude that $f(1) - f(0) < \max(\varepsilon_i)$. Therefore, c will move to the right strictly less than the root that moves the most.

□

This result has been especially influential in our research, primarily because it offers such a unique and valuable approach to analyzing the effects that changing roots has on a polynomial. This approach is an important tool that will help us in furthering our understanding of how roots and other characteristics of a polynomial interact.

When this theorem is first encountered, it is very natural to wonder exactly how far the critical numbers are moving. Following, we address the question of how far the average critical number travels in response to dragging a root ε units. However, to do so, we must first introduce the concept of the *centroid* of a polynomial $p(x)$, which is denoted by A_p.

Definition 2. *Given a polynomial $p(x)$, the centroid of p, or A_p is the average of the roots of $p(x)$. That is, if $p(x)$ has roots $r_1, r_2, \ldots, r_n$, then*

$$A_p = \frac{r_1 + r_2 + \cdots + r_n}{n}.$$

In 1998, Piotr Pawlowki [11] noted that the centroid of a polynomial is differentiation invariant. In other words, for any given polynomial, the average root is the same as the average critical number, which is the same as the average inflection point, and so on. This is an amazing feature of polynomials, and it allows us to quantify the average distance a critical number moves in reaction to dragging a root ε units. We will establish this result with a short corollary.

Corollary 1. *Let p be a monic, degree n polynomial with all real zeros $r_1, r_2, \ldots r_n$. If we drag a single root, r_i, ε units to the right, the critical numbers of p will move to the right by an average of $\frac{\varepsilon}{n}$ units.*

Proof. Let p be a monic, degree n polynomial with all real zeros $r_1, r_2, \ldots r_n$. Then the centroid of p is given by

$$A_p = \frac{r_1 + r_2 + \cdots + r_n}{n}.$$

If we drag the root r_i by ε units to the right, we will then have a new polynomial, p_ε, whose centroid is

$$\begin{aligned} A_{p_\varepsilon} &= \frac{r_1 + r_2 + \cdots + (r_i + \varepsilon) + \cdots + r_n}{n} \\ &= \frac{r_1 + r_2 + \cdots + r_n}{n} + \frac{\varepsilon}{n} \\ &= A_p + \frac{\varepsilon}{n}. \end{aligned}$$

Since the centroid is differentiation invariant, we have

$$A_{p'_\varepsilon} = A_{p'} + \frac{\varepsilon}{n}.$$

Therefore, moving r_i to the right ε units has caused the average critical number of p to move to the right $\frac{\varepsilon}{n}$ units. □

Since there are $n - 1$ critical numbers for a degree n polynomial, it may also be noted that the total sum of the distance travelled by the critical numbers in response to a single root being dragged ε units is $\frac{(n-1)}{n}\varepsilon$. So when dragging a single root, not only does each critical number move less than the root that is dragged, but all of the critical numbers combined move less than the root that is dragged. We may further consider what happens if we allow for the dragging of m roots, where $m \leq n$, and the m roots move distances of $\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_m$, respectively. It is simple to show that the average critical number of the polynomial would then move

$$\frac{\varepsilon_1 + \varepsilon_2 + \cdots + \varepsilon_m}{n}.$$

Note that this last result is true regardless of the sign of the $\varepsilon_i's$.

This idea of allowing roots to be dragged in opposite directions creates another question that the Polynomial Root Dragging Theorem does not answer. What happens to critical numbers of a polynomial in reaction to dragging roots in opposite directions? There is a theorem that is closely related to the Polynomial Root Dragging Theorem, called the Polynomial Root Squeezing Theorem [4], which addresses exactly this. This theorem may be thought of as an extension of the Root Dragging Theorem, and it has some interesting consequences considering the span of the derivative of a polynomial. For future reference, we will define here what is meant by *span*.

Definition 3. *The span of a polynomial is the distance between the least and greatest roots of the polynomial.*

Now, we will introduce the Polynomial Root Squeezing Theorem, followed by its proof.

Theorem 2. *Let p be a monic, degree n polynomial with all real roots $r_1 \leq r_2 \leq \cdots \leq r_n$ such that $r_1 = -b$ and $r_n = b$ for some positive real number b. Further, let $c_1 \leq c_2 \leq \cdots \leq c_{n-1}$ be the critical numbers of p. Let $r_j < r_k$ be any two interior roots of p and $d \in \mathbb{R}^+$ be such that*

$$d \leq \min\left\{r_{j+1} - r_j, r_k - r_{k-1}, \frac{1}{2}(r_k - r_j)\right\}.$$

Let $\tilde{p}$ be the polynomial that results from squeezing r_j and r_k together by a distance $2d$. That is,

$$\tilde{p}(x) = (x - r_j - d)(x - r_k + d) \prod_{i=1, i\neq j,k}^{n} (x - r_i).$$

Denote the critical points of $\tilde{p}$ by $\tilde{c}_1 \leq \tilde{c}_2 \leq \cdots \leq \tilde{c}_{n-1}$. Then for $1 \leq i < j$ we have $\tilde{c}_i \geq c_i$, and for $k \leq i \leq n-1$ we have $\tilde{c}_i \leq c_i$.

Proof. Let p be a monic, degree n polynomial with all real roots $r_1 \leq r_2 \leq \cdots \leq r_n$ such that $r_1 = -b$ and $r_n = b$ for some positive real number b. Let r_j and r_k be interior roots of p such that $r_j < r_k$. Further, let c_i be a critical number of p such that $1 \leq i < j$ or $k \leq i \leq n-1$. Let $d \in \mathbb{R}^+$ such that

$$d \leq \min\Big\{r_{j+1} - r_j, r_k - r_{k-1}, \frac{1}{2}(r_k - r_j)\Big\}.$$

Define $\tilde{p}$ to be the polynomial that results from squeezing r_j and r_k together by a distance $2d$, with critical points $\tilde{c}_1 \leq \tilde{c}_2 \leq \cdots \leq \tilde{c}_{n-1}$. That is,

$$\tilde{p}(x) = (x - r_j - d)(x - r_k + d) \prod_{i=1, i\neq j,k}^{n} (x - r_i).$$

If c_i is a root of the polynomial, then that root is repeated and we have three possible cases:

1. $r_i = c_i = r_{i+1}$ and neither r_i nor r_{i+1} are being shifted.
2. $r_i = c_i = r_{i+1}$ and r_{i+1} is being shifted to the right.
3. $r_i = c_i = r_{i+1}$ and r_i is being shifted to the left.

In case 1, since $\tilde{c}_i$ must still be the critical number between r_i and r_{i+1}, we have $r_i = \tilde{c}_i = r_{i+1} = c_i$, as desired. In case 2, according to Rolle's Theorem, $\tilde{c}_i$ must be greater than r_i. Therefore we have $\tilde{c}_i > c_i$. This is what we desired to show, as the fact that r_{i+1} is moving to the right implies that $1 \leq i < j$. Similarly, in case 3, Rolle's Theorem tells us that $\tilde{c}_i$ must be less than r_{i+1}, and hence, less than c_i. This is what we desired to show, as the fact that r_i is moving to the left implies that $k \leq i \leq n-1$.

We must now investigate what happens in the case where $r_i < c_i < r_{i+1}$. Since our goal is to develop a way to compare c_i and $\tilde{c}_i$, we can examine how $\tilde{p}'$ behaves near these points. We define the function $q(x)$ so that $p(x) = (x - r_j)(x - r_k)q(x)$. From this, we can rewrite $\tilde{p}(x)$ as $\tilde{p}(x) = (x - r_j - d)(x - r_k + d)q(x)$. Differentiating $p(x)$ yields

$$p'(x) = (x - r_j + x - r_k)q(x) + (x - r_j)(x - r_k)q'(x). \quad (5)$$

Differentiating $\tilde{p}(x)$ yields

$$\tilde{p}'(x) = (x - r_j + x - r_k)q(x) + (x - r_j - d)(x - r_k + d)q'(x). \quad (6)$$

We may now subtract equation (5) from equation (6) and obtain

$$\begin{aligned}
\tilde{p}'(x) - p'(x) =& [(x - r_j + x - r_k)q(x) \\
&+ (x - r_j - d)(x - r_k + d)q'(x)] \\
&- [(x - r_j + x - r_k)q(x) \\
&+ (x - r_j)(x - r_k)q'(x)] \\
=& (x - r_j - d)(x - r_k + d)q'(x) \\
&- (x - r_j)(x - r_k)q'(x) \\
=& [(x^2 - xr_k + dx - r_jx + r_jr_k \\
&- r_jd - dx + dr_k - d^2) \\
&- (x^2 - xr_k - r_jx \\
&+ r_jr_k)]q'(x) \\
=& (-r_jd + dr_k - d^2)q'(x) \\
=& d(r_k - r_j - d)q'(x).
\end{aligned}$$

Since $p'(c_i) = 0$, we can then evaluate this expression at $x = c_i$ to find that

$$\tilde{p}'(c_i) = d(r_k - r_j - d)q'(c_i). \quad (7)$$

Recall our assumption that $(r_k - r_j) \geq 2d$. Therefore, we have $(r_k - r_j - d) \geq d$, which we have assumed to be positive. Therefore, $\tilde{p}'(c_i)$ must have the same sign as $q'(c_i)$.

Now, consider the case where $c_i < r_j$. Clearly, for $r_i < x < r_{i+1}$, $p(x)$ is either strictly positive or negative. Let us assume that $p(x)$ is negative. We then know that $p(c_i)$ is negative. Since $p(c_i) = (c_i - r_j)(c_i - r_k)q(c_i)$, and since $(c_i - r_j)$ and $(c_i - r_k)$ are both negative, we can see that $q(c_i)$ must also be negative. If we now evaluate equation (5) at $x = c_i$, we obtain

$$0 = (c_i - r_j + c_i - r_k)q(c_i) + (c_i - r_j)(c_i - r_k)q'(c_i). \quad (8)$$

We know that $(c_i - r_j + c_i - r_k)q(c_i)$ is positive, since both factors are negative. Similarly, we know that $(c_i - r_j)(c_i - r_k)$ is positive. Therefore, to satisfy equation (8), we see that $q'(c_i)$ must be negative. Further, by equation (6), this tells us that $p'(c_i)$ must be negative as well. We may now consider the equation

$$p(x)(x - r_j - d)(x - r_k + d) = \tilde{p}(x)(x - r_j)(x - r_k). \quad (9)$$

Evaluating equation (9) at $x = c_i$, the left hand side of the equation becomes negative based on what we have shown so far. Therefore, $\tilde{p}(c_i)$ must be negative to make the equation true.

Let us refer to the ith root of $\tilde{p}(x)$ as $\tilde{r}_i$. Since we are still under the assumption that $i < j$, we know that $\tilde{r}_i = r_i$ and $r_{i+1} \leq \tilde{r}_{i+1}$. Therefore, when x is in the interval (r_i, r_{i+1}), x is also in the interval $(\tilde{r}_i, \tilde{r}_{i+1})$. Again, since the function $\tilde{p}(x)$ must be strictly positive or strictly negative over this interval, the fact that $\tilde{p}(c_i)$ is negative lets us conclude that $\tilde{p}(x)$ is negative on the entire interval $(\tilde{r}_i, \tilde{r}_{i+1})$. So we know that the sign of $\tilde{p}'(x)$ must change from negative to positive exactly once, namely at $\tilde{c}_i$, in this interval. We have shown that $\tilde{p}'(c_i)$ must be negative, and therefore, c_i must be less than $\tilde{c}_i$, which is what we set out to prove.

This argument is similar if we assume that $p(x)$ is positive for $r_i < x < r_{i+1}$.

Further, the same reasoning may be applied to show that for $k \leq i \leq n-1$ we have $\tilde{c}_i \leq c_i$. This completes our proof. □

A recent paper by Christopher Frayer and James Swenson [7] takes a more dynamic approach to this same problem of how critical numbers move with respect to changing roots. In their paper, entitled Continuous Polynomial Root Dragging, they let each root move with a prescribed velocity, and the location of the roots is then thought of as a function of time. They then show, at a given time, which way a specified critical point is moving. They call it the Polynomial Root Motion Theorem, and it is stated as follows:

Theorem 3. *Suppose that $c(t)$ is a critical point of the polynomial $p_t(x)$ for all t, with c differentiable and $c(t_0) = 0$. Further, for each root r_k, the root is moving at a velocity of v_k. If $p_{t_0}(x)$ has a double root at $x = 0$ (say, $r_k = r_k(t_0) = 0$ for $k \in \{i, j\}$), then $c'(t_0) = (v_i + v_j)/2$. Otherwise,*

$$c'(t_0) = \frac{-p_{t_0}(0)}{p''_{t_0}(0)} \sum_{i=1}^{n} \frac{v_i}{r_i^2}.$$

This theorem shows that roots affect critical points in almost the same way that gravity affects masses. Note that it assumes that the critical point of interest is at the origin. However, since any polynomial may be translated horizontally to make a given critical point land on the origin, this theorem can be used to show how any given critical point is moving at a given time.

We now have a much better understanding of how critical numbers interact with changing roots. However, the critical numbers are not the only things that change when we change roots. Remember, *every* characteristic is dependent upon the location of the roots. So how do other things change? The following result arises as another consequence of root dragging, and it is another great example of the kind of things we are trying to analyze. It appeared in a paper by Matt Boelkins, Jennifer Miller, and Benjamin Vugteveen in 2006 [5]. It uses a similar analysis as the Polynomial Root Dragging Theorem to illustrate the effect that dragging roots has on the curve's deviation from the x-axis. This theorem will be used later when we begin to explore some extremal problems.

Theorem 4. *Let $p(x) = \prod_{i=1}^{n}(x - r_i)$ be a degree n polynomial where $r_1 < r_2 < \cdots < r_n$. If an interior root, r_d, is dragged to the right by a distance of ε, where $0 < \varepsilon < r_{d+1} - r_d$, producing a new polynomial, $p_\varepsilon(x) = (x - r_d - \varepsilon)\prod_{i\neq d}(x - r_i)$, then the following inequalities hold:*

a. *If $x < r_{d-1}$, then $|p_\varepsilon(x)| \geq |p(x)|$, with equality only at the common roots.*
b. *If $x > r_{d+1}$, then $|p_\varepsilon(x)| \leq |p(x)|$, with equality only at the common roots.*
c. *If $r_{d-1} < x < r_{d+1}$ and $p'(r_{d-1}) > 0$, then $p_\varepsilon(x) > p(x)$. The reverse inequality is true if $p'(r_{d-1}) < 0$.*

Proof. Let $p(x) = \prod_{i=1}^{n}(x - r_i)$ be a degree n polynomial where $r_1 < r_2 < \cdots < r_n$. Let r_d be an interior root. Assume we drag r_d to the right by ε units, where $0 < \varepsilon < r_{d+1} - r_d$, such that we produce a new polynomial $p_\varepsilon(x) = (x - r_d - \varepsilon)\prod_{i\neq d}(x - r_i)$. Note that p and p_ε only intersect at values of $x = r_i$, $i \neq d$, and both take on the value of zero at these points. Further, since the degree of $p - p_\varepsilon$ is $(n-1)$, p and p_ε cannot intersect in (r_{d-1}, r_{d+1}). Also, it is important to recognize that for any two polynomials that share zeros at the endpoints of an interval and do not intersect in between the endpoints, the polynomial with the greater derivative at the left endpoint will have the greater value throughout the entire interval.

Notice that

$$p'(x) = \sum_{j=1}^{n} \prod_{i\neq j} (x - r_i),$$

and

$$p'_\varepsilon(x) = (x - r_d - \varepsilon)\sum_{j=1}^{n-1} \prod_{i\neq j,d} (x - r_i) + \prod_{i\neq d}(x - r_i).$$

Evaluating both p and p_ε at r_i, $i \neq d$, we see

$$p'(r_i) = (r_i - r_d) \prod_{j\neq i,d} (r_i - r_j),$$

while

$$p'_\varepsilon(r_i) = (r_i - r_d - \varepsilon) \prod_{j\neq i,d} (r_i - r_j).$$

Then, if $i < d$, we have $|r_i - r_d| < |r_i - r_d - \varepsilon|$, which makes $|p'(r_i) < p'_\varepsilon(r_i)|$. It then follows that $|p(x)| \leq |p_\varepsilon(x)|$ for all $x < r_{d-1}$.

Similarly, if $i > d$, $|r_i - r_d| > |r_i - r_d - \varepsilon|$, making $|p'(r_i) > p'_\varepsilon(r_i)|$ and $|p(x)| \geq |p_\varepsilon(x)|$ for all $x > r_{d+1}$. This completes parts (a.) and (b.) of the proof.

To prove part (c.) we must consider the fact that $p'(r_{d-1})$ can be negative or positive. Clearly, $(d-1) < d$, and we have already shown that $|p'(r_{d-1})| < |p'_\varepsilon(r_{d-1})|$. Therefore, if $p'(r_{d-1})$ is negative, then $p'_\varepsilon(r_{d-1})$ must be more negative, and will therefore make $|p(x)| \geq |p_\varepsilon(x)|$ on the entire interval (r_{d-1}, r_{d+1}). Similarly, if $p'(r_{d-1})$ is positive, then $p'_\varepsilon(r_{d-1})$ must be more positive, and will therefore make $|p(x)| \leq |p_\varepsilon(x)|$ over the given interval. This verifies part (c.) of the theorem, and thus completes our proof. □

The Polynomial Root Dragging Theorem was proven in 1993, while the Polynomial Root Squeezing Theorem was proven in 2008. However, in 1967 Gideon Peyser [12] proved something with striking similarities to the Root Dragging Theorem, and he proved these things using an analysis that is very similar to the one presented above in the Root Squeezing Theorem. En route to proving that there are upper and lower bounds for a polynomial's critical numbers, he proved that critical numbers were affected by both moving and omitting exterior roots. These results were in the form of lemmas that were used in proving his theorem about the bounds of critical numbers, but they did not receive the acknowledgment that Anderson's did. They were, however, quite a profound way to analyze polynomials, and clearly influenced the proof of the Root Squeezing Theorem. Following are the proofs of the theorem as well as the lemmas that Peyser used to establish upper and lower bounds for the critical numbers of a polynomial with all real roots. In the proof, all polynomials will be written in factored form, with the roots in increasing order. That is, for a polynomial $p(x)$, we will write

$$p(x) = (x - a_1) \cdots (x - a_n)$$

and

$$p'(x) = (x - c_1) \cdots (x - c_{n-1}),$$

where a_i and c_i are real numbers and $a_i \leq c_i \leq a_{i+1}$.

Theorem 5. *If a polynomial $p(x)$ has only real roots $a_1, a_2, \ldots, a_n$, and if $a_k < a_{k+1}$, then the unique root c_k of $p'(x)$ between a_k and a_{k+1} satisfies the inequality*

$$a_k + \frac{a_{k+1} - a_k}{n - k + 1} \leq c_k \leq a_{k+1} - \frac{a_{k+1} - a_k}{k + 1}.$$

To prove this theorem, it will be helpful to prove four lemmas concerning the roots of $p(x)$ and $p'(x)$. We first consider what happens when we omit the extreme left or right roots of $p(x)$:

Lemma 1. *Let $q(x) = (x - a_1) \cdots (x - a_{n-1})$ and $q'(x) = (n-1)(x-d_1) \cdots (x-d_{n-2})$. Then $d_k \geq c_k$ for $1 \leq k \leq n-2$.*

This lemma means that when considering the polynomial $q(x)$, obtained when we remove the last root of $p(x)$, all of the roots of $q'(x)$ are greater than or equal to the corresponding roots of $p'(x)$.

Proof of Lemma 1. Let $q(x) = (x - a_1) \cdots (x - a_{n-1})$ and $q'(x) = (n-1)(x - d_1) \cdots (x - d_{n-2})$. Then we have $p(x) = q(x)(x - a_n)$. Differentiating this yields

$$p'(x) = q'(x)(x - a_n) + q(x). \tag{10}$$

Now consider the two consecutive roots a_k and a_{k+1}. We know that for any value of x such that $a_k < x < a_{k+1}$, $p(x)$ will be either strictly positive or strictly negative. Without loss of generality, we may assume that $p(x) > 0$ on this interval. Since $(x - a_n) < 0$, we can see that $q(x) < 0$ $a_k < x < a_{k+1}$. Further, we know that since $q(x)$ is negative, as x increases over this given interval, $q'(x)$ will change sign from negative to positive one time. We know that $p'(c_k) = 0$. Therefore, we can see from (10) that $q'(c_k)(c_k - a_n) + q(c_k) = 0$. Since $q(c_k) < 0$ and $(c_k - a_n) < 0$, we can then conclude that $q'(c_k) < 0$. Hence, since $q'(x)$ will change from negative to positive at d_k, we can conclude that $c_k < d_k$. Thus, we have completed our proof of Lemma (1).

In a similar fashion, we may prove the following:

Lemma 2. *Let $r(x) = (x - a_2) \cdots (x - a_n)$ and $r'(x) = (n - 1)(x - e_1) \cdots (x - e_{n-2})$. Then $e_k \leq c_{k+1}$ for $1 \leq k \leq n - 2$.*

This lemma means that when considering the polynomial $r(x)$, obtained when we remove the first root of $p(x)$, all of the roots of $r'(x)$ are less than or equal to the corresponding roots of $p'(x)$.

We next consider what happens when we move the leftmost or rightmost roots to the right or left, respectively:

Lemma 3. *Let $s(x) = (x - (a_1 + \varepsilon))(x - a_2) \cdots (x - a_n)$ where $\varepsilon \geq 0$ is such that $a_1 + \varepsilon \leq a_{n-1}$ and let $s'(x) = n(x - f_1) \cdots (x - f_{n-1})$. Then $f_{n-1} \geq c_{n-1}$.*

This lemma shows that if we increase the leftmost root of $p(x)$ to obtain a new polynomial $s(x)$, then the rightmost root of $s'(x)$ is greater than or equal to the rightmost root of $p'(x)$.

Proof of Lemma 3. Let $s(x) = (x-(a_1+\varepsilon))(x-a_2) \cdots (x-a_n)$ where $\varepsilon \geq 0$ is such that $a_1 + \varepsilon \leq a_{n-1}$ and let $s'(x) = n(x - f_1) \cdots (x - f_{n-1})$. We will assume that $a_{n-1} < a_n$. Then we have

$$\begin{aligned} s(x) &= [(x - a_1)(x - a_2) \cdots (x - a_n)] \\ &\quad - [\varepsilon(x - a_2)(x - a_3) \cdots (x - a_n)] \\ &= p(x) - \varepsilon r(x), \end{aligned}$$

where $r(x) = (x - a_2)(x - a_3) \cdots (x - a_n)$, as discussed in Lemma (2). Without loss of generality, we may assume that $p(x) < 0$ for $a_{n-1} < x < a_n$. Then, since $x - a_1 > 0$ on this interval, we know that $r(x) < 0$, and thus, $s(x) < 0$ for all x values within this interval. Differentiating $s(x)$, we obtain

$$s'(x) = p'(x) - \varepsilon r'(x). \tag{11}$$

Evaluating (11) at $x = c_{n-1}$, since $p'(c_{n-1}) = 0$ we see that $s'(c_{n-1}) = -\varepsilon r'(c_{n-1})$. Since e_{n-2} is the greatest root of $r'(x)$, we may apply Lemma (2) to see that c_{n-1} is greater than every individual root of $r'(x)$. Therefore, $r'(c_{n-1})$ is a product of positive terms, and thus, is positive. Hence, $s'(c_{n-1}) < 0$. Again, as in the proof of Lemma (1), since $s'(x)$ changes sign from negative to positive values exactly one time in the interval from a_{n-1} to a_n, and $s'(f_{n-1}) = 0$, it follows that $c_{n-1} < f_{n-1}$.

In a similar fashion, we may prove the following:

Lemma 4. *Let $t(x) = (x - a_1) \cdots (x - a_{n-1})(x - (a_n - \varepsilon))$ where $\varepsilon \geq 0$ is such that $a_n - \varepsilon \geq a_2$ and let $t'(x) = (n - 1)(x - g_1) \cdots (x - g_{n-2})$. Then $g_1 \leq c_1$.*

This lemma shows that if we decrease the rightmost root of $p(x)$ to obtain a new polynomial $t(x)$, then the leftmost root of $t'(x)$ is less than or equal to the leftmost root of $p'(x)$.

We may now use these tools to prove our main theorem. The result of the theorem shows us that critical numbers cannot be found within certain intervals nearby the roots.

Proof. Let $p(x)$ be a polynomial of degree n that has only real roots $a_1, a_2, \ldots, a_n$, such that $a_k < a_{k+1}$ for all $k < n$, and critical numbers $c_1, c_2, \ldots, c_{n-1}$ such that $c_k < c_{k+1}$ for all $k < n - 1$. We will prove that the unique root c_k of $p'(x)$ between a_k and a_{k+1} satisfies the inequality

$$a_k + \frac{a_{k+1} - a_k}{n - k + 1} \leq c_k \leq a_{k+1} - \frac{a_{k+1} - a_k}{k + 1}.$$

Consider the polynomial $w(x) = (x - a_k)^k (x - a_{k+1})$. Differentiating $w(x)$, we obtain

$$\begin{aligned} w'(x) &= k(x - a_k)^{k-1}(x - a_{k+1}) + (x - a_k)^k \\ &= (x - a_k)^{k-1}[k(x - a_{k+1}) + (x - a_k)] \\ &= (x - a_k)^{k-1}(kx - ka_{k+1} + x - a_k) \\ &= (x - a_k)^{k-1}(x(k + 1) - ka_{k+1} - a_k). \end{aligned}$$

Therefore, $w'(x)$ has a root

$$c = \frac{ka_{k+1} + a_k}{k + 1} = a_{k+1} - \frac{a_{k+1} - a_k}{k + 1}.$$

We may now consider what happens when we take $p(x)$ and discard the roots $a_{k+2}, a_{k+3}, \ldots, a_n$, and drag $a_1, a_2, \ldots, a_{k-1}$ to a_k. The resulting polynomial is $w(x)$, and by applying Lemmas (1) and (3), we can conclude

$$c_k \leq c = a_{k+1} - \frac{a_{k+1} - a_k}{k + 1}.$$

Similarly, by considering the polynomial $y(x) = (x - a_k)(x - a_{k+1})^{n-k}$ and repeatedly applying Lemmas (2) and (4) to $p(x)$ to obtain $y(x)$, we can see that

$$c_k \geq a_k + \frac{a_{k+1} - a_k}{n + 1 - k}.$$

Thus, we have proven that the unique root c_k of $p'(x)$ between a_k and a_{k+1} satisfies the inequality

$$a_k + \frac{a_{k+1} - a_k}{n - k + 1} \leq c_k \leq a_{k+1} - \frac{a_{k+1} - a_k}{k + 1}.$$

□

Here we get our first glimpse of what are known as Bernstein polynomials, as given by $w(x) = (x - a_k)^k (x - a_{k+1})$ and $y(x) = (x - a_k)(x - a_{k+1})^{n-k}$. There will be much more on this very special family of polynomials later, but it is worth noting that $w(x)$ will maximize the k-th critical number for a degree $(k + 1)$ polynomial. Similarly, $y(x)$ will minimize the first critical number for a degree $(n - k + 1)$ polynomial. This makes a lot of sense when we think about it with respect to the Polynomial Root Dragging Theorem. Since all critical numbers will move in the direction of a root that is dragged, if we are trying to maximize or minimize a critical number, dragging all interior roots to the endpoints is a very intuitive solution.

In Lemmas 1-4, Peyser only addresses what happens when we omit or move exterior roots. The Polynomial Root Dragging Theorem extends the moving of roots to the interior. Here, using a very similar analysis to Peyser's, we extend this idea of omitting roots to see what happens to critical numbers when we remove interior roots. To our knowledge, this is a previously unanswered question. The proof of this lemma will follow the same assumptions presented in the previous theorem.

Lemma 5. *Let $v(x) = (x - a_1) \cdots (x - a_{k-1})(x - a_{k+1}) \cdots (x - a_n)$ and $v'(x) = (n-1)(x - h_1) \cdots (x - h_{n-2})$ where $a_i \leq h_i \leq a_{i+1}$ for $i < k - 1$ and $a_i \leq h_{i-1} \leq a_{i+1}$ for $i > k$. Then for every $j < k - 1$, $c_j < h_j$ and for every $j > k$, $c_j > h_{j-1}$.*

This lemma means that if $v(x)$ is obtained by omitting an interior root, r_k, of $p(x)$, then the first $k - 2$ roots of $v'(x)$ will be greater than or equal to the first $k - 2$ roots of $p'(x)$ and the last $n - k - 1$ roots of $v'(x)$ will be less than or equal to the last $n - k - 1$ roots of $p'(x)$.

Proof. Let $v(x) = (x - a_1) \cdots (x - a_{k-1})(x - a_{k+1}) \cdots (x - a_n)$ and $v'(x) = (n - 1)(x - h_1) \cdots (x - h_{n-2})$ where $a_i \leq h_i \leq a_{i+1}$ for $i < k - 1$ and $a_i \leq h_{i-1} \leq a_{i+1}$ for $i > k$. Then we have $p(x) = v(x)(x - a_k)$. Differentiating $p(x)$ gives

$$p'(x) = v'(x)(x - a_k) + v(x).$$

We know that for any value of x such that $a_j < x < a_{j+1} < a_k$, $p(x)$ will be either strictly positive or strictly negative. Without loss of generality, we may assume that $p(x) > 0$. Then, since $(x - a_k) < 0$, we can see that $v(x)$ must be negative for $a_j < x < a_{j+1}$. Further, $v'(x)$ will change sign from

negative to positive exactly once over this interval. We know $p'(c_j) = 0$, so we have

$$v'(c_j)(c_j - a_k) + v(c_j) = 0.$$

Since $v(c_j) < 0$ and $(c_j - a_k) < 0$, we can see that $v'(c_j)$ must be negative. Therefore, because $v'(h_j) = 0$, we can conclude that $c_j < h_j$.

We may now consider an interval such that $a_k < a_m < x < a_{m+1}$. Again, let us assume without loss of generality that $p(x)$ is positive on this interval. Then, since $(x - a_k) > 0$, we know that $v(x)$ must be positive on the interval. Further, $v'(x)$ will change signs from positive to negative exactly once over this interval. We know that $p'(c_m) = 0$, so we have

$$v'(c_m)(c_m - a_k) + v(c_m) = 0.$$

Since $v(c_m) > 0$ and $(c_m - a_k) > 0$, we can see that $v'(c_m)$ must be negative. Therefore, since $v'(h_{m-1}) = 0$, we can conclude that $h_{m-1} < c_m$. This is exactly what we intended to show. □

The establishment of bounds on the critical numbers of a polynomial is another very different kind of problem that the geometry of polynomials endeavors to understand. How can we estimate the value of other quantities pertaining to a polynomial's characteristics in terms of its roots and its degree? Peyser's results are a great example of this. They did, however, go relatively unnoticed for some time. In 1995, Peter Andrews [3] proved the same result of the bounds of a critical number in a different way, though he seemed unaware of Peyser's results. Then, in 2008 Aaron Melman [9] made an improvement on both of the previous theorems by a different argument through a new perspective. By considering the effect that the multiplicities of the adjacent, distinct roots have on the critical number lying between them, he made the possible interval where the critical numbers may be found slightly smaller. Note that Melman's approach to solving this problem employs a very creative application of the logarithmic derivative.

Theorem 6. *Let an nth degree polynomial $p(x)$ be given with only real roots r_i, $i = 1, 2, \ldots, n$, where $r_i \leq r_{i+1}$. If $r_k < r_{k+1}$ and the multiplicities of r_k and r_{k+1} are m_k and m_{k+1}, respectively, then the unique root c_k of $p'(x)$ between r_k and r_{k+1} satisfies the inequalities*

$$r_k + \frac{m_k}{n-k+m_k}(r_{k+1} - r_k) \leq c_k \leq r_{k+1} - \frac{m_{k+1}}{k+m_{k+1}}(r_{k+1} - r_k).$$

Proof. Let $p(x)$ be a degree n polynomial with only real roots r_i, $i = 1, 2, \ldots, n$, such that $r_i \leq r_{i+1}$. Further, let r_k and r_{k+1} be distinct roots with multiplicities m_k and m_{k+1}, respectively. We will prove that the unique root c_k of $p'(x)$ between r_k and r_{k+1} satisfies the above inequalities. We know that for some constant a,

$$p(x) = a(x - r_1)(x - r_2)\cdots(x - r_n).$$

Since $r_k < r_{k+1}$, we know that c_k is not a root of $p(x)$. In other words, $p(c_k) \neq 0$. Therefore, we can take the logarithmic derivative and evaluate it at c_k to obtain

$$\frac{p'(c_k)}{p(c_k)} = \sum_{i=1}^{n} \frac{1}{c_k - r_i} = 0.$$

We can then separate this sum into two pieces as follows:

$$\sum_{i=1}^{n} \frac{1}{c_k - r_i} = \sum_{i=1}^{k} \frac{1}{c_k - r_i} + \sum_{i=k+1}^{n} \frac{1}{c_k - r_i} = 0.$$

Subtracting $\sum_{i=k+1}^{n} \frac{1}{c_k - r_i}$ from both sides of the right-hand equation, we find that

$$\sum_{i=1}^{k} \frac{1}{c_k - r_i} = \sum_{i=k+1}^{n} \frac{1}{r_i - c_k}. \tag{12}$$

Note that for all $j \leq k$ we have $r_j < c_k$, and for all $j > k$ we have $r_j > c_k$. Therefore, all terms in equation (12) are positive. Since r_k is the largest root less than c_k, the greatest value that the left hand side of equation (12) can obtain is $\frac{k}{c_k - r_k}$. Further, since r_{k+1} has multiplicity m_{k+1}, the first m_{k+1} terms on the right side of equation (12) are identical. Since all of the terms are positive, we then know that the smallest value that the right hand side can obtain is $\frac{m_{k+1}}{r_{k+1} - c_k}$. This yields

$$\frac{k}{c_k - r_k} \geq \frac{m_{k+1}}{r_{k+1} - c_k}. \tag{13}$$

Similarly, since the multiplicity of r_k is m_k, we know that the last m_k terms of the left hand side of equation (12) are identical. So the smallest possible value that the left hand side of the equation obtains is $\frac{m_k}{c_k - r_k}$. Further, since r_{k+1} is the least root greater than c_k, and since there are $n - k$ terms on the right side of equation (12), the greatest value that the right hand side can obtain is $\frac{n-k}{r_{k+1} - c_k}$. This yields

$$\frac{m_k}{c_k - r_k} \leq \frac{n-k}{r_{k+1} - c_k}. \tag{14}$$

For notational purposes, let $\Delta = r_{k+1} - r_k$, $\Delta_k = c_k - r_k$, and $\Delta_{k+1} = r_{k+1} - c_k$. We can then rewrite inequalities (13) and (14) as

$$\frac{k}{\Delta_k} \geq \frac{m_{k+1}}{\Delta_{k+1}}$$

and

$$\frac{m_k}{\Delta_k} \leq \frac{n-k}{\Delta_{k+1}}.$$

With a little algebra we then obtain

$$\Delta_k \leq \frac{k}{m_{k+1}}\Delta_{k+1}$$

and

$$\Delta_{k+1} \leq \frac{n-k}{m_k}\Delta_k.$$

We know that $\Delta_k + \Delta_{k+1} = \Delta$. Therefore, we have

$$\Delta \leq \frac{k}{m_{k+1}}\Delta_{k+1} + \Delta_{k+1}$$

and

$$\Delta \leq \frac{n-k}{m_k}\Delta_k + \Delta_k.$$

Removing the Δ notation yields

$$r_{k+1} - r_k \leq \frac{k}{m_{k+1}}(r_{k+1} - c_k) + r_{k+1} - c_k$$

and

$$r_{k+1} - r_k \leq \frac{n-k}{m_k}(c_k - r_k) + c_k - r_k.$$

Finally, solving these inequalities for c_k, we obtain

$$c_k \leq r_{k+1} - \frac{m_{k+1}}{k+m_{k+1}}(r_{k+1} - r_k)$$

and

$$c_k \geq r_k + \frac{m_k}{n-k+m_k}(r_{k+1} - r_k).$$

Combining these last two inequalities gives us the desired result that

$$r_k + \frac{m_k}{n-k+m_k}(r_{k+1} - r_k) \leq c_k \leq r_{k+1} - \frac{m_{k+1}}{k+m_{k+1}}(r_{k+1} - r_k),$$

and thus completes our proof. □

Therefore, just by considering the multiplicities of roots a factor, Melman has successfully narrowed the possible interval in which a critical number may live. In his paper, he provides an example that is helpful in illustrating the value of this. For a polynomial $q(x) = (x-1)(x-2)^4(x-3)^2(x-4)$, according to Peyser and Andrew's method, the fifth critical number would fall between $2\frac{1}{4}$ and $2\frac{5}{6}$. However, by considering the multiplicities, Melman notes that the same root must actually fall between $2\frac{4}{7}$ and $2\frac{5}{7}$. This is quite an improvement over the previous theorems.

The following is one final example of the kind of problems we are interested in. It is a very short proof by Răzvan Gelca of a theorem dealing with the separation of zeros of a polynomial. Again, we see the use of the logarithmic derivative. In order to prove the theorem, we must make a few assumptions. For a polynomial $f(x) = \prod_{i=1}^{n}(x - x_i)$, with distinct real roots $x_1 < x_2 < \cdots < x_n$, we let $d = \delta(f) = \min_i(x_{i+1} - x_i)$ and $g(x) = f'(x)/f(x) = \sum_{i=1}^{n} 1/(x - x_i)$. If k is a real number, then the roots of the polynomial $f' - kf$ are also real and distinct.

Theorem 7. *If some j, y_0 and y_1 satisfy $y_0 < x_j < y_1 \leq y_0 + d$, then y_0 and y_1 are not zeros of f and $g(y_0) < g(y_1)$.*

Proof. Let j, y_0 and y_1 satisfy $y_0 < x_j < y_1 \leq y_0 + d$. We will prove that y_0 and y_1 are not zeros of f and $g(y_0) < g(y_1)$. It follows directly from the hypothesis that for all i, $y_1 - y_0 \leq d \leq x_{i+1} - x_i$. Then for $1 \leq i \leq j - 1$, we have

$$y_1 - y_0 \leq x_{i+1} - x_i.$$

Multiplying by (-1) yields

$$y_0 - y_1 \geq x_i - x_{i+1}.$$

A little arithmetic gives us

$$y_0 - x_i \geq y_1 - x_{i+1}.$$

Since $x_{i+1} \leq x_j$, we can then conclude that

$$y_0 - x_i \geq y_1 - x_{i+1} > 0.$$

Therefore, we have

$$\frac{1}{(y_0 - x_i)} \leq \frac{1}{(y_1 - x_{i+1})}. \tag{15}$$

Similarly, for $j \leq i \leq n - 1$ we have $y_1 - x_{i+1} \leq y_0 - x_i < 0$, and we still have the same inequality achieved in (15). Obviously, the inequality

$$y_0 - x_n < 0 < y_1 - x_1 \tag{16}$$

is true, so we have

$$\frac{1}{(y_0 - x_n)} < 0 < \frac{1}{y_1 - x_1}. \tag{17}$$

We have now shown that $y_0 - x_i \neq 0$ and $y_1 - x_i \neq 0$ for all $i \in \{1, 2, \ldots, n\}$. Therefore, neither y_0 nor y_1 are zeros of f. Further, adding (16) and (17) shows that $g(y_0) < g(y_1)$. □

We have now seen a broad range of problems concerning the geometry of polynomials. These fundamental theorems serve a few purposes. They provide us with tools that we may use in further investigating related problems, as well as an illustration of the kind of problems that the geometry of polynomials is concerned with answering. We now have a strong enough foundation to begin exploring some problems dealing with extremality.

3 Special Polynomials

There are two different families of polynomials that will be especially important to be familiar with in order to discuss extremal problems. These famous families are known as Chebyshev polynomials and Bernstein polynomials.

Chebyshev polynomials come in four different kinds. There are two that we are interested in discussing: Chebyshev polynomials of the first kind, and Chebyshev polynomials of the second kind. A degree n Chebyshev polynomial of the first kind is defined recursively as follows:

$$T_0(x) = 1 \qquad T_1(x) = x$$
$$T_{n+1}(x) = 2x \cdot T_n(x) - T_{n-1}(x) \qquad (n \geq 1).$$

These polynomials are equioscillatory, meaning the deviation of the curve from the x-axis at the critical values, and at the end points of the interval, is equal. These polynomials also have a closed form expression, which is much more useful in application. The following is a short proof highlighting this, and it is found in a Numerical Analysis text by Ward Cheney and David Kincaid [6].

Theorem 8. *For x in the interval $[-1, 1]$, the Chebyshev polynomials of the first kind have this closed-form expression*

$$T_n(x) = \cos(n \cos^{-1} x), \quad (n \geq 0).$$

Proof. To prove this, we must first recall the addition formula for the cosine:

$$\cos(A + B) = \cos A \cos B - \sin A \sin B.$$

From this, we obtain

$$\begin{aligned} \cos((n+1)\theta) &= \cos(\theta n + \theta) \\ &= \cos\theta \cos n\theta - \sin\theta \sin n\theta \end{aligned} \tag{18}$$

and

$$\begin{aligned} \cos((n-1)\theta) &= \cos(\theta n - \theta) \\ &= \cos\theta \cos n\theta + \sin\theta \sin n\theta. \end{aligned} \tag{19}$$

We may now add (18) and (19) together, and we get

$$\cos((n+1)\theta) + \cos((n-1)\theta) = 2\cos\theta \cos n\theta$$

which yields

$$\cos((n+1)\theta) = 2\cos\theta \cos n\theta - \cos((n-1)\theta). \tag{20}$$

Now, if we let $\theta = \cos^{-1} x$ and $x = \cos\theta$, we can see that equation (20) shows that the functions f_n defined by

$$f_n(x) = \cos(n \cos^{-1} x)$$

follow the system of equations:

$$f_0(x) = 1$$
$$f_1(x) = x$$
$$f_{n+1}(x) = 2x f_n(x) - f_{n-1}(x), \qquad (n \geq 1).$$

Therefore, we have proven that $f_n(x) = T_n(x)$ for all n. □

Using this closed form expression makes it easy to see that Chebyshev polynomials of the first kind are indeed equioscillatory on the interval $[-1, 1]$.

For Chebyshev polynomials of the second kind, we will start by introducing the closed form expression. A degree n Chebyshev polynomial of the second kind is defined on the interval $[-1, 1]$ as

$$U_n(x) = \frac{\sin((n+1)\arccos(x))}{\sqrt{1-x^2}}.$$

These polynomials do follow the same recursive definition as the Chebyshev polynomials of the first kind. That is,

$$U_{n+1}(x) = 2xU_n(x) - U_{n-1}(x), \qquad (n \geq 1).$$

Further, the first two kinds of Chebyshev polynomials have the very nice relationship that

$$U_n(x) = \frac{1}{n} T'_{n+1}(x).$$

These polynomials arise as minimizers in a couple of our extremal problems, as we will soon explore further. Figure 1 shows an example of each of the two kinds of Chebyshev polynomials that we are interested in.

On the flip side of extremal problems, Bernstein polynomials, as briefly introduced in Section 2, frequently arise as maximizers. A degree n Bernstein polynomial is defined as

$$B_{i,n}(x) = \binom{n}{i} x^i (1-x)^{n-i}.$$

This is a family of polynomials. To be a member of this family, a polynomial must have all of its roots at 0 or 1. However, since we are interested in monic polynomials with all real zeros in the interval $[-1, 1]$, we have scaled the Bernstein polynomials to meet our requirements. That is, for our purposes, we define Bernstein polynomials in the following way:

$$B_{i,n}(x) = (x+1)^i (x-1)^{n-i}.$$

Notice that neither of the forms provided here match the forms of the functions $w(x)$ and $y(x)$ from Theorem 5 in Section 2. This just shows that Bernstein Polynomials can be defined on any interval, and the only real requirement is that we distribute all of the roots between the endpoints of the interval. So we are interested in the monic Bernstein polynomials formed by placing all of the roots at either 1 or -1. Note that for any given n, there are $n+1$ degree n Bernstein polynomials. Understanding why these polynomials so frequently maximize different properties is of particular interest

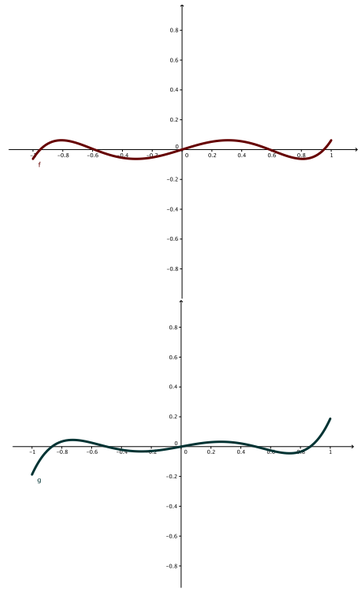

Figure 1: Degree 5 monic Chebyshev polynomials of the first and second kind

to us, and this will be the focus of much of the rest of the paper.

Figure 2 provides an example of a monic degree 5 Bernstein polynomial with four roots at 1 and one root at -1.

An in depth look at many problems concerning these two families of polynomials is to follow. Ultimately, we endeavor to further understand the phenomena of these families and their maximal and minimal qualities.

4 Extremal Problems

We now begin our discussion of problems concerning polynomials that possess maximal and minimal properties. There are many important results and concepts that must first be introduced. One important concept when dealing with these extremal problems is the idea of norms. Norms are types of functions that measure some aspect of another function. A norm is analogous to the absolute value function for real numbers, as it will return a non-negative real number that may be thought of as "size." There are other functions that we may use to measure properties as well, and these different ways to measure properties are the only way we can make sense of discussing maximal and minimal polynomials.

Specifically, we will be focusing on the supremum norm and the L^1 norm. The supremum norm of a function $p(x)$ is defined by

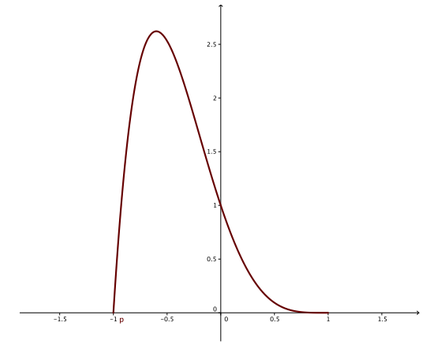

Figure 2: Degree 5 monic Bernstein Polynomial

$$||p(x)||_\infty = \max_{x \in [-1,1]} |p(x)|.$$

The L^1 norm of a function $p(x)$ is defined as

$$||p(x)||_1 = \int_{-1}^{1} |p(x)| dx.$$

Using these norms, and other functions, we will present a few examples of extremal problems in which the answer is either Chebyshev polynomials or Bernstein polynomials. Chebyshev polynomials have been shown to be the minimizer of the supremum norm and the L^1 norm, as we will see. We will also show that Bernstein polynomials are the maximizers of the supremum norm. A remaining question regards the maximizer of the L^1 norm. In this section we will also explore four other properties that are maximized by Bernstein polynomials.

To begin, we will provide a proof that the supremum norm is minimized by Chebyshev polynomials of the first kind. In light of Theorem 4, the fact that Chebyshev polynomials are equioscillatory makes them a good candidate for the supremum norm minimizer: since dragging roots makes the deviation grow in some places and shrink in others, it makes sense intuitively that the minimum maximum deviation must occur for a polynomial where the deviation at the critical points is equal. As it turns out, the leading coefficient for the degree n Chebyshev polynomial of the first kind is 2^{n-1}. Therefore, the monic Chebyshev polynomial of the first kind is $2^{1-n}T_n$. The following proof was presented in a Numerical Analysis text by Ward Cheney and David Kincaid [6].

Theorem 9. *If p is a monic polynomial of degree n, then*

$$||p||_\infty = \max_{-1 \leq x \leq 1} |p(x)| \geq 2^{1-n}.$$

Proof. Let p be a monic polynomial of degree n. We will prove that $||p||_\infty = \max_{-1\le x\le 1}|p(x)| \ge 2^{1-n}$. To do this, we will argue by contradiction. That is, we will assume that for $-1 \le x \le 1$,

$$|p(x)| < 2^{1-n}.$$

Let $q = 2^{1-n}T_n$ and $x_i = \cos(i\pi/n)$, where $0 \le i \le n$. We may now use properties of Chebyshev polynomials to see that q is a monic polynomial of degree n and

$$(-1)^i p(x_i) \le |p(x_i)| < 2^{1-n} = (-1)^i q(x_i).$$

Therefore, we may use algebra to see that for $0 \le i \le n$,

$$(-1)^i[q(x_i) - p(x_i)] > 0.$$

From this we see that the polynomial $q - p$ oscillates in sign $(n + 1)$ times between -1 and 1. However, as the leading terms in $q-p$ will cancel out, $q-p$ cannot have degree higher than $n-1$. Therefore, $q-p$ could not possibly oscillate $(n+1)$ times between -1 and 1. Hence, we have reached our contradiction, and may conclude that if p is a monic polynomial, then $||p||_\infty = \max_{-1\le x\le 1}|p(x)| \ge 2^{1-n}$, as we desired. □

Now, we present the theorem that proved the L^1 norm is minimized by Chebyshev Polynomials of the Second Kind. This proof is presented in the book *Topics in Polynomials: Extremal Problems, Inequalities, and Zeros*, by G.V. Milovanovic [10]. There was a lemma necessary to prove this, and here we present both the lemma and the theorem. We have omitted the proofs of these, as for our purposes, the results are only being used as an illustration of the minimality of Chebyshev polynomials.

Lemma 6. *Let*

$$U_n(x) = \frac{\sin((n+1)\arccos(x))}{\sqrt{1-x^2}}$$

be the n-th Chebyshev polynomial of the second kind. Then

$$I_{n,k} = \int_{-1}^{1} x^k sgn\, U_n(x)dx = \begin{cases} 0, & \text{if } 0 \le k \le n-1 \\ 2^{1-n}, & \text{if } k = n. \end{cases} \tag{21}$$

This lemma is then used to prove the following theorem:

Theorem 10. *Let $p(x) = \sum_{i=0}^{n} a_i x^i$, with $a_n = 1$, be an arbitrary monic polynomial of degree n. Then*

$$||p(x)||_1 \ge ||\hat{U}_n||_1 = 2^{1-n},$$

with equality only if $p(x) = \hat{U}_n(x)$, where $\hat{U}_n$ is the monic Chebyshev polynomial of the second kind of degree n. In other words, $\hat{U}_n(x) = 2^{-n}U_n(x)$.

We have now illustrated how Chebyshev polynomials arise as minimizers of certain properties. Let us now turn our focus to maximizers. By employing Theorem 4, we see that in order to maximize the deviation of the curve from the x-axis near a specific critical value, we must drag all of the roots as far away from that point as possible. In our case, since we are interested strictly in polynomials with roots that live in $[-1, 1]$, these maximal polynomials that we construct will turn out to be members of the Bernstein family. According to the definition of the supremum norm, we see that one of these Bernstein polynomials must maximize the supremum norm of a monic polynomial with all real zeros in the interval $[-1, 1]$. The next question, then, is which one? This question is also answered in the same paper that presented Theorem 4 [5].

Theorem 11. *Given a family of degree n Bernstein polynomials, $p_i(x) = (x+1)^i(x-1)^{n-i}$, the supremum norm of p_i will be maximized when $i = 1$ or when $i = n - 1$.*

Proof. Let $p_i(x) = (x+1)^i(x-1)^{n-i}$ be the family of degree n Bernstein polynomials in the interval $[-1, 1]$. Since each p_i must attain its supremum norm at a critical point, and each p_i will only have one critical point in $(-1, 1)$, we need only look at the value of p_i at this critical point, which we will call c_i. To find c_i, we must evaluate $p_i'(x) = 0$. Note that

$$\begin{aligned} p_i'(x) &= i(x+1)^{i-1}(x-1)^{n-i} \\ &\quad + (n-i)(x-1)^{n-i-1}(x+1)^i \\ &= (x-1)^{n-i-1}(x+1)^{i-1} \\ &\quad \times (i(x-1) + (n-i)(x+1)) \\ &= (x-1)^{n-i-1}(x+1)^{i-1}(nx + n - 2i). \end{aligned}$$

Therefore, for $p_i'(x) = 0$, x must either be 1, -1, or $\frac{2i-n}{n}$. Hence, $c_i = \frac{2i-n}{n}$, and the supremum norm of p_i is simply $|p_i(c_i)|$, which is

$$\begin{aligned} |p_i(c_i)| &= \left|\left(\frac{2i-n}{n}+1\right)^i\left(\frac{2i-n}{n}-1\right)^{n-i}\right| \\ &= \left(\frac{2^i i^i}{n^i}\right)\left|\left(\frac{2^{n-i}(i-n)^{n-i}}{n^{n-i}}\right)\right| \\ &= \left(\frac{2^n}{n^n}\right) i^i (n-i)^{n-i}. \end{aligned}$$

Now, to maximize the supremum norm for all p_i, we must find the value of i that makes the value of $|p_i(c_i)|$ the greatest. Since n will remain fixed, we can simply maximize $i^i(n-i)^{n-i}$. Instead, we may maximize the continuous function $g(t) = t^t(n-t)^{n-t}$ on $t \in [1, n-1]$. Since $g(t)$ and $\ln(g(t))$ have the same critical numbers, we can equivalently find the critical values of $f(t) = \ln(t^t(n-t)^{n-t})$. Using the chain rule, we obtain

$$\begin{aligned} f'(t) &= \ln(t) + 1 - \ln(n-t) - 1 \\ &= \ln(t/(n-t)). \end{aligned}$$

Therefore, $f'(t)$ will only be zero when $\frac{t}{n-t} = 1$. Hence, the only critical number of f, and consequently that of g, will be $t = \frac{n}{2}$. However, this value produces a minimum of g on $[1, n-1]$, and thus, g must be maximized at the endpoints. So the maximum of g and also that of $|p_i(c_i)|$ will occur when $t = 1$ or $t = n - 1$, and these values will be the same because of the symmetry of $|p_i(c_i)|$. □

This paper also establishes the maximum value of the supremum norm for a degree n monic polynomial with all real zeros. Since the maximum supremum norm of p_i will be attained when $i = 1$, we can see that

$$|p_1(c_1)| = \frac{2^n}{n^n}(n-1)^{n-1} = \frac{2^n}{n}\left(\frac{n-1}{n}\right)^{n-1}.$$

Hence, for any monic degree n polynomial, p, with all real zeros in $[-1, 1]$,

$$||p||_\infty \le \frac{2^n}{n}\left(\frac{n-1}{n}\right)^{n-1}.$$

Next, we present a conjecture that we have not yet been able to prove. It concerns the maximal L^1 norm. We are convinced that the following conjecture is true, and there is strong evidence to support this. Although we have tried many approaches to solve this, a formal proof eludes us.

Conjecture 1. *The L^1 norm of a degree n monic polynomial with all real zeros is maximized by a polynomial having the form $p(x) = (x+1)(x-1)^{n-1}$ or $p(x) = (x+1)^{n-1}(x-1)$.*

Now we offer an alternative proof to a maximal problem proven by Blagovest Sendov [14] in 2001. This is a problem related to the Sendov Conjecture, which is a notable unsolved problem.

Conjecture 2. (Sendov Conjecture) *If all the zeros of the polynomial $p(z) = \prod_{k=1}^{n}(z - z_k)$, $(n \ge 2)$ lie in the unit disk $D(0, 1) = \{z : |z| \le 1\}$, then for every z_k, the disk $D(z_k, 1)$ contains at least one zero of $p'(z)$.*

Before we state the theorem that we are providing an alternate proof for, we must first introduce some new notation. The problem we are answering concerns the *Hausdorff deviation* of the set of roots of a polynomial from the *convex hull* of the polynomial's critical numbers. We now present the definition of the Hausdorff deviation of a set B from a set A, which is noted $\rho(B, A)$.

Definition 4. *Given two sets A and B, the Hausdorff deviation of B from A, $\rho(B, A)$, is the supremum of the set $\{\rho(b, A) : b \in B\}$, where $\rho(b, A) = \inf\{|b - a| : a \in A\}$.*

Intuitively, the Hausdorff deviation of B from A can be thought of as finding the point in B that is furthest from the nearest point in A, and measuring the distance between the two points. It is now necessary to define the convex hull of a set A, which is denoted $H(A)$.

Definition 5. *Given a set A, the smallest closed and convex point set that contains A is called the convex hull of A, denoted $H(A)$.*

Finally, we introduce the notation $A(p)$, which represents the set of all distinct zeros of a polynomial. We are now ready to present the theorem.

Theorem 12. *For every polynomial p of degree n with all real zeros, the inequality*

$$\rho(A(p), H(p')) \le \frac{2}{n}$$

holds.

In order to understand fully what this theorem is asking, a picture may be helpful. Figure 3 illustrates what a possible degree 5 case of this theorem would look like.

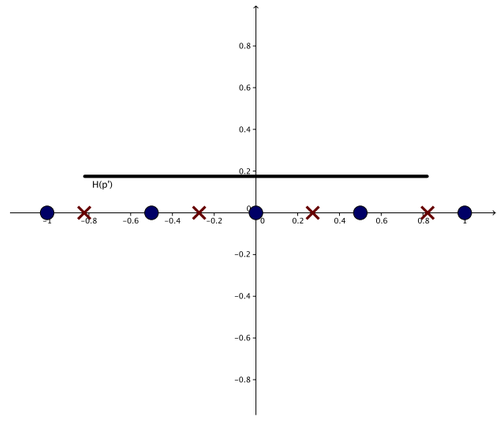

Figure 3: Degree 5 illustration of Theorem 12

In figure 3, the dots represent the roots, the "X's" represent the critical numbers, and the line above the x-axis represents the convex hull of the critical numbers. Note that in reality, the convex hull will be on the x-axis, but for sake of clarity it is shown above. The theorem is then saying that the maximum distance from the set of roots to the convex hull is $2/n$. It is important to note that all of the interior roots will also be elements of the convex hull of the critical numbers. Therefore, we are really trying to show that the distance from one of the exterior roots to the nearest critical number will never exceed $2/n$. We will prove this using a root dragging argument.

Proof. Let $p(x)$ be a degree n monic polynomial with all real zeros in the interval $[-1,1]$. We will prove that the maximum Hausdorff deviation of $A(p)$ from $H(p')$ is $2/n$. The Polynomial Root Dragging Theorem says that if we drag the interior roots of p to the right, the critical numbers of p will follow. Similarly, if we drag the interior roots to the left, the critical numbers will follow to the left. Therefore, by dragging the rightmost interior root to 1, the convex hull of the critical numbers has also moved to the right, and increased the Hausdorff deviation of $A(p)$ from $H(p')$. In order to maximize the Hausdorff deviation of $A(p)$ from $H(p')$, we may continue in this fashion and drag all of the interior roots to 1, creating a Bernstein polynomial with one root at -1 and $n-1$ roots at 1. Note that, due to the symmetry of Bernstein polynomials, $\rho(A(p), H(p'))$ would be the same if we dragged all of the interior roots to -1. So in order to maximize $\rho(A(p), H(p'))$, p must have the form of

$$p(x) = (x+1)(x-1)^{n-1},$$

or

$$p(x) = (x+1)^{n-1}(x-1).$$

So $\rho(A(p), H(p'))$ will be the distance from the critical point in $(-1,1)$ and the single non-repeated root. Again, because of the symmetry of Bernstein polynomials, this value will be the same in either case. Let us then find $\rho(A(p), H(p'))$ for $p(x) = (x+1)(x-1)^{n-1}$. We must first find the critical number of p in $(-1,1)$, which we will call c. Recall from Theorem 11 that $c = \frac{2-n}{n}$. So we have

$$\begin{aligned}\rho(A(p), H(p')) &= \left(\frac{2-n}{n}\right) - (-1)\\ &= \left(\frac{2}{n} - 1\right) + 1\\ &= \frac{2}{n}.\end{aligned}$$

Hence, the Hausdorff deviation of a degree n polynomial's roots from the convex hull of its critical numbers must be less than or equal to $2/n$, with equality only for these special Bernstein polynomials.

□

A similar extremal problem, considered by Piotr Pawlowski [11] in 1998, shows how we may maximize the distance from the centroid, A_p of a polynomial to its nearest critical number. That is, given a degree n polynomial p, with critical numbers c_k, the theorem shows how we can maximize the function

$$J(p) = \min_{1\le k\le n-1} |A_p - c_k|.$$

Pawlowski states that $J(p)$ cannot exceed $2/3$, and that it may only reach $2/3$ for a very specific kind of Bernstein polynomial. We do not present Pawlowski's proof of this result here, for it requires some very complex mathematics. However, we do state the theorem as proved by Pawlowski, which highlights the kind of Bernstein polynomial necessary for maximizing $J(p)$. Also, we provide a more intuitive reasoning for why $J(p)$ can never exceed $2/3$ and why n must be a multiple of 3 to maximize this property.

Theorem 13. *If $p(x)$ is a polynomial with all real zeros, then*

$$J(p) \le \frac{2}{3}.$$

Equality is attained if and only if n is a multiplicity of 3 and $p(x) = (x-1)^{\frac{2n}{3}}(x+1)^{\frac{n}{3}}$ or $p(x) = (x-1)^{\frac{n}{3}}(x+1)^{\frac{2n}{3}}$.

Recall that the centroid of a polynomial is the average of the roots. Therefore, in the case of a Bernstein polynomial, $B_{i,n}(x) = (x+1)^i(x-1)^{n-i}$, the centroid is

$$\begin{aligned}A_B &= \frac{(-1)i + (n-i)}{n}\\ &= \frac{n-2i}{n}.\end{aligned}$$

Further, by using the standard method for finding critical numbers, we may see that the interior critical number of $B_{i,n}$ is $(2i-n)/n$. So the centroid of a Bernstein polynomial is exactly the opposite of the single interior critical number of the polynomial. So the distance from the centroid to the nearest endpoint will be $1 - |(n-2i)/n|$, and the distance from the centroid to the interior critical number will be $2|(n-2i)/n|$. If we do anything to increase either of these distances, the other one must decrease. Therefore, since $J(B)$ measures the smallest of these two distances, maximizing $J(B)$ will require these values to be equal. We then must have

$$1 - \left|\frac{n-2i}{n}\right| = 2\left|\frac{n-2i}{n}\right|,$$

or

$$\left|\frac{n-2i}{n}\right| = \frac{1}{3}.$$

Hence, in order to maximize $J(B)$, we must have a centroid that falls exactly at $1/3$ or $-1/3$, making $J(B) = 2/3$. Now, we can clearly see that $|(n-2i)/n|$ can only be $1/3$ when n is a multiple of 3, which explains why this is necessary for maximization of this property.

Finally, we introduce our last example of a maximal problem. This problem, as solved by Raphael Robinson [13] in 1964, deals with maximizing the span of the k-th derivative of a degree n polynomial with all real roots. The proof of this result uses the very important concept of convexity, which we will explore more thoroughly in the next section. This approach to solving this problem is very creative, but again, we will simply highlight the result here.

Theorem 14. *The span of the kth derivative of a polynomial with all real zeros, $p^{(k)}(x)$, can be maximized only when all of the roots of $p(x)$ are at the end points, $x = \pm 1$.*

Note that this problem is trivial for values of k that are greater than $n-2$, for we want $f^{(k)}$ to have more than one root. The problem is also trivial if $2k+2 \le n$, because we could then simply place $k+1$ roots at both endpoints, and the span of the k-th derivative would be 2. Therefore, we may narrow our focus to the nontrivial cases, with $k+2 \le n \le 2k+1$. The proof shows that if we have a polynomial with all but one of its roots determined, the only way the span of the k-th derivative of the polynomial can be maximized is by placing the undetermined root at either 1 or -1. Then, by applying this argument to each root of the polynomial individually, it shows that the span of $p^{(k)}(x)$ can be maximized only when all of the roots of $p(x)$ are at 1 or -1. In other words, this property is only maximized by a Bernstein polynomial. However, while the evidence for an evenly distributed Bernstein polynomial is strong, it has not yet been proven which Bernstein polynomial will maximize the property.

So there is this obvious pattern in these maximal problems. As illustrated with the problems above, the family of Bernstein polynomials frequently provides us with the maximizer of a characteristic. This is the phenomenon to which we spoke in the opening of this paper, and from here, we may begin our discussion of our attempt of a general explanation.

5 Convexity

The theory of convexity tells us that any convex function over a compact, convex set must attain its maximum at an extreme point. This is precisely the idea that we believe will help us explain the Bernstein phenomenon. In order to understand this fully, there are a couple of key concepts that must be introduced.

Definition 6. *A convex set is a collection of points such that every line segment formed by connecting points in the set is contained within the set. In other words, a set A is convex if and only if given any two elements of A, a and b, and any real number α such that $0 \le \alpha \le 1$,*

$$\alpha \cdot a + (1-\alpha)\cdot b \in X.$$

Once we have a convex set, we may think about what are known as convex functions.

Definition 7. *A convex function is a real valued function over a convex set such that the region above the graph of the function is also a convex set. In other words, a function f is convex if and only if given any two elements of the domain, x and y, and a real number α such that $0 \le \alpha \le 1$,*

$$f(\alpha \cdot x + (1-\alpha)\cdot y) \le \alpha \cdot f(x) + (1-\alpha)\cdot f(y).$$

One of the first things we must do in order to use this as a tool is develop a method in which we may think of monic polynomials with all real zeros as a vector space. To have a vector space, we need closure under multiplication and addition. The set of monic polynomials with all zeros, however, is not closed under normal function addition. It is not hard to construct a counterexample that shows that we may add two monic polynomials with all zeros and obtain a polynomial with complex zeros. For example, consider the polynomials $p(x) = x^2 - 1$ and $q(x) = x^2 + 5x + 6$. The polynomial p has roots at -1 and 1, while q has roots at -2 and -3. However, when adding p and q, we obtain a new polynomial $r = 2x^2 + 5x + 5$, which has two imaginary roots. Therefore, we must develop a new way to add and multiply polynomials. Here we introduce two new operations, which we will denote $\oplus$ and $\otimes$, and we will prove that they make the set of monic polynomials with all real zeros a vector space.

Definition 8. *Given two degree n monic polynomials with all real zeros, $p(x) = \prod_{i=1}^{n}(x - r_i)$ and $q(x) = \prod_{i=1}^{n}(x - s_i)$, we define the $\oplus$ operator by the rule*

$$p(x) \oplus q(x) = \prod_{i=1}^{n}(x - (r_i + s_i)).$$

Definition 9. *Given any degree n monic polynomials with all real zeros, $p(x) = \prod_{i=1}^{n}(x - r_i)$ and any real number, α, we define the $\otimes$ operator by the rule*

$$\alpha \otimes p(x) = \prod_{i=1}^{n}(x - \alpha r_i).$$

We can think about these somewhat unusual operations in a very natural way with respect to root-dragging. When we "add" a polynomial q to a polynomial p, we may think of q as the polynomial that tells us how much we will drag the roots of p by. Similarly, when we "multiply" p by a scalar, α, if $0 < \alpha < 1$, it is as if we are simultaneously dragging all of the roots of p towards the origin by a certain multiple of themselves; if α is greater than 1, it is as if we are dragging the roots away from the origin. When defining polynomial addition and multiplication in this way, we have the zero element x^n, which we will denote 0_P. We will now show that under these two operations, the set of monic polynomials with all real zeros is a vector space.

Theorem 15. *Under the operations $\oplus$ and $\otimes$ as defined above, the set of monic polynomials with all real zeros forms a vector space.*

Proof. Let the operations $\oplus$ and $\otimes$ be given as in definitions 8 and 9, and let 0_P be the zero element of the set of monic polynomials with all real zeros. We will prove that under these assumptions, the set of monic polynomials with all real zeros is a vector space. To do this, we must show that the following properties hold true for any degree n monic polynomials with all real zeros, p, q, and r, and for any real numbers a and b:

i. $p \oplus q = q \oplus p$

ii. $(p \oplus q) \oplus r = p \oplus (q \oplus r)$

iii $0_P \oplus p = p = p \oplus 0_P$

iv. $(-p) \oplus p = 0_P = p \oplus (-p)$

v. $0_P \otimes p = 0_P$

vi. $1 \otimes p = p$

vii. $(ab) \otimes p = a \otimes (b \otimes p)$

viii. $a \otimes (p \oplus q) = (a \otimes p) \oplus (a \otimes q)$

ix. $(a+b) \otimes p = (a \otimes p) \oplus (b \otimes p)$

Let p, q, and r be monic polynomials with all real zeros, and let a and b be real numbers. To prove these properties hold true, we will let the roots of p, q, and r be represented as p_i, q_i, and r_i, respectively. Then we have $p(x) = \prod_{i=1}^{n}(x - p_i)$, $q(x) = \prod_{i=1}^{n}(x - q_i)$, and $r(x) = \prod_{i=1}^{n}(x - r_i)$. We will prove that each of these holds true one at a time:

(i.):

$$\begin{aligned} p \oplus q &= \prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - q_i) \\ &= \prod_{i=1}^{n}(x - (p_i + q_i)) \\ &= \prod_{i=1}^{n}(x - (q_i + p_i)) \\ &= \prod_{i=1}^{n}(x - q_i) \oplus \prod_{i=1}^{n}(x - p_i) \\ &= q \oplus p, \end{aligned}$$

(ii.):

$$\begin{aligned} (p \oplus q) \oplus r &= \left(\prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - q_i)\right) \oplus \prod_{i=1}^{n}(x - r_i) \\ &= \prod_{i=1}^{n}(x - (p_i + q_i)) \oplus \prod_{i=1}^{n}(x - r_i) \\ &= \prod_{i=1}^{n}(x - (p_i + q_i + r_i)) \\ &= \prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - (q_i + r_i)) \\ &= p \oplus (q \oplus r), \end{aligned}$$

(iii.):

$$\begin{aligned} 0_P \oplus p &= \prod_{i=1}^{n}(x - 0) \oplus \prod_{i=1}^{n}(x - p_i) \\ &= \prod_{i=1}^{n}(x - (0 + p_i)) \\ &= \prod_{i=1}^{n}(x - p_i) = p \\ &= \prod_{i=1}^{n}(x - (p_i + 0)) \\ &= \prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - 0) \\ &= p \oplus 0_P, \end{aligned}$$

(iv.):

$$\begin{aligned} (-p) \oplus p &= \prod_{i=1}^{n}(x - (-p)) \oplus \prod_{i=1}^{n}(x - p_i) \\ &= \prod_{i=1}^{n}(x - ((-p) + p_i)) \\ &= \prod_{i=1}^{n}(x - 0) = 0_P \\ &= \prod_{i=1}^{n}(x - (p_i + (-p_i))) \\ &= \prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - (-p_i)) \\ &= p \oplus (-p), \end{aligned}$$

(v.):

$$\begin{aligned} 0_p \otimes p &= \prod_{i=1}^{n}(x - 0 \cdot p_i) \\ &= \prod_{i=1}^{n}(x - 0) \\ &= 0_p, \end{aligned}$$

(vi.):

$$\begin{aligned} 1 \otimes p &= 1 \otimes \prod_{i=1}^{n}(x - p_i) \\ &= \prod_{i=1}^{n}(x - 1 \cdot p_i) \\ &= \prod_{i=1}^{n}(x - p_i) \\ &= p, \end{aligned}$$

(vii.):

$$\begin{aligned} (ab) \otimes p &= (ab) \otimes \prod_{i=1}^{n}(x - p_i) \\ &= \prod_{i=1}^{n}(x - (ab) \cdot p_i) \\ &= \prod_{i=1}^{n}(x - a(b \cdot p_i)) \\ &= a \otimes \prod_{i=1}^{n}(x - b \cdot p_i) \\ &= a \otimes \left(b \otimes \prod_{i=1}^{n}(x - p_i)\right) \\ &= a \otimes (b \otimes p), \end{aligned}$$

(viii.):

$$\begin{aligned} a \otimes (p \oplus q) &= a \otimes \left(\prod_{i=1}^{n}(x - p_i) \oplus \prod_{i=1}^{n}(x - q_i)\right) \\ &= a \otimes \prod_{i=1}^{n}(x - (p_i + q_i)) \\ &= \prod_{i=1}^{n}(x - a(p_i + q_i)) \\ &= \prod_{i=1}^{n}(x - (ap_i + aq_i)) \\ &= \prod_{i=1}^{n}(x - ap_i) \oplus \prod_{i=1}^{n}(x - aq_i) \\ &= \left(a \otimes \prod_{i=1}^{n}(x - p_i)\right) \oplus \left(a \otimes \prod_{i=1}^{n}(x - q_i)\right) \\ &= (a \otimes p) \oplus (a \otimes q), \end{aligned}$$

(ix.):

$$\begin{aligned} (a+b) \otimes p &= (a+b) \otimes \prod_{i=1}^{n}(x - p_i) \\ &= \prod_{i=1}^{n}(x - (a+b) \cdot p_i) \\ &= \prod_{i=1}^{n}(x - (a \cdot p_i + b \cdot p_i)) \\ &= \prod_{i=1}^{n}(x - a \cdot p_i) \oplus \prod_{i=1}^{n}(x - b \cdot p_i) \\ &= \left(a \otimes \prod_{i=1}^{n}(x - p_i) \oplus b \otimes \prod_{i=1}^{n}(x - p_i)\right) \\ &= (a \otimes p) \oplus (b \otimes p). \end{aligned}$$

Therefore, all nine properties hold true, and the set of monic polynomials with all real zeros is a vector space under the operations $\oplus$ and $\otimes$. □

Now we may analyze the relationship

$$(r_1, r_2, \ldots, r_n) \to \prod_{i=1}^{n}(x - r_i)$$

by thinking of the set of roots of a polynomial as a vector. Therefore, every point in $\mathbb{R}^n$ is associated with a monic polynomial with all real zeros. Since we are interested only in monic polynomials with all real zeros in the interval $[-1, 1]$, we may narrow our focus to points in $[-1, 1]^n$. This is a compact, convex set. We may now think of norms and other functions that measure some property of a monic polynomial with all real zeros as functions of the form

$$f : [-1, 1]^n \to \mathbb{R}.$$

Then, according to the theory of convexity, if we can show that any of these functions are convex, they must achieve a maximum value at one of the corners of $[-1, 1]^n$. These corners will correspond to Bernstein polynomials. This idea is still relatively undeveloped. However, it offers a new way of thinking about polynomials, and it provides us with a potentially very powerful tool. Further, if we can use this idea successfully, then we will have a very beautiful and concise explanation of why these Bernstein polynomials possess such maximality.

6 Conclusion

As we have endeavored to show, the geometry of polynomials is a dynamic area of mathematics. There remain unsolved conjectures and new, interesting questions to be asked. Because polynomials are fundamental building blocks for many types of functions, continued pursuit of deeper understanding

of them is important. Analyzing how root location influences a polynomial's properties is one way to further this understanding and to continue to expand the field of the geometry of polynomials. We have seen how polynomial root dragging demonstrates intuitive reasons why the Bernstein polynomials frequently arise as functions that maximize certain properties of polynomial functions with zeros in the interval [-1,1]: as these functions have their roots in the most extreme locations possible, it makes sense that these results often follow. Further, we have seen some of the wide variations possible among all polynomial functions, whether in measuring their supremum norm, L1 norm, span of the roots of derivatives, distance from the centroid to the nearest critical number, and more.

Our research has also generated new questions for us to continue to pursue. Some of our ideas for the future include investigating the sensitivity of critical numbers with respect to root motion and trying to quantify how the total change of the critical numbers' locations is distributed among them individually. Also, we aspire to develop fully the idea of using convexity as a tool to provide a more general theory that explains which properties are maximized by Bernstein polynomials. We may also explore other possible benefits that arise from thinking of monic polynomials with all real zeros as a vector space.

The geometry of polynomials is a beautiful and interesting field of mathematics that continues to provide rich problems for study, and it also helps to explain one of the most fundamental objects in mathematics.

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Campus Triple Bottom Line: College Sustainability and Grand Valley State University

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Colleges and universities in the United States and globally have mobilized around sustainability issues and engaged their campus community and communities-at-large in efforts to recycle, reduce carbon emissions, create green space, foster food security, and learn about and participate in creating sustainable communities. This study provides a literature review of sustainability programs within the United States and abroad, and commonalities across these programs were identified, grouped into four research streams, and used as the bases for the theoretical framework. This paper further expands on the subject of campus sustainability by presenting a case study of Grand Valley State University Sustainable Community Development Initiative, whose focus is to bring sustainable practices not only to the campus of Grand Valley State University (GVSU), but also to wider community stakeholders.

Review of Literature on Campus Sustainability Programs

Peer reviewed articles on sustainability programs within the United States and abroad were reviewed, and commonalities across these programs were identified and used as the bases for the theoretical framework. The articles that were examined were organized into four research streams: Research stream No. 1 (R1)—organizational learning and capacity building, highlights the campus as a learning organization for sustainable thinking and practices. Organizational learning has helped to create a campus culture that reduces waste, preserves the ecology, contributes to economic stability, and demonstrates socio-community responsibility. Research stream No. 2 (R2)—environmental management systems and strategy development, highlights environmental management systems (EMS) as a strategic tool for implementation and focuses on how colleges have established structural supports to implement, measure, and evaluate sustainability programs. Research stream No. 3 (R3)—student, education and involvement, is concerned with interdisciplinary approaches to student learning and sustainability. Interdisciplinary learning has allowed students to see the linkages between other areas of studies beyond the sciences, such as social science, community development, and political science. Students have been found to be formidable ambassadors for furthering sustainability both on and off campus. Students have also learned valuable skills that have led to personal job creation and entrepreneurship. Research stream No. 4 (R4)—local, regional, and global initiatives, looks at how colleges and universities have forged relationships with off-campus stakeholders. Higher education has brought the movement of sustainability beyond the campus to local, regional, and in some cases global initiatives (sees Table I).

Research stream No.1 (R1) overviews organizational learning and capacity building and highlights avenues in which the college campus can learn together of the importance and need for sustainable thinking. Organizational learning has helped to create a campus culture that looks at ways to reduce waste and contribute to the environment, ecology, and socio-community responsibility. Downey (2004) offers reflections on Sheffeld Hallam University's learning and capacity building through its transition from environmental focus to sustainability with emphasis towards corporate social responsibility. Gudz (2004) shares the need for universities' sustainable development policy to integrate teaching, research, operations and local community relations and move towards learning organizations that enable relationship-building and the development of learning capacities. Albrecht, Burandt, & Schalteggar's (2007) exploration of sustainability projects as a stimulation of organizational learning and creation of transparency adds to the discussion of creating legitimacy of universities' sustainability initiatives through action research.

Research stream No. 2 (R2) looks at environmental management systems (EMS) as a strategic tool for implementation and focuses on how colleges have set up structural supports to implement, measure, and evaluate sustainability programs. Price (2005) asserts that universities need to move from the preception that environmental management systems are marginally important and

Table I.
Summary of Literature on Campus Sustainability

Stream/Article	Methodology	Findings
Research Stream 1 *Strategy and* *Environmental Management Systems*		
Clarke, Kouri (2009)	Discussion/Case Study	Discusses various Environmental Management Systems from informal to formal frameworks and implications of EMSs as related to institutional drivers that led to framework implementation
Fisher (2003)	Discussion/Case Study	Discusses the use of ISO14001 as a tool for environmental review or management systems
Price (2005)	Overview/Case Study	Perception of Environmental Management Systems use in most UK universities settings as marginally important. Case study of University of Glamorgan Wales as first to have all operations accredited to ISO 14001
Spellerberg, Buchan, Englefield (2004)	Discussion/Case Study	Discusses the use of environmental policy and policy into practice as adequate for progress without the adoption of a formal EMS. Illustrates this via case study of Lincoln University, New Zealand
Research Stream 2 *Organizational Learning and Capacity Building*		
Albrecht, Burandt, Schaltegger (2007)	Theory Building/Case Study	Examines the use of transparency as incentive for organizational change, draws on theoretical concepts from organizational learning and applications to university context
Downey (2004)	Reflective/Case Study	Highlights the transformation of the Sheffield Hallam University, UK incorporation of sustainable practices within the formal university structure and advantages of student engagement
Gudz (2004)	Discussion/Case Study	Analysis of implications for organizational learning in preparing for creating a sustainable development policy. Embedded case study of University of British Columbia Faculty of Agricultural Sciences learning experience
Research Stream 3 *Student Education and Involvement*		
Domask (2007)	Case Study	Shows interdisciplinary curriculum, student work experiences and employment opportunities as effective learning approaches to sustainability
Bhasin, Bjardotti, Das, Dock, Pullins, Rosales, Savanick, Stricherz, Weller,.(2003)	Case Study	Campus and community engagement in sustainable development through sustainability networks, initiatives and educational programs
Stubbs, Crocklin (2008)	Literature Review/Case Study	Development of a sustainability framework to teach business student to use critical and reflective thinking and analysis of sustainability beyond the neoclassical economic thinking in which MBA students engage
Owens, Halfacre-Hitchcock (2006)	Case Study	Sharing of experience of students who implemented a sustainability initiative and measured its effect on both faculty and student attitudes, information levels and behaviors regarding sustainability
Walker, Seynour (2008)	Case Study	Investigates the use of the design charrette as a sustainability teaching tool and assessment of charette's role in promotion of sustainability in higher education
Research Stream 4 *Local, Regional, and Global Initiatives*		
Mochizuki, Fadeeva (2008)	Conceptual Paper	Provides an overview of the United Nations University's Regional Centres of Expertise on Education for Sustainable Development (RCE)
Itoh, Suemoto, Matsuoka, Ito, Yui, Matsuda, Ishikawa (2008)	Case Study	Highlights the Regional Centre of Expertise (RCE) on education and the contribution of Kobe University as a RCE
Stefanovic (2008)	Case Study	Highlights the role the University of Toronto has had in establishing a Regional Centre of Expertise (RCE) in Education for Sustainable Development in Toronto and the RCE's impact on the larger community and its partnerships
Keen and Baldwin (2004)	Case Study	An analysis of student involvement in community-based research and service learning programs

a "soft control issue" and separate from campus sustainability operations to a more integrated system within university sustainability. Clarke & Kouri (2009) highlight many different frameworks of EMSs: ISO14001; Higher Education 21 (UK); the EMS Self-Assessment Checklist (USA); the Auditing Instrument for Sustainability in Higher Education (Netherlands); The Osnabrück University model (Germany) and the Sustainability University Model (Mexico). They argue that colleges and universities require EMS frameworks that are specific to their sector yet consider individual institution drivers. Fisher (2003) highlights EMS as a way to bring the business world into the classroom, which may provide usefulness for environmental education. Spellerberg, Buchan, & Englefield (2004) argue that an environmental policy and implementation plan can be just as appropriate and effective as an EMS and illustrates this through a case study of Lincoln University in New Zealand.

Research stream No. 3 (R3) is concerned with the interdisciplinary approach to involvement of students in education and practice in the area of sustainability. Students have been found to be formidable ambassadors for furthering sustainability both on and off campus. This engagement has allowed students to see the linkages between other areas of studies beyond the sciences, such as social science, community development, and political science. Students have also been able to learn valuable skills that have led to personal job creation and entrepreneurship. Domask (2007) lauds the benefits of experiential learning and shows how it can accomplish connecting the academics with real-world practice; foster interdisciplinary curriculum implementation; link students to practicum and job opportunities; and engage and empower students in the academic learning process. Stubbs and Cocklin (2008) create a framework in which business MBA students can look at varied aspects of sustainability in business (ecocentrism, ecological modernization and neoclassical economic paradigm) and use critical thinking and reflection to expand their knowledge of the "schools of thoughts" around sustainability and be able to articulate each side of the sustainability debate. The impact of a culturally diverse, student led, nine-part series exploring international sustainable development issues formed the basis for the University of Minnesota's efforts in moving its sustainability initiative forward (Bhasin, Bjardotti, Das, Dock, Pullins, Rosales, Savanick, Stricherz, Weller, 2003). Walker and Seymour (2008) share the benefits of using interdisciplinary studies as a means for students to explore sustainability. More specifically, the focus was on an example of a design charrette that involved students, faculty, and professionals from the areas of architectures, civil engineering, business, natural sciences, landscaping contracting, and management in analyzing the complex issues of the devastation of the Mississippi Gulf by Hurricane Katrina in order to create a conceptual model of sustainable development in the area.

Research stream No. 4 (R4) looks at how colleges and universities have forged relationships with off-campus stakeholders. Higher education has brought the movement of sustainability beyond the campus to local and regional initiatives, and in some cases, participated in global initiatives. The papers reviewed include case studies of various universities' involvement with the United Nations University Institute for Advanced Studies (UNU) Regional Centre of Expertise (RCE) on Education for Sustainable Development, which is a "network of existing formal, non-formal, and informal education organisations, mobilised to deliver education for sustainable development to local and regional communities" (United Nations University Institute for Advanced Studies, 2010). Mochizuki and Fadeeva (2008) provide an overview of the RCE and how institutions of higher education (IHEs) can create linkages that allow them to break from compartmentalization of knowledge and to link campus policies with practices. They further highlight that IHEs that are partners in RCEs can use action research as a means to modifying action rather than generating new knowledge (Mochizuki and Fadeeva, 2008, pg. 378).

Itoh, Suemoto, Matsuoka, Ito, Yui, Matsuda, and Ishikawa (2008) reinforce these thoughts by showing how the RCE Hyogo-Kobe University built on existing education for sustainable development work that had begun at Kobe University, which created opportunities for interdisciplinary action research in collaboration with regional stakeholders and created further opportunity for internal coordination within the university. Stefanovic (2008) highlights the work of University of Toronto and the establishment of a RCE. The work that was done at University of Toronto focused on relevant interdisciplinary action research that helped students and professors bring environmental awareness and make an impact on the local and broader communities and represent equity and diversity in programming. Keen and Baldwin's (2004) research focuses on collaboratively designed research between institutions of higher education and the community. Findings included students being influenced on their life choices as it pertained to environmental concerns, increased ability to deal with complexity, and engagement with others and a valuing of perspectives.

The four research streams served as a context to explore the sustainability practices in each case study and to provide a lens through which to view the sustainability practices of the Grand Valley State University Sustainability Initiative. In addition, the research streams and the Grand Valley Case Study allow for the formation of a theoretical framework and a suggested implementation model for institutions of higher education that would like to start a sustainability initiative. These areas will be further discussed in the remainder of this paper.

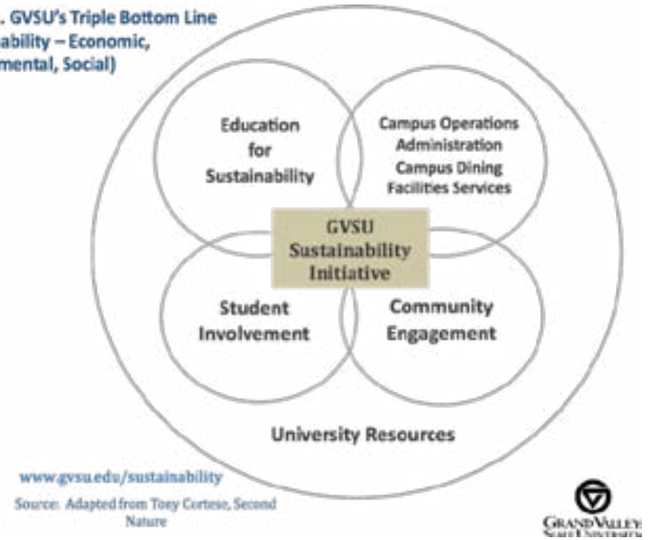
Grand Valley State University Sustainable Community Development Initiative

Grand Valley State University (GVSU) is a four-year public university providing fully accredited liberal undergraduate, graduate and PhD programs. GVSU's main campus is located in Allendale, Michigan, with campuses in downtown Grand Rapids, Holland, Muskegon, and Traverse City, Michigan. In addition, it works in cooperation with other colleges and universities at two regional centers, one in Muskegon and the other in Traverse City. GVSU has over 24,400 students supported by 2,890 faculty and staff (Grand Valley State University: 2008 Sustainability Indicator Report, pg. 1-2).

The GVSU Sustainable Community Development Initiative (SCDI) officially began in 2004 with the adoption of guiding principles that emphasized the triple bottom line of sustainability and led to the formal creation of the Sustainability Initiative within the College of Interdisciplinary Studies (GVSU Sustainability Recognitions, 2010). The SCDI was one of the founding members of the Community Sustainability Partnership (CSP), which was first comprised of Grand Valley State University, the City of Grand Rapids, Aquinas College, Grand Rapids Community College, and Grand Rapids Public Schools. It has now grown to 189 endorsing partners as of March 2010 (Community Sustainability Partnership, April 2010). As a member of CSP, GVSU is also a participant in the first U.S. designation of Grand Rapids Regional Center of Expertise (RCE). The SCDI has received recognition in many areas, and highlights include national recognition for Sustainability Innovation from the Sustainable Endowment Institute, 2008 U.S. Green Building Council recipient, 9 LEED facilities, and President Thomas Haas's signing of the Talloires Declaration and The American College & University Presidents Climate Commitment (GVSU Sustainability Recognitions, 2010).

The SCDI's work is guided by many thought leaders in sustainability but notably the SCDI's Sustainability Initiative model is based on the work of Dr. Anthony Cortese, ScD of Second Nature (figure 1). This model complements the research streams previously discussed and will be interwoven throughout the case study discussion, as it offers examples of the research stream in practice. This case study will not focus on the linear history of the GVSU SCDI as much as it will highlight activities that correspond to the research streams and the GVSU SCDI model. Thus the focus from this point will be the following: Education for Sustainable Development (Research stream No. 1. —Organizational Learning & Capacity Building), Campus Dining and Facilities Services (Research stream No. 2—Strategy and Environmental Management Systems), Student Involvement and Service Learning (Research stream No. 3—Student Education and Involvement), and Community Development (Research stream No. 4). As previously mentioned, the research streams form the lens through which to explore GVSU SCDI and the formation of the theoretical framework that will follow.

Figure 1. GVSU's Triple Bottom Line (Sustainability – Economic, Environmental, Social)



Education for Sustainable Development (Research stream No. 1—Organizational Learning & Capacity Building)

Education for Sustainable Development (R1) is focused on campus awareness and learning about sustainable practices. The GVSU SCDI model formed the basis for building awareness throughout the campus and helped to establish a common framework from which to work on threading sustainability concepts and practices that were to come. GVSU SCDI has used many ways to build awareness and encourage participation from staff, faculty, and students. The initiative has created a dynamic website that is rich with information and resources for students, faculty, and the community.

The most notable efforts have been through the campus wide sustainability week, RecycleMania (a national competition) and interdisciplinary studies. Sustainability Week focuses on various topics and activities around sustainability. Students and faculty are encouraged to participate, and faculty are encouraged to integrate the topic of sustainability into their lesson plans. RecycleMania is competition over a 10-week period that is held between college and university recycling programs in the United States "to see which institution can collect the largest amount of recyclables per capita, the largest amount of total recyclables, the least amount of trash per capita, or have the highest recycling rate" (RecycleMania is Here! April 10, 2010).

Campus Dining and Facilities Services (Research stream No. 2—Strategy and Environmental Management Systems)

This area focuses on the administrative strategies and the embedment of sustainable practices in operational areas. It is important that institutes of higher education leadership support sustainability by setting the tone and helping to create awareness, interest, and involvement (Velazquez et al., 2005, pg. 384). GVSU leadership began to set this tone in the creation of sustainability indicators, and President Thomas J. Haas's signing of the Talloires Declaration and The American College & University Presidents Climate Commitment (GVSU Sustainability Recognitions, 2010).

Each year, since the SCDI's start, Campus Dining Services have increased sustainable practices without compromising the quality of food or service. This unit has focused on sustainable procurement from local sources (including fair trade sources) and seafood sources that focus on sustainable practices in farming (Grand Valley State University: 2008 Sustainability Indicator Report, pg. 4-10 through 4-11). Campus Dining Services has also focused on waste management and recycling by elimination of trays, which helped in reduction of energy, water, and detergent use, saving 1,619,000 gallons of water from 2007-2008 (Sustainability and Campus Dining, 2010).

Campus Facilities Services has participated in campus recycling efforts and the guidance

and coordination of engineering projects, which includes new and existing building energy efficiencies. Facilities have worked diligently to bring awareness via information distribution and energy awareness competitions within the Housing department. These efforts have benefited GVSU, and overall electricity consumption has decreased from 55 million kilowatts in FY2006 to less than 53 million kilowatts in FY2008. Energy reduction awareness has created an annual savings of $861,000 since 2001 (Grand Valley State University: 2008 Sustainability Indicator Report, pg. 4-6).

GVSU Facilities Services continues to evaluate opportunities to incorporate alternative energy use in operations. As explained in the GVSU 2008 Sustainability Indicator Report, some most notable examples are the use of alternative energy sources in the Laker Turf Building (Allendale Campus), Michigan Alternative and Renewable Energy Center (Muskegon) and the John C. Kennedy Hall of Engineering Building (Robert C. Pew Grand Rapids Campus):

> Grand Valley – the Laker Turf Building and Michigan Alternative and Renewable Energy Center (MAREC) – incorporate photovoltaic as a partial energy source to provide power to building energy controls and some building heat support. Geothermal wells also have been added as an alternative energy option for the Turf Building. Geothermal technology helps maintain the heating and cooling levels within the building by transferring heat from the wells to the building in the winter, and from the building to the cooler wells in the summer months. Ice block technology was added to our John C. Kennedy Hall of Engineering building on the Robert C. Pew Grand Rapids Campus. This technology, which allows us to freeze a large ice block during nighttime hours, helps cool refrigerant lines during the daytime hours and helps offset peak electrical costs.
> (Grand Valley State University: 2008 Sustainability Indicator Report, pg. 4-7).

Other areas of focus include the decrease of water use to 151.5 million gallons in FY2008, and surface water quality and storm water management systems and planning, which includes the use of rain gardens and sustainable landscaping practices (Grand Valley State University: 2008 Sustainability Indicator Report, pg. 4-8 through 4-10).

Student Involvement and Service Learning (Research stream No. 3—Student Education and Involvement)

GVSU wanted to show commitment to their work in sustainability by establishing interdisciplinary studies and student involvement in service learning projects. Included in this area are the aforementioned Sustainability Week and RecyclingMania programs. The interdisciplinary studies provided at GVSU offer students and faculty the opportunity to engage deeply in the area of sustainability. Students have the opportunity to major or minor in a Liberal Arts degree in sustainability. Students and faculty are also afforded the opportunity to gain knowledge and build skills in service learning projects and internship and research opportunities. Notable activities beyond the classroom include the Student Sustainability Partnership, which focuses on bringing to together SCDI students and student organization leaders to collaborate on sustainability projects (Sustainability Community Development Initiative, Student Sustainability Partnership, 2010), and a most recent internship project with West Michigan Symphony, Sustainability: A West Michigan Journey, which focuses on "a multi-media concert based on sustainability with supporting education and community engagements programs" (Sustainability Community Development Initiative, Internships, 2010). These activities add variety by allowing the student to engage outside of the classroom and text and create mutual understanding and practicality of sustainability between the community and the student.

Community Engagement (R4)

Since its inception, the GVSU SCDI has worked to foster connections and learning between the various GVSU campuses and the wider community. These connections have created viable partnerships that have added to community awareness of sustainable practices as well as advancing community and economic development. As noted before, GVSU SCDI's participation in the Community Sustainability Partnership (CSP), the Grand Rapids Regional Center for Expertise in Education and Sustainable Development (a United Nations University Institute of Advanced Studies program), and GVSU President Haas as signatory to the Talloires Declaration and The American College & University Presidents Climate Commitment all create local, national and international visibilities. GVSU is participating in the development and monitoring of city and community sustainability indicators reports as well as assisting with developing sustainable neighborhoods and communities (GVSU, Making it Happen, Applied Sustainability at GVSU, 2009).

Figure 2.
Definition of Campus Triple Bottom Line
(Sustainability – Economic, Environmental, Social)

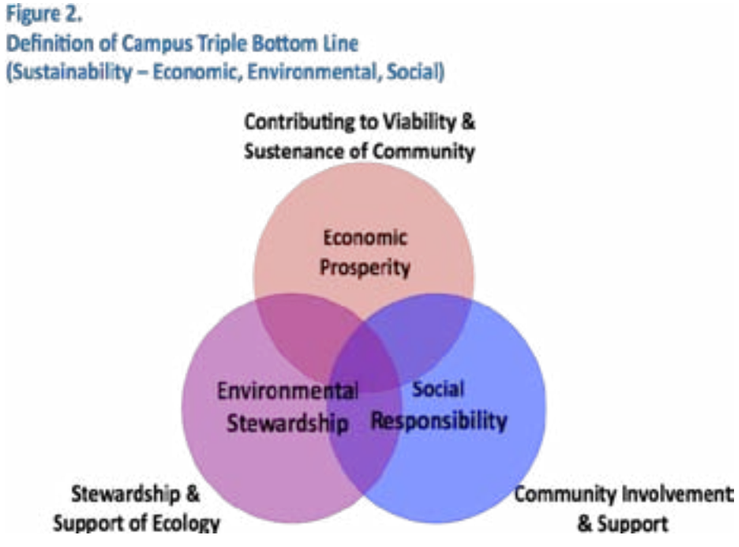
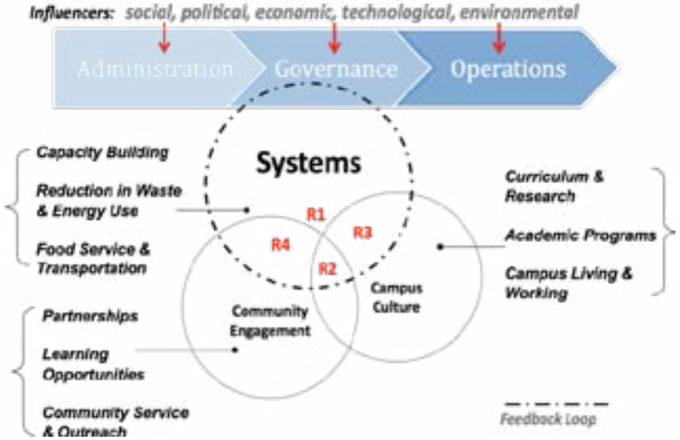


Figure 3. Theoretical Framework



An additional area that should be noted is the Grand Valley State University Michigan Alternative and Renewable Energy Center (MAREC) housed in a LEED certified (Gold) facility that opened in fall of 2003. Among the collaborators were the Community Foundation for Muskegon, Muskegon Area Chamber of Commerce, and Muskegon First. MAREC's focus is on creating economic development opportunities in the area of renewable and alternative energy providing space and support for uniquely focused and innovative business start-ups and projects in these areas. GVSU SCDI highlights that "MAREC's strategic focus revolves around four key initiatives: 1) managing a leading-edge facility, 2) implementing visionary energy projects, 3) providing alternative energy education, and 4) supporting the economic development of Muskegon and the state" (Sustainability Community Development Initiative, LEED Buildings, 2010).

Theoretical Framework for Sustainability

The four research streams and the GVSU case study have contributed to the development of a theoretical framework for sustainability that can be used by institutes of higher education as they look to incorporate sustainable practices on their campus or develop a campus wide initiative focused in this area.

The proposed Theoretical Framework for Sustainability works from the perspective of the Triple Bottom Line, as illustrated in Figure 2: Definition of Campus Triple Bottom Line. The main focus here is on contributing to the viability and sustenance of the community via economic prosperity, social responsibility as demonstrated by community involvement and support, and being a good steward of the environment and ecology.

The Theoretical Framework for Sustainability (TFS) model (Figure 3) looks at external influencers that impact an institute of higher education's participation in sustainability. Administration, Governance, and Operations are all impacted by social, political, economic, technological, and environmental external influencers. In general terms, a college or university may decide to engage in sustainability initiatives out of pressures or encouragement it may receive from the external environment. Pressures could include social, political, or economic student activism around the procurement of resources or supplies from an unsustainable or inhuman source (for example: boycott of university pennant shop goods because of the use of sweatshops, or factory farming use). Technological and environmental pressures could come into play when facilities and Information Technology departments are pressured to maximize resources and minimize waste. Both facilities and IT personnel are pressured to build sustainable practices into overall operations. Both groups have massive responsibilities throughout the campus and often multiple sites.

In the TFS Model, a main driving point is the creation of administrative, governance, and operational systems that support, interact and connect with the campus and community. This system has embedded in it capacity building, waste and energy reduction and sustainability practices around food service and transportation. These systems should foster a campus culture that includes research and interdisciplinary curriculum and academic program development. It should also insure that it integrates principles of sustainability into campus living and working environments. It should further integrate community engagement opportunities that focus on partnerships, learning opportunities, and community service and outreach. Integral to this system is a constant feedback loop of communication.

Campus Administration can begin the work of sustainability by putting into place a Proactive Implementation Model for Sustainability (PIMS). Figure 4 shows a suggested PIMS for phasing in sustainability onto the campus. Phase 1 looks at creating a learning organization and building capacity around sustainable practices. In this phase, an understanding of what sustainability is and ways to achieve it is developed. Top leadership is crucial to this first phase. In reflecting on the GVSU case study, it can be seen that the participation of the president of GVSU, Thomas J. Haas, was an integral piece to leading the charge of creating a campus environment for this change.

The second phase focuses on setting visions and objectives, identifying champions, forming teams and putting into place assessments and reviews that help to support the initiative. A system for strategy and environmental management, the GVSU Sustainability Indicators were shown to be important in bringing attention to the need for GVSU to focus on sustainability. This document was the catalyst for the campus community to become involved in creating a campus environment that fosters sustainability.

The third phase looks at implementation

Figure 4.
Proactive Implementation Model for Sustainability (Phases)

and programming. The second phase can be the driver for more substantial work to be carried out in the areas of procurement, facilities, interdisciplinary curriculum development, campus participation in local, regional, and global initiatives, and faculty and student involvement in programming. GVSU and other college campuses highlighted in this research became involved in both on campus and off-campus initiatives. For some institutions of higher education, off-campus engagement can be a starting point for sustainability projects.

The fifth and final phase focus is on incorporation of continuous learning and improvement at a systemic level. This can be accomplished through program evaluation practices, such as sustainability indicators, or more targeted work around climate action. This phase also focuses on looking at redesign and revision as a part of growing and developing.

The research streams and the implementation phases can be conceptually integrated to show the relationship between the theory and suggestion for program development, implementation, and monitoring.

Conclusion

The campus sustainability programs that were reviewed varied in form and demonstrated broad and diverse methodologies and applications of data collection, programming, stakeholder involvement, and program measurement. The examples from the research streams and the Grand Valley State University Sustainable Community Development Initiative show that there is room for applying models for a Theoretical Framework for Sustainability and Proactive Implementation. Institutes of higher education should examine critical success factors that can help and inhibit the quality and effectiveness of campus sustainability programs before and during the process.

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Co-localization of Histamine and eGFP in the Central Nervous System from pHdc-5'-UTR-eGFP Transformants of *Drosophila melanogaster*

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Abstract

Histamine is a biogenic amine synthesized by the enzyme histidine decarboxylase (Hdc) and used as a neurotransmitter in the central nervous system of Drosophila melanogaster. *We are interested in understanding how tissue-specific expression of Hdc is controlled by examining the function of both the Hdc 5'-UTR (*Untranslated region*) and 3'-UTR through the regulation of the expression of the reporter gene, eGFP. Initial studies reported here examine the function of the 5'-UTR of the Hdc gene by determining whether eGFP expression can be demonstrated in histaminergic cells of transformant flies containing the pHdc-5'-UTR-eGFP transgene. To determine if all cells expressing eGFP in these transformants are also histaminergic, examination of histamine-stained CNS preparations from various developmental stages of transformant flies was conducted and analyzed using fluorescence microscopy. Results indicate that many histaminergic cells appear to express eGFP as well. These results indicate that the 5'-UTR region of Hdc can induce expression of eGFP in centrally located histamine-containing neurons. Differences in the level of expression of eGFP observed between cell types and developmental stages suggest that the 3'-UTR of Hdc may still be required for complete expression. Since the co-localization of eGFP and histamine in cells has been achieved, new areas of research may now be conducted to investigate the function of histaminergic cells in culture, leading to a better understanding of the role that histamine cells play in the central nervous system.*

Introduction

Histamine has been shown to be an important neurotransmitter, a chemical that transmits signals between neurons, for photoreceptor cells and other sensory cells in *Drosophila melanogaster* (Sarthy, 1991; Melzig et al.,1996). The enzyme that catalyzes the decarboxylation of histamine, forming histamine in the central nervous system of *Drosophila melanogaster*, is histidine decarboxylase, with mutations in the Hdc gene having also been identified (Hdc; Burg et al., 1993). An earlier study indicated that a 9.4 kb genomic DNA fragment containing the Hdc gene could be used to restore Hdc function in mutant flies lacking Hdc function (Burg and Pak, 1995). Further studies also identified regions necessary for expression of Hdc in the central brain complex (Burg and Pak, 1995). More recently, the gene encoding the enhanced green fluorescent protein (eGFP) was inserted at the 5' end of the Hdc gene in *Drosophila melanogaster* using the pGreenPelican vector (Anderson and Burg, 2007) and transformed into flies, with one pHdc-5'-UTR-eGFP transgene being located on chromosome 2 and another on chromosome 3 (Miller and Burg, 2008). Transformants carrying the pHdc-5'-UTR-eGFP can therefore be used to determine whether the 5'-UTR region is sufficient for normal Hdc expression.

In addition to identifying cells that contain histamine, this type of labeling of histaminergic neurons may lead to a more thorough study of the regulation of Hdc itself. For example, not much is known concerning how the Hdc protein is regulated within a cell. As in other vertebrate HDC proteins, regions known as "PEST" regions have also been identified in both the "N"- and "C-" terminal regions of the Drosophila HDC protein. These regions may mediate cleavage of the HDC protein in Drosophila, as has been identified to occur in other species during the maturation of the HDC protein (Fleming and Wang, 2000). Due to this type of maturation, it has been difficult to purify or tag the protein with various epitopes, such as green fluorescent protein (GFP). Without the ability to purify or tag HDC, identification of living cells containing HDC activity remains elusive, and thus, the pHdc-5'-UTR-eGFP transgene may serve as such a marker for living histaminergic neurons. Thus, the co-localization of the transmitter histamine in the same cells expressing eGFP in the central nervous systems from pHdc-5'-UTR-eGFP transformants is shown in this paper, which should now allow the identification and study of living histaminergic neurons.

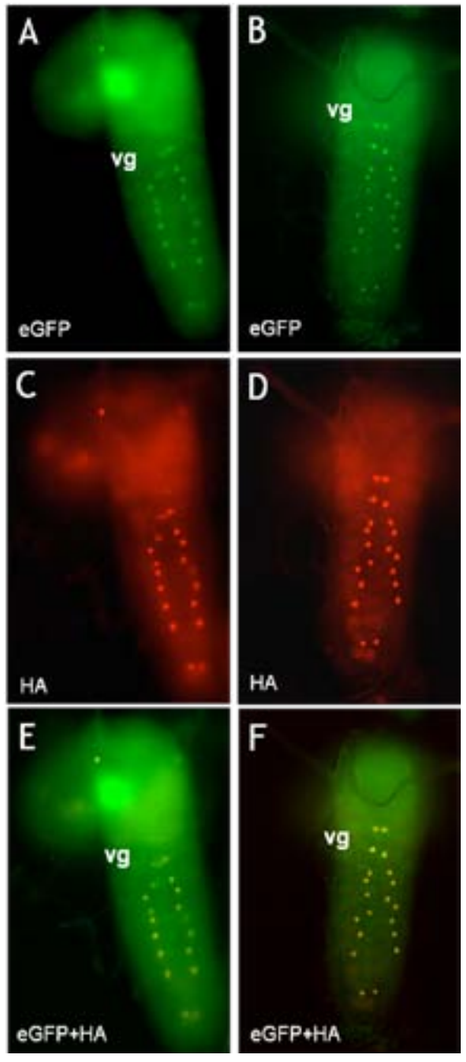

Figure 1: Whole-mount 2nd instar larval brains demonstrating eGFP expression induced by the pHdc-5'UTR-eGFP transgene detected using an FITC filter (A,B; eGFP). Histamine immunoreactivity is shown in panels C,D (HA). E,F: merged images of A+C and B+D, demonstrating co-localization of eGFP and histamine (note yellow cells; eGFP+HA). Histamine staining and the eGFP flourescence appear to co-localize, indicating that the pHdc-5'UTR-eGFP transgene induces expression of eGFP in histaminergic cells. Specimens in these images are from the pHdc-5'UTR-eGFP transformant with insert on chromosome 2.

Identification of living cells containing Hdc activity, and consequently histamine, will allow the study of the differentiation and development of the histaminergic cells *in vivo*. It will also allow the identification of these cells for future physiological and other biochemical analysis, increasing our knowledge of the action of histamine in the central nervous system.

Methods and Materials

Histamine Immunocytochemistry: The central nervous systems from various developmental stages of pHdc-5'-UTR-eGFP transformant flies were dissected in a 2% EDAC fixative (Sigma Chemical Co., St. Louis, Mo) in a phosphate buffered saline, pH 7.2. The resultant tissue was then washed with *Drosophila* Ringer's solution twice for 10 minutes each, after which the tissue was incubated in 5% normal goat serum (NGS; Invitrogen, Inc.) for one hour. The tissue was then incubated overnight in a rabbit histamine polyclonal antibody (Immunostar Inc., Stillwater, MN) diluted 1:1000 in PBS containing 1% NGS, at 4°C. After the overnight incubation, the tissue was washed with TBS + 1% NGS + 0.3% Triton X-100 twice for 20 minutes each and then incubated in an Alexa-fluor 555 goat anti-rabbit antibody diluted 1:1000 (Invitrogen, Inc.) for 30-60 minutes. The tissue was then washed in TBS + 1% NGS + 0.3% Triton X-100 twice for 10 minutes each time and then washed in PBS and placed on microscope slides for microscopic analysis (protocol adapted from Pollack and Hofbauer, 1991).

Fluorescence Photomicrography: For bright-field microscopy, specimens were examined using an Olympus AX70 microscope using DIC optics, and images were captured using a high-resolution digital camera. To co-localize histamine and eGFP using epifluorescence microscopy, an Alexa-fluor 555 goat anti-rabbit antibody (detecting histamine)

was visualized using a rhodamine excitation filter set. eGFP was detected in whole mount tissue using epifluorescence microscopy using a FITC excitation filter set. Images were collected and digitally merged using Adobe Photoshop, adjusting only brightness and contrast.

Results

Specimens of *Drosophila melanogaster* from both the larval and adult stages that contain the pHdc-5'-UTR-eGFP transgene were dissected, fixed, and stained with a rabbit histamine antibody diluted 1:1000 and then incubated with a goat-anti-rabbit secondary antibody labeled with the Alexa-fluor 555 dye diluted 1:1000. After these incubations, each specimen was placed on a microscope slide, viewed and imaged using a fluorescent microscope equipped with a high resolution digital camera. Figures 1-3 show images with each column representing the image of the same specimen at the same focal plane using different excitation filters. The first row of images was generated using an FITC excitation filter, which allows excitation of eGFP, normally providing a green fluorescence and indicating the location of eGFP. The second row of images was generated using a rhodamine excitation filter, which in this case shows the location of histamine. The third row of images results from the digital merging of the first row of images with the second row of images.

The images in Figure 1 contain the results from different 2nd instar stage larval brains, clearly demonstrating that all cells that contain eGFP (Fig. 1A, B) were also positive for histamine (Fig. 1C, D); see also merged images in Fig. 1E, F. While there were differences in the intensity of the eGFP staining between preparations, co-localization of eGFP and histamine was consistently demonstrated. Next, a 3rd instar larval brain was examined for both eGFP and histamine, demonstrating results from different focal planes, one more ventral (Fig. 2 A, C, E) and the other more dorsal (Fig. 2B, D, F). Both sets of images support the previous observation in 2nd instar larval brains that eGFP expressing cells also contain histamine (note the merged images which indicate only "yellow" colored cells, indicating the presence of both red and green fluorescence). The histamine staining observed appears to be identical to previously published reports of histamine staining in the brain of the 3rd larval instar brain (Python and Stocker, 2002).

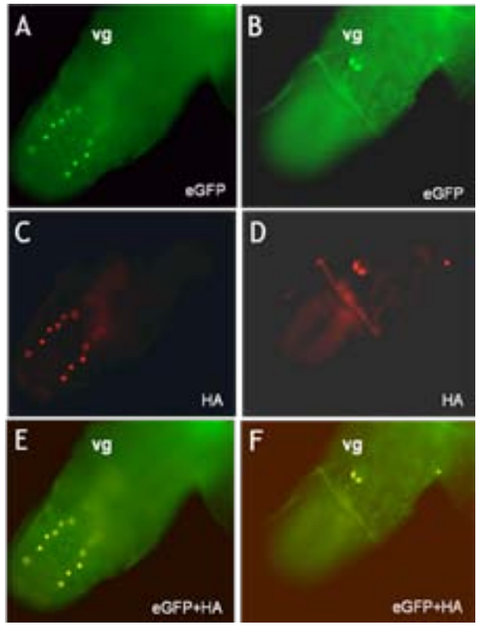

Figure 2: Images from whole-mount 3rd instar larval brains demonstrating eGFP expression induced by the pHdc-5'UTR-eGFP transgene detected using an FITC filter (A,B; eGFP). Histamine immunoreactivity is shown in panels C and D (HA). E: merged image of A and C; F: merged image of B and D. Both E and F demonstrate co-localization of eGFP and histamine (note yellow cells; eGFP+HA). A, C, E are the same image using either the FITC (A), rhodamine-cutoff filter set (B), or combined image (E) from a more ventral focal plane as compared to the image in B, D, F, which is a more dorsally oriented focal plane. vg, ventral ganglia; anterior toward top of image.

While larval brains examined previously for histamine appeared as expected (Python and Stocker, 2002), intact adult nervous tissue was also examined for histamine localization, which has not been as well characterized. Figure 3 demonstrates the results from co-localization experiments carried out showing 2 different focal planes taken of the adult thoracic ganglia from pHdc-5'-UTR-eGFP trasnformant flies. While eGFP expression appears to be stronger than in the larvae, the eGFP appears to still co-localize to cells that contain histamine (Figs 3A, C, E as well as 3B, D, F). Thus, results demonstrate that, in all tissues thus far examined, eGFP and histamine co-localize in cells of the central nervous systems from pHdc-5'-UTR-eGFP transformant flies.

Discussion

Histamine, synthesized by Hdc, likely acts as a neurotransmitter in *Drosophila melanogaster*. Currently, the only effective way to view histamine in the central nervous system of *Drosophila melanogaster* requires fixation of the tissue. Results from this study demonstrate that, in the pHdc-5'-UTR-eGFP transformant flies, eGFP can be localized in neurons that also contain histamine, and thus, can serve as a marker for living histaminergic neurons.

The co-localization of eGFP and histamine shows that the 5' UTR region of Hdc is sufficient to drive expression of histamine in most histamine-containing neurons of the central nervous system. This also means that histaminergic neurons can be viewed in live tissue of transformant flies with the eGFP insert, opening many avenues of histamine-related research and potentially enabling the discovery of more pertinent information regarding the function of histamine in the central nervous system.

Future studies will need to be conducted to determine if all histaminergic cells in the central nervous system co-localize with eGFP in the pHdc-5'-UTR-eGFP transformant fly. It is unclear whether the 3' UTR region of the Hdc gene is necessary for increasing the levels of Hdc gene expression. Construction of a transgene containing both the 5'-UTR and the 3'-UTR controlling expression of eGFP, and comparison of eGFP expression to the pHdc-5'-UTR-eGFP transgene, may demonstrate what function the 3'-UTR has with respect to cell-specific expression or level of expression.

Whether copy number of the pHdc-5'-UTR-eGFP transgene can improve eGFP detection has yet to be clearly determined. Transposition of the pHdc-5'-UTR-eGFP transgene to other locations in the genome is necessary before this type of analysis can continue. Currently, attempts to transpose the pHdc-5'-UTR-eGFP transgene to another chromosome are being initiated.

There were also differences in the signal intensity for eGFP when directly compared to the levels of signal observed in histamine detection. To improve the signal of eGFP in fixed tissue, a monoclonal antibody against eGFP will be used, which is planned to be done in future work. Once carried out, this enhanced detection for eGFP should clearly demonstrate whether all histamine-containing neurons express eGFP in the pHdc-5'-UTR-eGFP transformants at various developmental stages.

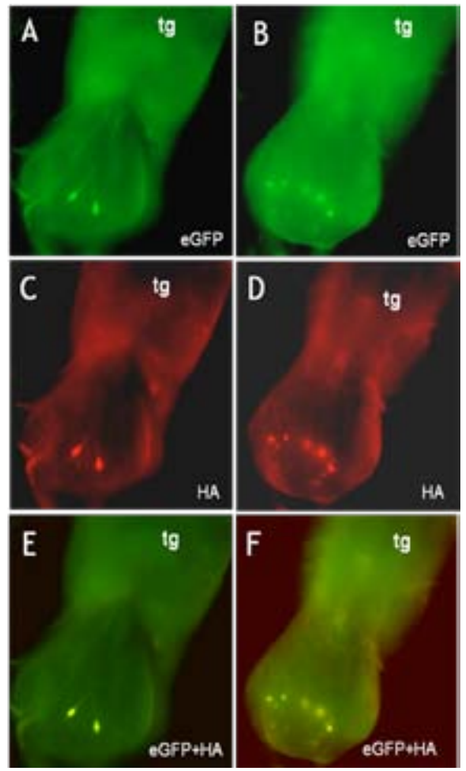

Figure 3: Images from whole-mount adult thoracic and abdominal CNS demonstrating eGFP expression induced by the pHdc-5'UTR-eGFP transgene in adult tissue, detected using an FITC filter (A, B). Histamine immunoreactivity is shown in C and D. E: merged image of A and C; F: merged image of B and D. A, C, E are the same image using either the FITC (A), rhodamine-cutoff filter set (B), or combined image (E) from a more ventral focal plane as compared to the image in B, D, and F. Histamine staining and the eGFP fluorescence appear to co-localize, indicating that the pHdc-5'UTR transgene induces expression of eGFP in histaminergic cells. While all histaminergic cells in the thoracic and abdominal nervous system appear to be expressing eGFP, the neurons in the central brain do not appear to be as easily detected (data not shown). This suggests that while the majority of the pHdc-driven expression is present, it may not be completely expressed in all histamine-containing cells. tg, fused thoracic ganglia; anterior toward top of image.

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From Soldadera to Adelita: The Depiction of Women in the Mexican Revolution

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Abstract

Popular images of women during the Mexican Revolution (1911-1920) often depict them as dressed provocatively, yet wearing a bandolier and gun. Although the image is common, its origin is not well known. An examination of secondary literature and media will show the transformation in the image of the female soldier (soldadera) over the course of the Revolution from that of the submissive follower into a promiscuous fighter (Adelita). The soldaderas exhibited masculine characteristics, like strength and valor, and for these attributes, men were responsible for reshaping the soldadera's image into the ideal (docile, yet licentious) woman of the time.

A gun is strapped to her back, as are bandoliers across her chest. She wears a flowing skirt, a revealing blouse, and a carefree expression on her face. This image has been reproduced repeatedly on t-shirts, calendars, address books, advertisements, and even in the media through movies, songs, and art (see Figure 1). She embodies the image of *soldaderas*, or women soldiers, who fought during the Mexican Revolution in the years between 1911 and 1920.[1] At this time in Mexican history, a patriarchal society constrained women and limited their lives in nearly every aspect. Women's responsibilities to their families and the expectations of the Catholic Church stifled any possibility of equality with men. Whether intentional or not, becoming a soldadera allowed some women to leave behind part of their responsibilities and begin a journey that would ultimately help them gain equality with men. Over the years, the image of the soldadera has been misrepresented in popular culture. The brave, strong woman who fought for equality, such as the anonymous soldadera depicted in Figure 2, has been transformed into the promiscuous woman often referred to as La Adelita, described above.[2] Unlike the true soldadera, La Adelita hardly seems capable of fighting in a war. How and why has the image of the soldadera evolved into that of La Adelita? More importantly, why are the romanticized images of the soldadera perpetuated to this day in popular culture, including *corridos* (love songs) and movies?

This paper examines the transformation of the soldadera into La Adelita. To this end, I provide an overview of Mexico during the Porfiriato (1876-1911), specifically focusing on the plight of women and their status as second-class citizens. Next, I analyze the soldaderas themselves, including the different types of women who fought and their participation in the Mexican Revolution. Finally, I

[1] The word *soldadera* has its origins in the Spanish Conquest. The soldaderas were responsible for aiding the army by finding food and caring for injured soldiers. The term has also been applied to Spanish women who fought during the Conquest. As Spanish became Mexico's language after the conquest, the term *soldadera* was used to describe all women who fought and aided in the Mexican conflicts. The first time it appeared in print was 1865. For more information, see Elizabeth Salas' *Soldaderas in the Mexican Military: Myth and History* (Austin: University of Texas Press, 1990), 11-33.

[2] There are many myths surrounding the identity of La Adelita, however her true identity is unknown.

discuss the evolution of the soldaderas' image over time in song and in film. What I found suggests the romanticized depictions of La Adelita are a result of men's framing of these women soldiers in the way they recorded history. Men sought to recast the soldaderas' legacy as strong, assertive, and in some cases, violent women because these women exhibited masculine characteristics that clashed with societal expectations of how women should act. Therefore men downplayed the accomplishments of soldaderas on the battlefield and instead emphasized their beauty and loyalty to the men in their lives. By rendering female soldiers in a romanticized manner, men effectively neutralized the threat these women posed to their masculinity.

The Porfiriato and the Plight of Women

Porfirio Diaz, governor of Mexico from 1876-1880 and 1884-1911, created conditions that pointed towards revolution. His presidency was marred by deception, corruption, and violence. Upon seizing power in 1876, he espoused an anti-reelection platform that prohibited consecutive terms for a president. Díaz's successor, Manuel González, had the constitution amended to permit presidential reelection, which allowed Díaz to be elected again in 1884 - a position he held until the outbreak of the Revolution. Díaz's policies had a profound impact on Mexico, mostly benefiting the upper classes as well as foreigners in Mexico. Díaz was well known for favoring foreign interests over domestic ones. This was obvious in the 1906 Cananea labor strike that killed over twenty people. Díaz allowed the American mine owner to pay Mexican workers lower wages than their American counterparts at the same mine, which provoked the strike. When the miners went on strike and violence ensued, Díaz welcomed the arrival of U.S. troops into Mexico to quell the disturbance, in effect undermining Mexico's sovereignty.[3] Countless indigenous and peasants also suffered under Díaz. They experienced the loss of their lands at the hands of the landed elite through a series of agrarian laws. The peasants and indigenous lacked any feasible means to support themselves. Their exploitation increased and so did their anger at the government that ignored them. Díaz's government also overlooked women and treated them as second-class citizens under the law. The Constitution of 1857 and Civil Code of 1884 greatly restricted women's rights. For example, the Constitution did not define citizenship for women, and by law women without citizenship could not vote.[4] Although suffrage was important for women, their lack of citizenship was more problematic. Without it, women lacked rights and were dependent on their husbands or fathers in ways that made life difficult. According to the Civil Code of 1884, married women could not enter into a contract, sell property, or oversee their children's education.[5] Moreover, a Commercial Code also prohibited them from working as teachers or attorneys for anyone except their husband or children.[6] In 1910, Francisco I. Madero, an upper-class land owner, challenged Díaz in the presidential election but was jailed and subsequently lost the election. Nevertheless, Madero had the support of many Mexicans, and the time was right for a change. The following year, the Mexican people rose up in revolt against the Porfiriato; the Revolution was underway.

Not all people fighting in the Revolution pursued the same objectives, and neither were they all men. Some men took up arms in opposition to Díaz's policies or in support of opposition leaders, such as Pancho Villa and Emiliano Zapata. There were, however, some women who joined in the fighting to advance their own causes. Not only were women's lives limited by the law, but gender roles were also constraining to women. A woman remained under the control of a man her entire life: in her childhood, it was her father; in her adulthood, it was her husband, brother or uncle. If she joined a convent, her life was regulated by the Catholic Church. Women were expected to serve their families faithfully, especially the men in their lives. Moreover, they were producers, in that they needed to contribute economically to the family's income, and reproducers, because they were expected to bear children and serve as their primary caregiver. They

Figure 1. Reproduction of Angel Martin's "La Adelita" on Hecho en México Address Book, 1996.

Figure 2. *Soldadera*. Reprinted from Casasola, vol. 1, p. 263. Found in Shirlene Soto, *Emergence of the Modern Mexican Woman Her Participation in Revolution and Struggle for Equality, 1910-1940*. Denver, Colo: Arden, 1990.

[3] Soto, Shirlene Ann. *Emergence of the Modern Mexican Woman: Her Participation in Revolution and Struggle for Equality, 1910-1940*, (Denver: Arden Press, 1990), 24.
[4] Ibid.,10.
[5] Op Cit.
[6] Soto, 11.

accomplished all of this while upholding an image of innocence and purity, much like the Virgin Mary, who dutifully and faithfully accepted her destiny without complaint. This was the ideal woman in Mexican society. Participation in the Mexican Revolution, however, would open an avenue to liberation from the patriarchal society.

Who Were the Soldaderas?

One way women were emancipated was by becoming soldiers in the Mexican Revolution. As soldaderas, women found they were able to rise above some of the limitations in their lives. When soldaderas left home to take up arms, they left behind their traditional roles at the same time. Women shed their docile image, strapped on bandoliers and wielded guns – much like men. The idea that a woman could take up a non-traditional profession as a soldier was a radical idea. Many women were active participants during the Revolution. Though it is not known how many women fought, they did so on behalf of the federal government (federales) and also on the side of those opposing the dictatorship, including the armies of Pancho Villa, Emiliano Zapata, and Venustiano Carranza.[7]

Each of these revolutionary leaders attracted a sizeable following of women soldiers. However, Pancho Villa was not as receptive toward female soldiers as the other leaders, but they still figured among his troops. Because Villa used quick attacks and swift troop movements, he did not like to travel with soldaderas.[8] There are also conflicting stories about Villa's opinion of soldaderas and women in general. One story describes Villa as a man who wanted to protect women and relegate them to "the back of firing line to places of safety."[9] Yet in another story, Villa orders the massacre of ninety women and children prisoners under his command, believing that one of them conspired to kill him.[10] Villa's views on the soldaderas are not clear; nonetheless, both stories suggest he likely did not want them fighting alongside his troops. Emiliano Zapata must have felt differently about the soldaderas because he included many women among his troops. Although some would assume that Zapata's forces would attract lower-class women, he drew support from women of diverse backgrounds, including farmers and unmarried professors.[11] Venustiano Carranza also welcomed women from all social classes in his army. In addition to their aid in the Revolution, he also looked for women's support to advance his political career.[12] In exchange for their support, Carranza enacted social reforms benefiting women during his presidency.[13] Regardless of whom they supported, women's participation was a key component of the Revolution.

Women who fought in the Revolution did so for a variety of reasons. Elizabeth Salas provides a description of different soldaderas in her book *Soldaderas in the Mexican Military: Myth and History*.[14] Some women fought in support of revolutionary ideals like agrarian reform. Others fought because the men in their lives were fighting, and they wanted to support them. One example is Manuela Oaxaca, who was fifteen years old when she decided to follow her boyfriend into the war.[15] Salas describes other young girls, twelve and thirteen years old, who were forced to accompany their parents into war and later became soldaderas themselves.[16] There were also women who did not become soldaderas of their own volition. Some women were forced to join the war after they were kidnapped by men in the Federal Army or the revolutionary forces.[17] This was a common occurrence; many of the soldaderas joined the Revolution after seeing this happen to family members and friends. Angela Jimenez joined the war after watching her sister kill a soldier who attempted to rape her.[18] Jimenez's sister subsequently killed herself after shooting the officer.[19] This prompted Jimenez to avenge her sister's death by joining her father in the Revolution, where she eventually attained the rank of lieutenant colonel.[20] Additionally, older women entered the war seeking revenge for the death or capture of their husband, son, or brother. Examples of such soldaderas include Señora María Sánchez, who took her brother's place in a rebel army after his death, and Señora Pimental, who freed her son from a Federal prison by killing two guards.[21] Thus, women of all ages actively participated as soldaderas, albeit for different reasons.

Diverse backgrounds also played a role in women's motivation to take up arms. Most soldaderas came from the lower rungs of society. Some were the indigenous or mestiza, of mixed indigenous and Spanish ancestry, daughters of farmers or merchants.[22] In the

[6] Soto, 11.
[7] There is little information on the number of soldaderas who fought due to the vague definition of who was a soldadera. For example, camp aides and women fighters might be counted differently. Also, the wives of soldiers who fought may not have been counted. Salas affirms that there were thousands of soldaderas, Salas, 39. A *Washington Post* reporter remembered over 500 soldaderas in one battle. ("Amazons Under Fire." *Washington Post* [Del Rio, Mexico] 3 Nov. 1913: 3).
[8] Salas, 45.
[9] Op Cit.
[10] Salas, 46.
[11] Soto, 45.
[12] Ibid., 49.
[13] Ibid., 58.
[14] Salas, Elizabeth. *Soldaderas in the Mexican Military: Myth and History*, (Austin: University of Texas Press, 1990).
[15] Salas, 72.
[16] Ibid., 73.
[17] For more information on these soldaderas, see Salas, 40.
[18] Salas, 71.
[19] Op Cit.
[20] Salas, 68.
[21] "Women Fight on Both Sides." *New York Times* [Del Rio, Mexico] 3 Nov. 1913: 3.

pictures of soldaderas from this era, many of the women had a darker complexion, most likely indicating their indigenous or mixed ancestry. The pictures included in Shirlene Soto's book, *Emergence of the Modern Mexican Women*, reveal their tattered, worn clothing, which may attest to their lower class background or might simply be a reflection of inadequate supplies.[23] In most cases, social class also dictated the reasons why the women fought. An indigenous woman or mestiza woman's livelihood depended on farming. This woman was more likely to support Zapata and fight against Díaz or other presidential aspirants who did not embrace agrarian reform. However, a woman whose economic situation improved under the government in power was probably fighting on behalf of the Federal Army. One example of a soldadera from a higher class background was a woman referred to as La Neri, who was "a natural leader, with absolute command of her [all-women] forces."[24] Because of the conflicting stories surrounding La Neri, it is unclear on which side of the Revolution she fought. Due to her upper-class status, one might assume that she fought for the Federales, but it was common for such women to sympathize with the revolutionary forces and fight with their armies. Because of the different reasons for which women fought, it is important not to generalize about the soldaderas.

Similar to the diversity in the soldaderas and their motivations, the responsibilities of these women also varied as they performed many of the necessary jobs that enabled the army to function on a day to day basis. Women were primarily responsible for two tasks. The first task involved taking care of the men, much like the women did at home. They cooked for the soldiers, nursed them back to health after injury, and carried their equipment and supplies from one battle to the next.[25] Among the supplies the soldaderas transported was bedding for the soldiers because they were not supplied with these materials.[26] At this time, the Federal Army did not have a department responsible for these tasks; neither did the revolutionary armies have the organization or manpower to arrange for these. Therefore, armies depended on the women to perform these tasks, especially to set up camp between battles. Women typically arrived at the camp site before the men to put up tents and begin preparing the food.[27] Without the benefit of a well-supplied army, soldaderas were responsible for procuring food by whatever means possible, even if it meant foraging and looting. Soldaderas in the Federal Army often bought food with a portion of the pay that the men received. Meal preparation occurred whenever and wherever the troops stopped for the day. Women were known to start making tortillas in the middle of a desert and even on top of moving trains.[28] Perhaps what is so remarkable about these women is that some brought along their families while they tended to the soldiers. Soldaderas brought their children with them to the camp sites and even accompanied the troops while pregnant.[29] An onlooker who wrote for an American newspaper recorded how impressed he was that women would carry all the equipment and their children. The author remarked, "without these soldaderas the army could not move..." as fast as they did.[30] The women's role in the war effort was integral, albeit frequently overlooked. Without the women's help, the men would have been slowed down with daily tasks that took time away from pursuing their military objectives.

There were women who became soldaderas in an effort to improve their own economic situations. Such women looked for a way to support themselves in an economy that did not provide for all citizens, and becoming a soldadera did this for them. Women became soldaderas both to serve soldiers and to provide for their own families. They received money from the soldiers to buy food and kept some of it for themselves. In doing so, the women would have enough money to feed themselves and even their children if they brought them along.[31] As noted above, the women and their children traveled with the troops wherever they went, providing services the soldiers needed in order to survive. Although these women did not participate in the war because of their ideals or to support their husband, lover, or son in the war, they were still an important part of the Revolution.

The second way women supported the war was to fight valiantly alongside the men. Women who did so did not limit their participation to tasks that they already performed in the home. Instead, the soldaderas took up arms and integrated themselves into the Federal Army as well as the opposition forces. Women were often among the lowest ranks of the soldiers; nonetheless, skilled, assertive soldaderas could become colonels and generals. One example of a *capitana* (captain) was Petra Herrera. She fought for Venustiano Carranza's forces disguised as a man for most of her military career. Using the *nom de guerre* of "Pedro Herrera," she rose up through the ranks to become a captain and later a colonel.[32] She earned fame for her fearlessness, skills on the battlefield, and temper.[33] Herrera did not reveal her true identity until she was a well-established member of Carranza's forces. When her secret was revealed, she was awarded command of an all-women regiment and led them to many battlefield victories.[34] Thus, Herrera is an example of a woman who believed in the Revolution and allowed nothing to stand in the way of her participation.

There were other brave women like Herrera, and some of these soldaderas even caught the attention of foreigner observers. María Quinteras de Mares was one such soldadera. She was married to a captain in Pancho Villa's army, and their daughter accompanied them on all their campaigns. Coronela Quinteras de Mares was so committed to the Revolution that she refused to be paid.[35] Her skills on the battlefield caught the attention of many observers in Mexico and the United States. In 1914, a reporter from the *El Paso Morning Star* wrote that she "has led many desperate charges and her followers have come to believe she is endowed with some supernatural powers."[36] Soldaderas' exploits were also documented in popular American newspapers like *The Washington Post* and *The New York Times*. For example, *The New York Times* referred to soldaderas in a 1913 piece entitled, "Women Fight on Both Sides."[37] The five hundred soldaderas were said to be "expert with both knife and rifle."[38] Also, another soldadera previously mentioned, La Neri, could "shoot and ride almost as well as men."[39] These women were recognized for their talents and contributions at a time when women in the United States were not allowed to participate in armed combat. Although these were only a few examples of women who fought, they are representative of the soldaderas' motivations for fighting and how their actions were viewed by onlookers.

Through their participation in the war, these soldaderas were deservedly liberated from cultural norms and achieved equality in ways that went beyond the ideals of the Revolution. Even if a soldadera took care of the troops, she had left her home, where society wanted and expected her to remain. Soldaderas received payment for their work, but more importantly, they were released from the house and the attachment to a man. If she wanted to work for a particular soldier, she could; if she wanted to move on to another for any reason, she could also do that. There were no rules or expectations that governed her movement. She was free to do as she pleased. By virtue of such actions women were able to attain equality with men in Mexican society, if only in this context. Their equality was derived from having fought alongside men, taking "machetes and [killing] as many as the federal men..." killed.[40] Moreover, female soldiers died like their male counterparts, as described in the article "Battle on At Night," in which a woman was bound with her child and thrown into a burning building along with other male soldiers.[41] Based upon these examples, there is no doubt that women fought heroically and died valiantly, as did men. Women's contributions and participation in the Revolution were a liberating experience, and their sacrifice was rewarded with equality.

The soldaderas' newly acquired freedom led some women to reject the societal norms imposed on them. Women were able to engage in open relationships with men at this time. Liberated from the Catholic Church, many women chose to have sexual relationships with men they were not married to and had no plans to marry. They could behave like the men who had controlled them for so many years. Soldaderas sometimes formed sexual relationships with the soldiers they worked for or soldiers with whom they fought alongside. These relationships empowered women and may have made them more assertive, which helped in their military work. As a profession, becoming a soldadera unfettered women in ways that would have been impossible if they had remained at home and were still constrained by males. As much as fighting in the war helped the soldiers, it also helped women advance their position in society.

Upper-class women found ways to further their rights under the law. Although some upper-class women fought in the Revolution, most found ways to liberation through political activism. They formed groups seeking to obtain women's suffrage and greater access to education and contraception, and in support of political candidates. Examples of such groups include the Consejo Feminista [Mexican Feminist Council] and the Liga Feminista Mexicana [Mexican Feminist League].[42] The former worked for "the economic, social, and political emancipation of women," while the latter was dedicated to women's suffrage.[43] These groups exerted pressure on whatever presidential administration was in power to see that their objectives were met. However, it was not until the 1920s and 1930s, after the revolution had ended, that these groups were successful. Even though these women were not physically fighting for equality like the soldaderas, they were still working to obtain freedom and fairness under the law.

Women were an integral part of the Revolution. They aided troops in every way imaginable, allowing the armies to carry out daily tasks that made the war possible. In fighting alongside men, women matched their bravery and valor. Some women ultimately became famous colonels and generals. In doing so, they challenged common stereotypes of docile and submissive Mexican women. Both as a camp aide or combatant, the women liberated themselves from some of the restraints in their lives and achieved equality with men. Unfortunately for the women, their participation is often overlooked, unlike that of Pancho Villa or Emiliano Zapata.

[22] Salas, 70.
[23] Soto, Shirlene Ann. *Emergence of the Modern Mexican Woman: Her Participation in Revolution and Struggle for Equality, 1910-1940*, (Denver: Arden Press, 1990).
[24] "Mexico City Menaced." *Washington Post* 15 May 1911, Special ed.: 3. The name "La Neri" probably referred to Margarita Neri. There are many stories surrounding her identity as a soldadera, however there are conflicting accounts as to which side of the revolution she fought. For more information on Neri, see Soto, 45.
[25] "Funny Side to Mexican Wars." *Washington Post* [Real Mexico] 3 May 1914: M1.
[26] Salas, 59.
[27] "Funny Side to Mexican Wars." *Washington Post* [Real Mexico] 3 May 1914: M1.
[28] Herrera-Sobek, Maria. *The Mexican Corrido: A Feminist Analysis*, (Bloomington: Indiana University Press, 1990), 80.
[29] Salas, 50.
[30] "Funny Side to Mexican Wars." *Washington Post* [Real Mexico] 3 May 1914: M1.
[31] Soto, 36.
[32] Ibid., 48.
[33] Op Cit.
[34] Soto, 49.
[35] Ibid., 42.
[36] Op Cit.
[37] "Women Fight on Both Sides." *New York Times* [Del Rio, Mexico] 3 Nov. 1913: 3.
[38] Op Cit.
[39] "Mexico City Menaced." *Washington Post* 15 May 1911, Special ed.: 3.
[40] "Battle on at Night." *Washington Post* 23 May 1912: 3.
[41] Op Cit.
[42] Soto, 103.
[43] Op Cit.

The Image of the Soldaderas over Time

The soldaderas' legacy is clouded by misconceptions. Although women made progress by virtue of their accomplishments on the battlefield, the transformations in their gender roles were not always looked upon favorably. Women's participation and subsequent success threatened patriarchal structures. Men were supposed to be the strong figure in Mexican society. Successful women in the Mexican Revolution had to be remembered in a way that would not threaten the men's masculine characteristics. Therefore, men recast the image of women in a way that allowed the men to retain their dominance in society and that subjugated the soldaderas to a subordinate role. Soldaderas were portrayed in a romanticized manner that was at odds with who they were in real life. The woman in Figure 1 has come to embody the image of the female soldier. Clearly this woman does not resemble the actual soldadera, like the one in Figure 2. This romanticized depiction of the soldadera highlights her sexuality and omits her bravery. Although the image retains the assertive traits of the woman, it also subtly undermines her with sexual overtones. Despite the soldaderas' efforts to support the Revolution and pursue equality, their memory has been replaced by the idealized one that men have conjured up in their imagination.

Additional sources for this over-sexualized image can be found in another type of woman who broke down gender roles: prostitutes.[44] Although soldaderas and prostitutes would seem very different, there are many commonalities. For example, prostitutes were some of the most liberated women in Mexico at the time of the Revolution. They rejected the cultural norm that women were supposed to be under male control for the duration of their lives, in that they were not committed to one man through marriage or sex, as was the case of the soldadera. Also, these women sought equality by emulating the sexual behavior of men. The soldadera and the prostitute were able to have sexual relationships with whomever they pleased. Also, the soldaderas were fighting for equality on the battlefield, while the prostitutes achieved equality by other means. Some people even saw prostitution as the logical result of feminism, which most people associated with female soldiers. In a review of Rodolfo Usigli's play E*l Eterno Femenino [The Eternal Feminine]*, Georges Batailles argues that "not every woman is a potential prostitute, but prostitution is the logical consequence of the feminine attitude."[45] Although the play was written in the 1950s, it shows that many people previously equated feminism with prostitution or simply the idea of a "loose" woman. Any unattached woman was considered "loose" or "easy" in Mexican society. Unmarried soldaderas therefore were also in this category of women. They were seen as a potentially disruptive force within society because they were unable to control their sexuality and thus needed to be under a man's control. The prevailing image of the promiscuous soldadera is probably derived from the sexual behavior associated with the prostitute.

Popular Culture: Corridos (Love Ballads) and Film

While prostitution bestowed a promiscuous image upon the soldaderas, the Mexican *corrido*, or love ballad, created a more feminine image of beauty and devotion. The corrido was one of the primary methods for spreading information, especially about the war in this era. Dating back to the Spanish colonization, the Mexican corrido has maintained its validity for disseminating information throughout history.[46] Although these ballads have been used to circulate all types of information, at the beginning of the twentieth century they were used to tell stories about the participants and events in the Mexican Revolution. One of the most prevalent topics was that of the women soldiers. The soldaderas were remembered in many ways. Men wrote most of these corridos and, therefore, their interpretations are based upon a male point of view. Because these are men's views of the soldadera, they contributed to the depiction of the soldadera that was popularized at the time of the Revolution and that remains popular to this day. According to the research by Rosalva Resendiz, the corridos categorized women into different archetypes: "good mother, goddess, the lover, and the soldier."[47] The female soldier is usually remembered in the corridos as either brave or a love interest. By examining the different depictions of the soldaderas in corridos we can see how they contributed to the romanticized image of La Adelita in history.

The brave soldaderas' accomplishments as well as their beauty were described in *corridos*. Depending on the composer, the portrayal of these women varied. There are more songs that describe how gorgeous these women soldiers were than how fiercely they fought.[48] For example, Petra Herrera was one of the soldaderas whose exploits in war granted her a corrido. Herrera's song dates back to 1911 and the battle of Torreón.[49] An excerpt of the song follows:

"La valiente Petra Herrera
En el fragor del combate
Aunque cayó prisionera
Ni se dobla ni se abate ...

Que viva Petra Herrera
Que vivan los maderistas
Que mueran con los pelones
Los cobardes porfiristas!"

"The valiant Petra Herrera
In the heat of the battle
And even though she was taken prisoner
She doesn't surrender or give up ...

Long live Petra Herrera
Long live the Maderistas!
Let the baldies (Federales) die!
With the cowardly Porfiristas! "[50]

In these lyrics, Herrera does not share the spotlight with any other soldaderas or male soldiers. This illustrates the esteem the author had for his female subject. For Herrera to have a corrido dedicated to her as a woman, she must have been regarded as valiant as other revolutionary leaders, such as Emiliano Zapata and Pancho Villa. According to María Herrera-Sobek, Petra Herrera is only one of three women remembered in corridos by their first and last name.[51] The mere mention of this soldadera by her full name is indicative of the level of acclaim she received, especially from a male composer. Unfortunately, the popularity of this type of soldadera was limited to that time period, as there was no lasting legacy of her like there is of the other type of woman soldier.

The inspiration for the famous picture of the soldadera (Figure 1) probably has its origins in the corridos that describe how beautiful the women were. Unlike Petra Herrera, the women in these songs were not mentioned by their first and last name. Often they were referred to by a nickname and were probably fictional characters. The lack of a real name for these women downplays their significance. However, the woman in this type of song has a more prominent legacy than Herrera. Instead of being the work of a composer who was impressed by the soldaderas' bravery, these songs were written by soldiers who were most likely love sick and writing about the women with whom they wanted to be. Such ballads described the extent of women's beauty and femininity, alluding to the prevailing standard of women's physical appearance in Mexican society.

Figure 3. María Félix in Doña Diabla. Found in *Mediating Two Worlds Cinematic Encounters in the Americas,* (Annapolis: British Film Institute. 1993) 155.

There are two popular corridos, not only in Mexico, but in other Latin American countries, that can best be described as tributes to the women soldiers. One particular song was so popular that the character's name, La Adelita, has now become a generalized name for all soldaderas.[52] The song titled "La Adelita" was most likely written at the beginning of the Revolution. There are several theories about the identity of La Adelita, including that she was a soldier in Pancho Villa's army, his lover, or a nurse who helped a soldier return to good health after an injury.[53] There is no way of verifying who she really was, but we are left with the following lyrics excerpted from *The Mexican Corrido* that describe who she could have been:[54]

"...y una moza que valiente los seguía
Locamente enamorada de su sargento
Popular entre la tropa era Adelita,
La mujer que el sargento idolatraba
Porque además de ser valiente, era bonita

"And a young woman who valiantly followed
Madly in love with the sergeant
Popular among the troops was Adelita
The woman the sergeant adored
Because she was not only valiant but beautiful"

In this particular excerpt, La Adelita is immortalized for her valor as well as her beauty, but the rest of the corrido describes how much the men desired her. She is described as being so beautiful "si Adelita se fuera con otro, la seguiría por tierra y por mar" [if Adelita left me for another, I would follow her by land and sea].[55] This woman was the perfect archetype for a soldadera because she was brave, although men still idolized her for her beauty.

La Valentina is another corrido that described women in the same way. The song gained popularity in 1914 and describes the depths of love the composer has for this soldadera.[56] The lyrics are as follows:

"Una pasión me domina
Es la que me hizo venir
Valentina, Valentina
Yo te quisiera decir"

"A passion dominates me
That's what brought me here
Valentina, Valentina
I wish to tell you so"

The composer's passion for this woman gives the reader the impression that La Valentina was beautiful. She was inspired by a fierce woman fighter; however, the lyrics do not reflect that. It is obvious by the omission of her accomplishments on the battlefield that La Valentina was best remembered as a beautiful woman, rather than as a heroic participant in the Revolution.

This misrepresentation of the soldadera fits better with how Mexican society and men in particular, viewed women at that time. They were objects of desire, rather than equals on the battlefield. Although it is widely accepted that these women were fighters, their true legacy has been lost. For example, in another excerpt of La Adelita, she is noted for being respected by the colonel, but the composer goes on to describe how she is viewed as a love object rather than a soldier: "...Y si Adelita quisiera ser mi novia, y si

[44] Castillo, Debra A. *Easy Women: Sex and Gender in Modern Mexican Fiction*, (Minneapolis: University of Minnesota Press, 1998).
[45] Ibid., 21.
[46] Resendez, Rosalva, "Female Subjectivity and Agency in Popular Mexican Corridos (Ballads): An Examination of Images and Representations of Soldaderas (Female Soldiers) in the Mexican Revolution 1910-1920." PhD dissertation, Texas Woman's University, 2001, pg. 7.
[47] Ibid., 8.
[48] Herrera-Sobek, 103.
[49] Ibid., 93.
[50] Op Cit.
[51] Herrera-Sobek, 94.
[52] Ibid., 108.
[53] Salas, 92-93.
[54] Herrera-Sobek,107.
[55] Op Cit.
[56] Herrera-Sobek, 109.

Adelita fuera mi mujer, le compraría un vestido de seda, para llevarla a bailar al cuartel" [If Adelita would like to be my girlfriend, If Adelita would be my wife, I'd buy her a silk dress to take her to the barrack's dance.][57] The rest of the song goes on to describe her physical appearance, rather than her exploits in combat. Conservative Mexican society did not want to acknowledge that women broke free of the cultural expectations when they became soldiers, even when some achieved success as fighters. This helps explain why La Adelita and La Valentina are the models upon which the popular images of all soldaderas are based. These songs became popular throughout Mexico by word of mouth and also with the invention and the popularity of the radio. The prevalence and appeal of these songs led to the widespread acceptance of La Adelita as the embodiment of the soldaderas. In this way, the corridos had a lasting impact on the image of the soldaderas and women in Mexican society.

The new version of the soldadera that emerged from the corrido has continued to live on through film. Several themes and characteristics have evolved. For example, La Adelita is commonly portrayed as beautiful, brave, and passive. Whereas the songs spawned the characters, the movies created the storylines that were readily understood by Mexican viewers. Popular culture has given these women storylines that followed them, especially Mexican women, into the present day. They also exemplify other stereotypes that Mexican society has about women, including the labels of the good woman and the bad woman. These stereotypes and other categories of women can be seen in the movies examined in the following sections.

Mexican cinema and Hollywood were responsible for the perpetuation of these stereotypes and others beginning in the early twentieth century. Mexico and the United States were closely intertwined long before the Mexican Revolution, but in this era filmmakers in the United States started to use Mexican conflicts as inspiration for entertainment. Dating back to the onset of the Revolution, the film industry in the U.S. had produced many movies that shaped popular perception of the "Mexican wars" and society.[58] Hollywood created lasting stereotypes of Mexican men and women, the state of the country, and society as a whole. One theme that emerged often portrayed mestizo men as villains, a white American male as the hero, and the Mexican woman as strong and assertive, yet easily tamed by the hero.[59] Moreover, the Americans were depicted as peacemakers and the Mexicans as unreasonable and savage. Many films made in this era adhere to this formula, including *The Americano* (1917) *and Captain Alvarez* (1914).[60] The depiction of women in these movies left a lasting impression that continues to shape the perception of women today. Mexican women in American movies were a true paradox: strong and beautiful, yet they could be docile and easily seduced. In *The Americano*, a Mexican woman spies on a man who appears to be Mexican but is an American in disguise. He appears more chaste and sensitive than his Mexican counterparts in the movie.[61] Because of these characteristics, he is the obvious choice as the love interest for the Mexican woman. The women in these movies are not representative of the majority of Mexican women. For example, the actress María Félix (depicted in Figure 3) is not mestiza like many women in Mexico, but instead is fair-skinned, denoting her Spanish ancestry.[62] Perhaps she was more appealing to an American audience, as opposed to a mestiza woman. The actresses in the movies clearly resemble the famous picture of La Adelita (Figure 1). La Adelita appears sensual, subservient as she kneels, and her complexion is much lighter than many of the actual soldaderas from the Mexican Revolution. Even though these movies did not specifically depict the women as soldaderas,

Figure 4. María Félix and Jorge Negrete. *Los Dos Grandes Del Cine de Oro Mexicano***.** Nov. 1953. El Rapto (Film). <http://www.flickr.com/photos/chalio777/1416978400/>

they established an archetype of a Mexican woman that has been transferred from the corrido to film.

The Mexican cinema was not far behind Hollywood in its depiction of Mexicans, especially women. Although it originated in the early 1920s, the Mexican film industry reached its height of popularity later between the 1930s and the 1950s. Using Hollywood as a model for success, Mexican cinema tried to imitate every aspect of filmmaking including plots and, most importantly, characters. However, the Mexican cinema exploited its own society's cultural norms, myths, and attitudes.[63] While Mexican movies lacked the American male as the hero, they did show strong Mexican men in their place, and the role of the woman did not change.

Women in Mexican society draw their inspiration from two archetypes: The Virgin Mary (good woman) and La Malinche (bad woman). For the mostly Catholic Mexican population, the Virgin Mary is the most venerated woman in society.[64] She represents innocence, purity, and self-sacrifice. In contrast, La Malinche is one of the most despised women in Mexico. She is the indigenous woman who betrayed the Mexican people in helping the Spanish conquistador, Hernán Cortez, defeat the Aztecs. Additionally, she was Cortez's lover; their child was the first mestizo born in Mexico. Therefore, La Malinche represents betrayal and unbridled sexuality. Mexican movies often portrayed women as either of these archetypes. It is also common in Mexican movies for the bad woman to be portrayed in the beginning, to be tamed or domesticated as the movie progresses, and transformed into a good woman by the end of the film. The aforementioned María Félix was one actress who earned acclaim for her roles as the bad woman. She was a strong, assertive woman and even prone to violence toward her male counterparts.[65] In Figure 4, Félix's body language implies resistance, yet at the same she time allows a man to embrace her. If we recall that the ideal image of the Mexican woman embodies both the Virgin Mary and La Malinche, Felix's resistance represents La Malinche, while her softness is representative of the Virgin. This theme is persistent throughout Mexican cinema and other forms of popular entertainment as well as in society. Hollywood influenced Mexican society in the creation of images for women that have followed them throughout the twentieth century.

The soldaderas suffered equally from the stereotypes of women in the film industry. Much like the images of women that Hollywood and Mexican cinema portrayed, the soldaderas were often framed in a similar manner. A variety of films made between the 1930s and the 1970s offers strong messages about the women from this era. Most of the movies depict a brave soldadera who falls in love with a general, with the plot focusing more on the love interest rather than the soldadera's accomplishments. *La Adelita* (1937) and *La Valentina* (1938) were two movies that followed this same pattern. These movies also looked to gain popularity from the fame of the two corridos with the same name.[66] Like the women in the corridos, the main characters were soldaderas, but the focus of the movie was about the women's relationships. Besides giving less attention to the women's participation on the battlefield, the other popular theme is the domestication or taming of women's behavior. Like American and Mexican movies which show the bad women transformed into the good women, popular films about the soldaderas were no different. In *La Cucaracha* (1958) the main character was a rude, violent soldadera that subsequently is passed up as the love interest of the general because of her behavior. She only becomes a more appealing woman after she becomes pregnant. Ironically, after giving birth she becomes a camp aide and does not return to the life of a fighting soldadera.[67] Here we see that it was more acceptable for a woman to exhibit feminine qualities, rather than masculine traits. Mexican viewers wanted to see a woman in a relationship with a man and as a mother rather than a gun-wielding, successful soldier. Thus, soldaderas were no exception from the stereotypical attitudes that governed the film industry.

The physical descriptions and personalities of these protagonists have also transcended time. In present-day depictions of this revolutionary era, women are continually shown as over-sexualized, yet assertive characters. Based upon a visual examination of these women, one can see that not much has changed. Looking at Figure 1 and Figure 5, one can notice many similarities. The promotional posters for *Bandidas* (2006), starring Salma Hayek and Penelope Cruz and set in the early 1900s, replicate the image that the corridos and earlier films used to portray women in this era. Hayek and Cruz are both carrying guns and bullets and wear a revealing blouse, much like the woman in Figure 1. There is no doubt that these images were taken from the descriptions that were informed by corridos and movies. Another film featuring Hayek, *Desperado* (1995) (Figure 6), also portrays her in similar attire and wielding a gun. All the women in the more recent movies are tough fighters, but those characteristics are overshadowed by their sexual imagery. Like the soldaderas who came before them, these women are typecast by the expectations that society has made for them.

Figure 5. **Bandidas.** The International Movie Database.<http://www.imdb.com/media/rm3156578816/tt0416496>.

Figure 6. Desperado. The International Movie Database. <http://www.imdb.com/media/rm3892811008/tt0112851.

[57] Ibid., 107.
[58] King, John, Ana M. López, and Manuel Alvarado, eds. *Mediating Two Worlds Cinematic Encounters in the Americas*, (Annapolis: British Film Institute1993), 6.
[59] Ibid., 8, 12, 13.
[60] Ibid., 6.
[61] Ibid., 13.
[62] Op Cit.
[63] King, Lopez, and Alvarado, 143-145.
[64] Olcott, Jocelyn, *Revolutionary Women in Postrevolutionary Mexico*, (Durham: Duke University Press, 2005), 50; also King, López, Alvarado, 150.
[65] Salas, 99.
[66] Ibid, 98.
[67] Ibid., 100.

The Depiction of Women in the Mexican Revolution

The popular image of La Adelita does not do justice to the real-life soldadera. Glamorous characters in movies played by María Felix, Penelope Cruz, and Salma Hayek, among others, are romanticized representations of the real women soldiers. The true women fighters battled adversity in Mexico at a time when the dominant patriarchal society restricted their actions with gendered expectations and cultural norms. Becoming a soldadera provided these women with an opportunity to break away from the control of men and assert their equality with their male counterparts.

The idea of participating in the Revolution was liberating in itself because it meant the women were not forced to stay at home in their traditional gendered roles. Although some women performed the same tasks on the battlefield as they did in the home, it was by their choice. Soldaderas also fought valiantly alongside the men in every rank of both the Federal Army and the revolutionary forces. They became feared soldiers and advanced through the ranks, some even becoming generals. Though many women gained acclaim for their accomplishments on the battlefield, their efforts were soon forgotten or misrepresented after the Revolution.

Women's actions on the battlefield were framed in such a way so that they fit with societal expectations. As soldaderas, women posed a threat to the male's dominant position in society. Assertiveness, bravery, and violence were male attributes, and their presence in women made many men uncomfortable. Thus, men began to portray soldaderas in a non-threatening way by emphasizing the female soldiers' beauty and depicting them as objects of desire. The image of the strong women fighters was neutralized in such a way that coincided with males' expectations of women. This resulted in a paradox that was at odds with Mexican gender roles.

Popular culture, in particular, corridos and films, was an effective way to disseminate this image of women and the soldaderas over the course of the twentieth century. Corridos idolized beautiful, submissive women and established the archetype that was popularized. These corridos created female characters that would later be immortalized in American and Mexican movies as either the good woman (Virgin Mary) or the bad woman (La Malinche). Subsequent depictions of soldaderas fell victim to these same stereotypes. Successful films showed talented women-soldiers as they were tamed. Their transformation from the bad woman (soldadera) to the good woman (mother) satisfied conservative viewers who wanted to see women in this role.

The accomplishments of women on the battlefield are often overlooked or misrepresented in the media. Women overcame many obstacles and achieved limited forms of equality through their participation in the Revolution. However, Colonel Petra Herrera is now virtually unknown, while La Adelita remains a permanent fixture in our collective memory. Not many people can recall the heroics of Herrera like they can those of Emiliano Zapata or Pancho Villa; instead, La Adelita has come to embody the myriad women with varying backgrounds, motivations, and accomplishments who fought in the Revolution. La Adelita represents a sexual yet at the same time brave woman during Mexican cinema's golden age (1930s-1950s) and in the years following. She symbolizes all the characters in the corridos and movies that depicted women in that manner. Even though her image is still controversial, with the birth of the Chicano movement in the 1960s, the name of La Adelita began to represent more of who the soldaderas really were.[68] Some Mexican women have begun to take pride in La Adelita because she represents a strong fighter, working for equality; if she chooses, she can appear overtly sexual, but she no longer is forced into that role. She stands for independence from any oppressive force. She is less associated with the image of the women in the revealing blouse, than she is aligned with her own image of a remarkable woman, much like who the soldaderas really were.

[68] Salas, 115-17.

Language, Culture, Perception and Knowledge

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Abstract

The complexity of our diverse communities requires us to reflect on pre-conceived notions of understanding that shape worldviews. This project examines approaches that exclude divergent perspectives, while promoting intolerant ideologies that limit our possibilities for shared learning. It also explores crucial elements that shape our understanding in an effort to expose the limitations created by absolute frames of mind. This research involves an analysis of scientific and religious fundamentalist outlooks that negate vital opportunities for discovery through mutual collaboration and the acknowledgment of exclusive and incomplete perspectives that discourage and undervalue diversity.

The world without language becomes unimaginable, since language makes the articulation of our thoughts and the human experience possible. Through an interactive connection with symbols, signs, and sounds, language enables us to express complex concepts while allowing us to process and convey the abstract, thus creating an environment of communication through the exchange of ideas.

The human need for expression and contact with one another connects us with the origin of language. Once the connection takes place, the cultural components of language begin to develop an interactive relationship between our traditions and our verbal living experiences as a society. It is through this association that our world begins to take shape, and the perception of our world becomes outlined by culture and language. This bond between language and human thought becomes our cultural reality, as well as the medium through which we relate to one another. Through the interrelated nature of language and its cultural components, the way we learn and recognize the world becomes predetermined and dependant on our specific system of symbols and sounds used within our communities, developing our sense of reality and cultural identity.

My main argument explores the relationship between language and its cultural components from a linguistic anthropological and philosophical perspective and investigates the role language and culture play in shaping our perception and epistemological understanding of the world as well as the development, recognition, and acceptance of knowledge. If our cultural identity originates through language, then the foundation for learning and development of worldviews also relies on the existence of language. Edward Sapir[1] speaks about the power of language and culture as he warns us that our cultural traditions potentially imprison our thoughts as well as our acceptance of reality. He states, "Once they had become a part of a linguistic system, they would then be more likely to be imposed on it because of the tyrannical hold

[1] Edward Sapir was a student of Frank Boas, who was widely acknowledged as the founder of American Anthropology (The Anthropology of Language).

that linguistic form has upon our orientation of the world" (Ottenheimer, 25). Sapir's statement reasonably causes mixed responses among scholars, philosophers, and psychologists, and his radical outlook on language does not necessarily receive worldwide support; nevertheless, the study and recognition of cultural elements ingrained in our verbal traditions may begin to clarify the role that language plays in shaping our perception as well as our understanding of the world.

Gadamer speaks about our verbal traditions and their role as perception shapers. He tells us about our inevitable connection with language and the correlation between perception and understanding. He reminds us that, "All kinds of human community are kinds of linguistic community" (443). This relationship between people and language develops our connection with knowledge, and it opens a medium that allows us to interpret the world through its cultural components.

A valuable source for exploring the relationship between language and culture is the written language. An ethno-semantic[2] examination of words and symbols offers us both a broader understanding of the factors influencing our perception as well as a more detailed explanation of the power that our cultural traditions carry into the written form. This power is not exclusive to one language, but it manifests throughout many cultures around the world. The Japanese culture gives us an example of the weight of language and its influential role as an interpreter of reality and a designer of perception. In Japanese the word for spirit is "ki" (気).[3] This word represents the essence of something supernatural, the substance of a force beyond the material world, a different dimension, or the core nature of a mystical entity. Yusua Yasuo describes more in depth the importance of the "ki" element within the Japanese culture in his book *The Body, Self-Cultivation and Ki-Energy*, when he states, "The ultimate secret of Japanese martial arts is said to lie in letting the mind unite with ki" (Yasuo, XI). The essence of "ki" is later transferred into words such as "electricity" (電気), "weather" (天気) and "health" (元気). It is notable that the words "electricity," "weather," and "health" are combined with the"ki"character, perhaps injecting the essence of something mystical into their meaning. It is also worth noting the character preceding "ki" (気) in the word "weather" is pronounced "ten" (天) and it means heaven. When words like "electricity," "health," and "weather" carry potentially supernatural connotations, combined with the historical importance of nature and spirituality to the Japanese culture, it makes sense that the reflection of these cultural elements comes through the language, resulting in a perception of the world that adjusts to these components.

The cultural factors shaping our understanding and interpretation of knowledge through language guide us into a specific worldview that conforms to the reality of that particular cultural community. These elements are transferred from generation to generation and continue to live through the language that is spoken. Edward Sapir's theories on the power of language originate in part from the concept of linguistic determinism, which argues that language has an effect in the way we recognize the world.[4] Many of these components display themselves through different cultural forms of expression, such as religion, politics, and social traditions. Recognizing the metamorphosis of language and its influence on our specific worldviews and accepted perspectives of reality is important, because it allows us to avoid falling into narrow forms of interpretation that understand the world through a limited connection with knowledge that originates from pre-determined cultural and historical perspectives.

Sapir and his student Whorf developed theories that became known as the Sapir-Whorf hypothesis. Their theories investigate the role of culture within the world of language as well as its influential force. Anthropologist Michael Agar describes the difference between the two primary outlooks explored by Sapir and Whorf and explains their composition. He suggests that the "Strong Whorf theory might be compared to the idea that language is a prison, while the Weaker Whorf might be compared to the idea that language is a room, but you can leave the room and enter other rooms, and return to your original room, shifting perspectives as you go" (Ottenheimer, 26). Both theories share similar concepts but vary in intensity. The Weaker Whorf theory perhaps displays language as a more flexible medium of understanding, one that could be left behind and returned to at will, while the Strong Whorf theory paints a more linked relationship between language and thought, making us ponder on the potential influences of language and human thinking.

The development of our cultural understanding as well as the establishment of our cultural traditions takes place in the world of language. Gadamer communicates the importance of language not just as a perception shaper, but also as the main component for human understanding. He adds, "Language is not just one of man's possessions in the world; rather, on it depends the fact that man has a world at all" (440). The exploration of language and its influence in designing our human experience becomes crucial for a better understanding of our worldviews as well as recognizing outlooks that develop narrowly within their cultural constraints and connect with the world through a medium that underestimates the cultural weight of our traditions and the role they play in the developing of our accepted reality.

Before advancing into a more detailed exploration of incomplete perspectives that claim knowledge of our living experiences, let us continue to examine language through its cultural components and its vital connection with perception. This is important because the process illustrates the potential narrowness of language and its influence in the human experience. For instance, in the United States time is perceive differently from how it is perceived in the Czech Republic. North Americans picture the hour that just passed, while Czechs look at the hour ahead[5]. If the time is 9:15, most North Americans will state that is its fifteen minutes after nine or a quarter past nine, but people in the Czech Republic describe it as a quarter of ten. These definitions of time may seem trivial, but they could indicate a cultural tendency to focus on the past rather than the future based on a given outlook and interpretation of time. North Americans will address the hour that is coming up next usually when is closer to the hour, therefore 9:45 could be a quarter to ten, but 9:15 is rarely expressed as having a relationship with the next hour[6].

Issues that cultural communities consider important are incorporated into the language as they begin to highlight our cultural understanding of the world around us. A morphological[7] analysis of words connects us with the formation of language based on its cultural emphasis. For example, in the Yupik Inuit culture (Central Canada), there are many different words for snow; Anuit: packed snow, Mixik: very soft snow, Natibvik: snowdrift, Mavsa: snowdrift overhang ready to fall, Nutabaw: fresh snow, powder snow and Sitxiq: hard crusty snow (Ottenheimer, 15). Observing the structure of these words allows us to see that no specific pattern is followed, and each word displays no resemblance to the other words. Although they all represent snow, each word carries its own independent composition emphasizing its importance. In English an adjective or describer is normally attached to the noun to describe more in depth the type of snow (snow flurries, loose granular snow, corn snow, crud snow, powder snow). In English we find words that independently describe types of snow, such as slush or hail, but for the most part the word snow is used to complement each denomination, therefore downgrading its importance. To elaborate further on the possible implication of the radical differences between words and their meaning, we must continue to explore the morphological structure of language.

Languages in general follow some basic pattern, and they share a common blueprint. The study of this universal design is explored through an analysis of words and how they are formed. "There are two parts to a morphological analysis: 1. Identifying morphemes (the smallest unit of meaning in a language) and 2. Analyzing the way morphemes are arranged in words" (Ottenheimer, 83). Although this two-step process is complex and requires detailed explanation, describing some of the fundamental elements of this method becomes essential in order to understand the complexity of the practice as well as the shape that language takes based on its cultural representation.

Here is an example based on two languages displaying the use of morphemes:

Shinzwani	**English Equivalent**
hufua	**to** work metal
hujua	**to** know
hulagua	**to** speak, talk
huloa	**to** fish

As it becomes noticeable, the words in Shinzwani have the morpheme "hu" at the beginning of each word. Although this minimal unit is not separated from the rest of the word, the morpheme carries the same meaning. As a result, when compared with the sentences on the right, we notice that "hu" means "to" in English and that, every time a new word comes up with the morphene "hu," its meaning is understood without understanding the rest of the word. Examples of morphemes in English would be:

Farm	Farm**er**	Farm**ers**
Walk	Walk**er**	Walk**ers**
Jump	Jump**er**	Jump**ers**

Although there are exemptions to the rules and not all morphemes behave equally, some of the elements of the smallest unit of language help us understand many of the universally shared characteristics of languages regardless of their cultural nature. Returning to the Yupik Inuit example, one discovers the importance of snow in this culture, since a completely new word is used to describe the different forms of snow, and morphemes or adjectives are not attached. This could represent the possibility that, for this culture in central Canada, snow is a vital part of their lives, and that minimizing the nature of each denomination of snow by attaching an adjective or a morpheme to it would not display the important essence that each form of snow carries for this culture. If Mavsa (snow overhang ready to fall) is something that people deal with on a regular basis, and if this represents danger to others or it carries a tremendous amount of importance on its own, then it makes sense that a completely new word independent from describers or morphemes is created, since its importance is designated by its people and it is reflected through the language.[8]

Language Shaping Interpretation

So far, language offers us the best medium for communicating the abstract. It is central to my research to suggest that, through the recognition of the influential role of language as a perception shaper, we may begin to understand its capacity for shaping worldviews, thereby giving us the tools necessary to analyze our own perceptions with a more receptive mind, conscious that the cultural elements of our language do not have to keep us prisoners of their own limitations. Through a medium of openness and awareness, our limited interpretations begin to expand, offering us the opportunity to engage with a wider range of possibilities and innovative thinking. Stephen Rowe expresses this need for awareness when he describes the importance of becoming conscious of our own worldviews in order to expand the opportunities for intellectual growth: "Our times require that we make conscious that which had been unconscious, and that we act in the ways that become evident from the perspective of that consciousness" (10). This entails the necessity to understand that our perception is partially shaped and prescribed by our past traditions, and that only through a medium of awareness that recognizes our limited perception

[2] Ethnosemantics: an anthropological approach in which vocabulary is analyzed to learn about systems of meaning and perception (The Anthropology of Language).
[3] Ki, 気 1. Spirit; soul. 2. Feeling. 3. Intention; inclination (The Random House Japanese-English English-Japanese Dictionary).
[4] Linguistic Determinism: the idea that language affects, even determines, your ability to think about things as well as to talk about them (Ottenheimer, 265).
[5] Ottenheimer claims that the perception of time could be influenced through the spoken language. He states "even as a beginner I found myself thinking differently when I used these two different languages" (Ottenheimer, 28).
[6] Ottenheimer displays the potential differing views of time based on our cultural understanding. He explains that 9:30 is "half past nine" for English speakers while it is "half of ten" for Czechs (Ottenheimer, 28).
[7] Morphological analysis: The analysis of word structure; it has two parts identifying and describing morphemes, and analyzing the way morphemes are arranged into words (Ottenheimer, 272).
[8] The ethnosemantics breakdown of language based on its cultural emphasis is clearly explained in chapter two of Ottenheimer's book, The Anthropology of Language. This chapter displays many of the differing views people display based on the language spoken and the important elements of their culture.

we can begin to distinguish open channels that offer a more expanded interpretation of our past, present, and future. This new level of awareness would let us perceive our perceptions and interpret our interpretations in unconventional ways, making our understanding less biased and more effective.

Stephen Pinker argues that the idea that language shapes our reality is ridiculous and bizarre. He states, "The idea that thought is the same thing as language is an example of what can be called a conventional absurdity" (47). Pinker negates the possibility that language shapes our perception, and he rejects the idea that language shapes our thinking. He implies that thought is not directly connected to language. He says, "To have a feeling, there has to be a 'what we mean to say' that is different from what we said" (47). Although his theory displaying language as an instinct[9] makes us wonder about the possibility of our thoughts not being limited by language, it is nearly inconceivable to think without language. The moment we engage in the thought process, the moment we begin to describe the abstract, an active interaction with language takes place; without it, the possibilities for understanding and for any kind of thought process seem rather impossible to grasp. Gadamer states, "All understanding is interpretation, and all interpretation takes place in the medium of a language that allows the object to come into words and yet is at the same time the interpreter's own language" (390). This connection between language and interpretation is important to recognize in order to continue exploring the interactive nature of language, culture, and human thought.

The Homogenization of Knowledge

In her book, A Place to Stand, Julie Lindquist speaks about awareness as an essential component for a more in depth cultural understanding; "To understand the particulars of persuasion for a given culture is to understand how that culture establishes itself as a culture" (Lindquist, 4). It is in the place of origin that many of the given characteristics of language are shaped, and it is also in this place where we potentially become slaves of our own perception through language. Lindquist also states, "Apart from its status as a special form of talk, every argument is a cultural event and has a layer of meaning as such" (123). Although language potentially shapes our perception through its cultural components and ancient traditions, by becoming aware of this process, we transition from a place of complacent ignorance to a place of appreciation and recognition of our traditions, culture, and worldviews.

The development of our worldviews through language establishes our different perspectives of reality based on our cultural inclinations. Due to different perspectives and belief systems, nations have gone to war, and the world finds itself in chaos and discontentment. In order to find a place of mutual understanding and respect, we shall begin by recognizing our own biases and our own sense of the real and the unreal. Through this awareness, one begins to comprehend the limitations of our views and the influence of language for limiting our understanding of the world. An educated perspective of the relationship between language and culture gives us some of the fundamental steps needed to understand our thinking process as well as new ways to define and reshape our knowledge.

Gadamer recognizes the importance of understanding our connection with knowledge based on our perception of the world. This recognition keeps us from limiting ourselves to one specific way of knowing. He argues that, "understanding always includes interpretation" (Gadamer, 400). As long as we are able to distinguish the role that language plays in prescribing our interpretations of reality, we establish a connection with knowledge that is not regulated by unoriginal thinking and become free of regulated views.

The homogenization of knowledge restricts knowledge itself by confining understanding to a single interpretation of reality. If language influences our perception of the world based on its cultural components, and if our perception of the world varies according to our exposure with cultural elements, then we must not designate knowledge to a single orientation. Our understanding originates from a diversity of perspectives; any attempt to narrow it separates us from a connection with unlimited wisdom. The need for a universally accepted method that accesses knowledge undermines the diversity of our worldviews in postmodern times, while it establishes a dominant position that underestimates the value of our different perspectives and promotes uniformity of thought. This research explores the cultural characteristics of language in order to expose the narrowness of methods of understanding that speak a single language and expect everyone else to conform to specific guidelines.

The assertion of knowledge claimed by allegedly universal perspectives leads me to explore fundamentalist[10] assumptions enforcing a kind of reality as the recognized truth. Claims of infallible methods of knowing dangerously narrow the chances for knowledge expansion by engaging in the practice of inclusion of sameness and exclusion of differences. In order to understand our limited understanding, we need to look at methods of knowing that claim absolute certainty of knowledge. I will focus on the language of religion and the language of science and the role they play in promoting single methods of knowing through fundamentalist perspectives of reality.

Science and religion both serve essential purposes in our society, and it is clear that the world without faith or science is nearly as imaginable as a world without language. My exploration of the methods used by science and religion does not imply that both areas of knowing function only through fundamentalist perspectives; instead, I focus on the radical viewpoints that each approach offers when it begins to claim the acceptance of reality only through its acquired methods.

The Language of Science

Let us start by recognizing that modern science breakthrough discoveries have changed the way we view the world. The scientific systematic approach carefully analyses data through selected steps that create desired outcomes. Although the success of this precise system shows itself through technological advancements and groundbreaking medical discoveries, its exclusive approach to understanding[11] reality narrows the possibilities for innovation through different mediums that do not comply with scientifically approved theories of knowing. Huston Smith speaks about this issue when he states, "What science discovers somehow casts doubt on things it does not discover" (34). The fast growing success and acceptance of this methodology that supplies us with systematic answers reduce our ability to consider unconventional ways of knowing as possible sources for knowledge.

Science speaks a language that relies on physical evidence as the condition for accepting something as real. Richard Dawkins places emphasis on the need for tangible data in order to recognize something as real. He states, "We believe in evolution because the evidence supports it" (320). The prominence of this selected method for judging reality demands a mechanical analysis of data through a process that relies on guidelines founded on a particular version of understanding that recognizes and values the materialness[12] of the universe as the main component for accurate conclusions. This singular approach efficiently develops hypothesis through a trial and error technique that narrows the possibilities for miscalculations, creating a form of knowledge that bonds itself to strict principles for its success. By focusing on matter as the main component for identifying the real, supplemented with a system that supports the selected theories, modern science finds ways to minimize mistakes and arrive at conclusions with results that can be duplicated. In his essay, "The Will to Believe," William James questions the integrity of the scientific method with this statement, "She has fallen so deeply in love with the method that one may even say she has ceased to care for the truth by itself at all. It is only truth as technically verified that interests her" (Stewart, 233). Richard Dawkins expresses his willingness to change his view, but not the method, making his reality dependant on a given system. An attitude that relies fully on the steps of a specified method for determining the truth takes away our autonomy of thought since, in order to explore ideas, we must adjust to the rules and regulations provided by the accepted technique.

Huston also describes the essence of the scientific language when he points out that "Number is the language of science; the more knowledge can be expressed quantitatively, in probability equations and the like, the more scientific it is considered to be" (Smith, 10-11). Numerical formulas aid in the process of pre-determining and confirming the validity of the information gathered. The distinctive scientific approach to reality, based on a confident method that pre-determines it, produces a specific type of result that overlooks diverse possibilities for discovery. Based on a perception of knowledge that excludes opportunities for unconventional findings through different mediums, this single view of reality restricts new opportunities for intellectual development by locking unexplored channels of unknown truths. The world of knowledge and discovery becomes property of a specific methodology or language that recognizes no other.

In his book, *Truth and Method*, Gadamer speaks about the scientific approach to reality when he says, "Each science, as a science, has in advance projected a field of objects such that to know them is to govern them" (449). This need for control pre-determines an outcome that is shaped by a particular vision. Gadamer discusses the selective method that science offers and criticizes its narrowness. He adds, "But the knowledge of all natural science is knowledge for domination" (447). The restrictions placed on knowledge by a specific method promote the singularity of one way of knowing, while excluding or discrediting mediums that reach for the truth through unconventional channels.

The modern scientific approach derives its power from its narrowness. This carefully selected method proves itself effective at arriving at dominant positions within its confined structure. My research does not attempt to discredit the usefulness of science, nor the fact that its objective approach provides us with great resources for truth and knowledge. However, we must explore constricted methods for determining the truth through claims of absolute certainty. This attitude undermines the possibilities of unexplored options, and it sets apart knowledge to an elite group of like-minded people, while it stagnates the growth of awareness itself by encouraging exclusive agendas, where suggestions become discarded through a filtering organism that endorses contraction rather than expansion and operates on exclusiveness rather than inclusiveness. The Chinese philosopher, Chuang-Tzu[13], known as a rival of Confucius and mocker of logical thinking, reminds us of the danger of narrow-thinking: "My life flows between confines, but knowledge has no confines" (62). The idea that a carefully designed system creates a single medium for truth expansion ignores the importance of our diverse cultural communities.

Chuang-Tzu suggests an approach that explores unconventional thought through unconventional channels. He indicates the importance of a connection with reality and knowledge not founded on and guided by logical methods. He emphasizes the need for acknowledging our fixed limitations in order to explore unrestricted territories. The reality of a world that is real only through fixed principles precludes an opportunity to explore unexplored channels of wisdom that may open a new realm of possibilities never considered by pre-approved methods. David Stewart addresses the importance of being open-minded so that no one is restricted to single versions of reality. He speaks about our reliance in logic and states, "This emphasis on rationality is one-sided, for human beings are not just creatures of reason, but function through a complex unity of reason, emotion, will, appetites and feelings" (5). The recognition of other components shaping reality and making us human becomes essential in our quest for knowledge.

Recognizing one method, one language, one form of thinking as universal, neglects the existence of multiple perspectives of reality and cultural differences. Science conditions our thought process through the prin-

[9] "The Language Instinct (How the Mind Creates Language)" argues that language is not created by culture, but that instead we are genetically pre-disposed to learn it.
[10] Fundamentalism: Strict maintenance of ancient or fundamental doctrines of any religion or ideology (The New Oxford American Dictionary).
[11] Understanding: intelligence; ability to comprehend and judge (Webster's English Dictionary).
[12] Huston Smith speaks about science reliance on the physical as a determinant factor for acknowledging the real. He quotes Paul Dirac, the father of antimatter and his point reads as follows: "All matter is created out of some imperceptible substratum. This substratum is not accurately described as material, since it uniformly fills all space and is undetectable by any observation. In a sense it appears as nothingness—immaterial, undetectable, and omnipresent. But is is a peculiar form of nothingness, out of which all matter is created."
[13] Chuang-Tzu's life dates back to the reign of King Hui of Liang or Wei (370-319 BC) and King Hsuan of Ch'i (319-301 BC).

ciples that create and establish its credibility. Huston Smith speaks about liberating our minds from constricted thinking when he states, "The Zenith of Being is Being Unlimited, Being relieved of all confines and conditionings" (Smith, 25). Becoming entrapped by a single vision that accepts the truth of the universe and our human beginnings through a singular method confines us to the limited world of a limited perspective.

The Language of Religion

Throughout history, religious fundamentalism has enforced self-interested agendas that exclude opportunities for intellectual and spiritual growth by promoting confident claims of knowledge that restrict opportunities for discovery and expansion through unconventional channels. The overconfidence of these selected principles overlooks the existence of different mediums of understanding, while it engages in a behavior that encourages discord and segregation. John Hick speaks about this exclusive approach in his essay "The Pluralistic Hypothesis," where he communicates the importance of open-minded methods of knowing that acknowledge the reality of multiple perspectives. He reflects on the narrow views of religious ideologies based on fundamentalist approaches, and he questions the idea of salvation reserved for a select few as others are condemned for not complying with the rules of a given dogma. He expresses his frustration toward ideologies that segregate people by engaging in agendas of exclusion rather than inclusion. He asks for an approach that welcomes other views and is not founded on narrow perspectives. He states, "It is not possible to establish a unique moral superiority of any one of the great world faiths" (Hick, 39). Dogmatic approaches attempt to own knowledge of the truth based on their accepted agenda.

As stated earlier, the cultural components of language connect us with interpretations of reality that shape our understanding of the world. This connection with knowledge outlined primarily through our cultural traditions sets the foundation for specific ways of thinking that characterize worldviews. Single minded worldviews become troubling issues when they ignore the existence of multiple perspectives while affirming a particular view of the world as the standard for universal understanding. By crafting a system that asserts infallibility, single theories that deny the importance of diversity in postmodern times restrict the potential for knowledge growth through mutual collaboration.

A method of knowing that is carefully prescribed diminishes the potential for spiritual growth. The primary components of early Christianity paid little attention to religion's diversity and the variety of cultural traditions across the world. Hick states, "We have to see the world religions as vast complex religio-cultural totalities, each a bewildering mixture of varied goods and evils" (39). The moment we claim absolute knowledge, we close the door for on an assortment of potential opportunities for discovery, while limiting the world of knowing to limited perspectives. Claims of the only truth by religious ideologies engage in convinced and dogmatic approaches of understanding that undermine different mediums of knowing, since in order for a person to hold the outlined truth, one must adopt their existing principles.

Religious fundamentalism continues to enforce its inflexible agenda throughout the ages. Many denominations claim to hold the truth while negating and discrediting others. Some speak of tolerance and acceptance, but their rules are written to be followed; attempts to deviate from the given concepts are seen as immoral, evil, and wrong. Chuang-Tzu criticizes these claims of infallibility when he states, "We do not yet know of anything which we now affirm that we shall not deny it fifty nine times over[14]" (102). These claims of knowledge and absolute understanding function through a very specific outline that defines our world through their constricted views.

Fundamentalist religions frequently base their ethical standards and belief system on the literal interpretation of a book. This text becomes a symbolic icon that establishes and regulates the faith through pre-assumed accurate interpretations of the written metaphors. A belief system founded on literal interpretations of written works is questionable since, not only do they become the rules and guidelines that believers must follow in order to gain approval and the acceptance of the Ultimate, but these written messages are also translated into hundreds of different languages, thereby complicating the authenticity and integrity of the message even further. The process of translation complicates the validity of a message, since the process of translation deals with many cultural elements existing within the language.

Gadamer speaks about the difficulties of carrying the original message through translation. He reminds us that "The requirements that a translation be faithful cannot remove the fundamental gulf between the two languages" (387). The gap between two languages and their cultural components complicates the possibility for transferring the essence of a message into another language literally. In his book, *Truth and Method*, Gadamer sympathizes with the people who engage in the difficult task of translation. He states, "The translator is often painfully aware of his inevitable distance from the original" (388).

The original meaning of a message may be altered or lost through the translation process, making literal translations and interpretations nearly impossible. Ottenheimer further elaborates on this issue of translation in his book *The Anthropology of Language* by sharing the difficulties encountered between one idea and another across the world of language. For example, the word Ruka in the Russian language means "hand" and "arm" in English. The word "love" in Ukrainian has two different meanings; one describes love in general, while the other refers to romantic love. In the Russian language there is also one word for foot and leg. In Standard English the words lend and borrow are divided, while in Shinzwani the word kopa expresses both actions. These different interpretations become difficult to translate accurately since the cultural elements of language vary from culture to culture and from language to language. If only one word describes "love" in Ukrainian, but the word has more than one interpretation for this culture, then it is important to consider the role that language plays before attempting to achieve literal translations of meaning.

The Epistemology of Knowledge

Chuang-Tzu believes that, in order to connect with knowledge--in order to learn and reach unknown levels of spiritual knowledge and intellectual understanding--we must remove ourselves from ourselves. The real connection takes place by discovering the truth within ourselves, and this original truth is not defined by conventions and traditions. It is through the discovery of our unconventional selves that a connection with knowledge and wisdom takes place.

Our interpretation and understanding of the world are shaped by factors such as society, religion, culture, and language. To rely fully on our ability of interpretation would be to deny other mediums of knowledge. This approach not only separates us from the rest, but it also closes us to the possibilities of growth by unwelcoming and denying other perspectives. By confining our choices to limited perceptions, we connect with fabricated ideas of the real and the unreal through a limited medium. Chuang-Tzu's connection with knowledge is one that welcomes all perspectives regardless of their differences, leaving knowledge thriving in a spirit of oneness that integrates and welcomes all possibilities. It is important not to confine the continuous growth of knowledge to a simple or complex interpretation, since knowledge stagnates the moment it is claimed, and the prospects for development and creativity become nearly extinct.

It is essential to move beyond concepts of tolerance[15] and visit a stage of knowing that addresses and recognizes our differences and thrives in a spirit that is welcoming and accepting. It is also crucial to recognize our own view of the world and our cultural understanding of it in order to engage with different perspectives with a receptive mind. Leonard Swidler speaks about our distant past and our secluded existence when he reminds us that groups of people would live their lives with little or no interaction with another one, and for the most part they were unaware of each other's way of life and simply lived within their cultural understanding of the world. Reflecting on our isolated past experiences Swidler states, "Everyone for the most part talked to their own cultural selves" (1). This unawareness of their cultural differences confined knowledge to single societies, each describing their understanding of the world through their given perspectives. Although we have come a long ways from living in small communities oblivious of each other's presence, the voluntary endorsement of a single method of knowing continues to segregate concepts of combined knowledge by promoting single ideologies that attempt to demote or discourage integrative thought.

Although Chuang-Tzu lived thousands of years ago in a small village in China, within the confines of his own cultural community, he was able to recognize the importance of thought diversity as well as the dangers of confining knowledge to single perspectives. He was aware that an understanding of the world is simply that, one understanding, and it does not make it the only valid source of knowledge. In his essay, "Death or Dialogue,"Swidler addresses the need for a new level of consciousness that recognizes our worldviews as limited and welcomes different perspectives. This new level of consciousness is similar to the one that Chuang-Tzu spoke about a couple of millenniums ago. Swidler expresses the need for awareness when he mentions that, "More and more of us, both individually and even at times institutionally, are gaining enough maturity to notice that there are entire other ways of integrating an understanding of the world than the way we and our forebears grew up in" (2). Awareness of multiple worldviews may give us a glimpse into the diversity of thought and human experiences across the globe, but it does not automatically create a medium that welcomes the exchange of ideas as a valuable source for knowledge growth; instead we are required to take additional steps that move us from tolerating our differences to accepting them, giving us all an opportunity to transcend from fixed mediums of knowing to flexible ones that thrive in a spirit of coexistence in the plurality of thought.

Advocating a flexible worldview that is open to others and recognizes its own limitations does not promote the disintegration of our traditions or cultural values; rather it functions through a system of openness that feeds on different sources of understanding, while shaping and strengthening our own views, allowing us to understand our own cultural connection with our traditions and views of the world more in depth through an interactive relationship with multiple perspectives. Stephen Rowe elaborates on this elastic approach to different perspectives when he points out, "This is not to say that I do not have (or am not serious about) my own particular understandings of the Good and the True, but rather that I am able to see that my understandings are limited because I—and the people, my community and my tradition, and everything about me! – am limited, *and* that I am capable of growth" (36). This recognition of our own limitations originates from a place of humility rather than overconfidence, from a place of trust rather than insecurity, and from a place that practices the inclusion of all ideas rather than the exclusion of unknown or disliked ones.

Fundamentalism thrives in narrowness. It questions our right to ask questions as it promotes a single ideology that compromises independent and unconventional thought in order to provide a version of knowledge that is enforced by the people who benefit from a formed perspective. As we become more and more aware of our differences and interconnectedness with one another across the globe, let us remind ourselves of the importance of open dialogue and open mediums that encourage wisdom and value knowledge growth through unlocked channels.

Our ideas are expressed through language. These ideas and views of the world, based on its cultural components, potentially become our accepted reality. It is through the recognition of our own biased perspectives that we may begin to understand the roots of our fixed vision. This understanding will develop a new foundation of thought that is more flexible and welcoming of new concepts not founded on our accepted methods of knowing.

Language and culture both play an influential role in our development of worldviews; our world takes shape through their relationship, and we begin to form our convictions based on inherited cultural principles. The language of science and the language of religion both benefit our world in innumerous ways. Science explores the universe through

[14] Chuang-Tzu was primarily referring to Confucius in this statement. He stated, "Confucius by the age of sixty had sixty times changed his mind; whenever he began by judging 'That's it' he ended by judging 'That's not' (Chuang-Tzu, 102). He reminded us through this concept that we must understand the limitations of our knowledge through a medium that acknowledges our own misunderstanding of understanding itself.

[15] Tolerance: capacity for enduring; allowable deviation (Webster's English Dictionary).

technical methods that display the creativity and imagination of the human race, while religion searches for meaning within the soul and the mystical essence of humanity. Let us thrive in the combination of our strengths and the recognition of our weaknesses in order to integrate human thought and maximize the possibilities for reaching unknown levels of knowledge through nameless mediums of discovery. This integration[16] does not imply the assimilation of knowledge into oneness, but rather it values the diversity of perspectives while it develops a new version of knowledge more elastic and less rigid. The choice to become prisoners of our own thoughts through our given worldviews is more of an option today than it has ever been before. The media and technological advances keep us informed of the latest events and the newest conflicts and discoveries taking place around the world. Information is readily available and it is no longer affordable to hide behind the blanket of ignorance.

Diverse pools of methods for engaging with the truth allow us to expand knowledge through a variety of perspectives. Huston Smith reminds us, "The world is not as science says it is; it is as science, philosophy, religion, the arts, and everyday speech say it is" (16). The integration of human thought, from all areas of creativity, with a search for meaning is essential in order to reach unconventional knowledge. In his book, *Exploring the Philosophy of Religion*, David Stewart mentions: "There is no such a thing as religion, only religions" (2). It is in the recognition of our own limited interpretations that the process of growth and discovery becomes unlimited through an understanding that our worldview is valid without a need to discredit or dismantle different ones.

As we continue to witness death and destruction by arrogant and narrow-minded practices that encourage the exclusion rather than inclusion of diversity of thought, we must consider the importance of flexible approaches to spirituality and human knowledge that recognize the limitations of human thought in order to engage in a process that thrives in the diversity of ideas, rather than in the homogenization of human thinking; a process that flourishes through the integration of multiple perspectives rather than uniformity of thought.

Let us coexist in a world that welcomes the autonomy of thought rather than the uniformity of it. Huston Smith reminds us of the importance of unrestricted and unconventional thinking when he speaks about being unlimited and relieved from all confines; these words resonate with those from Chuang-tzu, which express his concern with confining knowledge to limited perspectives. Universal standards do not promote diversity; instead they constrain the possibilities for growth (spiritual and intellectual) by enforcing the homogenization of notions to single perspectives.

Culture and language influence our views and perhaps shape our interaction with the world. Our vision of the real connects with our inherited cultural interpretation of the world as well as with the interconnected elements of language and human thought. We must become aware of this relationship among language, culture and the development of worldviews and fundamentalist thinking in order to practice a more flexible approach that not only tolerates different views and opinions, but also thrives in the exploration of other ways of thinking as a medium for expanding knowledge itself. When speaking about dandelions in his book, *The Anthropology of Language*, Ottenheimer states, "But in your culture dandelions are a kind of lettuce and can be put into salad and in my culture dandelions are a kind of weed and must be dug out of lawns and gardens and thrown away" (18). These two different maps of the world provided by our cultural connection with it define and mold our interpretation, regulating our perception, and outlining our understanding.

As our worldviews become influenced by our connection with language and culture, let us thrive in the recognition of an understanding that explores the world through its multiplicity of understandings. The assimilation of thought into a medium that claims absolute certainty does not take into account that dandelions are beautiful and delicious while ugly and unwanted at the same time. Let us respect our diverse perspectives while striving for visions that crave for truths and understandings of the world through diversity rather than a truth or a single definition and interpretation of it. Our worldviews carry the essence of our cultural understanding. Through their fundamental natures we may find a need to go beyond appreciating our own, wanting to explore a variety of them, so that we may become unrestricted and unconfined from concepts that claim the universality and uniformity of the human existence.

[16] Allen F Repko, in his book Interdisciplinary Research, speaks about integration and describes it as "An activity of critically evaluating and creatively combining ideas and knowledge to form a new whole or cognitive advancement" (16).

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Assessing the Utility of Genetic Data as a Monitoring Tool: A Case Study of Eastern Red Bats (Chiroptera: Vespertilionidae: *Lasiurus borealis*)

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Abstract

High levels of bat and bird mortalities have been documented at wind energy facilities; particularly hard-hit among bats are the tree-roosting migratory species Lasiurus cinereus, L. borealis*, and* Lasionycteris noctivagans*, which together compose approximately 79% of affected bats. Traditional mark-recapture monitoring methods have proven ineffective for these species due to the fact that these bats roost in small numbers, fly very high, and are difficult to catch. Thus it is hard to tell what effect these deaths at wind energy facilities are having on population numbers. Genetic data may provide a means of monitoring populations when demographic methods are unsuitable. We used coalescent-based simulations to determine the efficacy of genetic data as a monitoring tool for short-term changes in population size. Simulations were run under demographic models parameterized using mitochondrial DNA sequence data and microsatellite genotypes from the eastern red bat,* Lasiurus borealis*. DNA sequence data and microsatellite genotypes were simulated in both panmictic and structured populations using the computer program,* ms*, and analyzed using statistical software (*microstat*) to interpret the results.* ms *is a coalescent-based program that simulates genetic data under specific population models that are parameterized by initial population size, rate of decline, time since the onset of decline, mutation rate of the chosen molecular marker, and pattern of population structure. Initial estimates of these parameters were taken from previous studies on* L. borealis *(initial population size = 3.3 million individuals, rate of decline = –1% per year, mitochondrial mutation rate = 10-5 substitutions per gene per generation, no significant population structure). Simulations were allowed to run from 1 to 1000 generations following the initial onset of population decline to determine the timescales necessary to observe significant loss of genetic diversity under biologically realistic conditions. Loss of genetic diversity was assessed using summary statistics including the number of segregating sites, nucleotide diversity, and Tajima's* D *for DNA sequence data; analogous measures for microsatellite data included average heterozygosity, ϑP, and Cox's Δ. We found that direct measures of diversity (segregating sites and average heterozygosity) are much more informative for detecting population declines than neutrality tests such as Tajima's* D *and Cox's Δ. Between the two types of markers, microsatellites provided more power to detect population declines over shorter timescales (hundreds of generations for microsatellites as opposed to thousands of generations for sequence data). These results demonstrate that even quickly-evolving microsatellite data are unlikely to be useful for the type of year-to-year comparisons needed by monitoring agencies. We conclude that genetic data do not appear to be a useful metric for monitoring red bat population declines due to wind turbine-associated deaths. We emphasize that these conclusions are limited to the population parameters examined in this study, specifically those for eastern red bats facing population declines from wind turbines. Similar questions in other species (e.g., little brown bats facing local extirpation from white-nose syndrome) should be addressed using models appropriately parameterized for those systems.*

Introduction

One application of conservation genetics is the analysis of molecular data to determine the amount of genetic variation present in an endangered population (Hedrick & Miller 1992). High levels of genetic variation are typically associated with healthy populations, and many conservation efforts place great emphasis on maintaining or increasing genetic diversity in threatened populations (O'Brien et al. 1983). Conservation agencies are increasingly relying on genetic monitoring of threatened and endangered populations with the assumption that these data are very quickly responsive to population size changes while requiring relatively small sample sizes and minimally invasive sampling techniques (Luikart et al. 1998).

Molecular markers have proven to be useful for detecting population bottlenecks (Garza & Williamson 2001). Luikart et al. (1998) showed that a loss of alleles and decrease in variance at microsatelite loci can signal population bottlenecks with greater statistical power than more commonly used measures such as losses in heterozygosity. However, Luikart et al.'s (1998) analyses assumed an extremely severe bottleneck in a single panmictic population and evaluated only microsatellite data. Such power analyses may be limited in their applicability; ideally, the use of genetic data as a monitoring tool should be evaluated on a case-by-case basis (Hedrick & Miller 1992). Specifically, population parameters such as the initial population size, the degree to which populations are structured across the landscape, the level of gene flow connecting structured populations, and the rate of population decline must be considered in order to judge the utility of genetic monitoring (Hedrick 2001).

Polymorphism studies can be conducted using relatively small datasets (Nordborg 2001). The coalescent approach is useful in such studies due to the practicality of modeling the genealogy backward in time (Nordborg 2001; Hudson 2002). This approach traces lineages of alleles from a sample of the current population back to their most recent common ancestor, and imposes mutations upon these models (Harding 1998). Parameters such as effective population size, rates of population growth or decline, and patterns of population structure can be inferred from the shape of the resulting coalescent genealogies and the timing of genealogical coalescent events. Such coalescent methods prove particularly useful in power analyses for conservation genetic studies, since simulation software can be utilized to evaluate evolutionary histories specific to a species of interest. Here, we use such analyses to evaluate the utility of genetic monitoring techniques for a bat species threatened by wind turbines in North America.

Wind power is among the fastest growing sectors of the energy industry (Pasqualetti et al. 2004). However, the low cost and infinite renewability (U.S. Department of Energy 2005) of wind power are coupled with unexpected consequences (Morrison & Sinclair 2004; Kunz et al. 2007b). The presence of wind turbines is documented as having a negative effect on some bird and bat species. Bird fatalities have been estimated around an average of 2.19 fatalities per turbine per year in the U.S. for all species (Erickson et al. 2001), while more recent reports of bat fatalities range from 18.5 to 69.6 carcasses per turbine per year (reviewed in Kunz et al. 2007b).

Wind turbines predominantly affect tree roosting migratory bats, including eastern red bats (*Lasiurus borealis*), hoary bats (*L. cinereus*), and silver-haired bats (*Lasionycteris noctivagans*), the three of which represent 72.8% of the annual bat fatalities reported for wind energy facilities in the United States (Table 1; Kunz et al. 2007b). Most of these fatalities in North America appear to be concentrated during the fall migration of the affected species (Cryan 2003). Because these species roost in low densities in relatively unpredictable locations, the population-level impact of these fatalities is currently difficult to assess and traditional demographic approaches have limited utility with these three species of bats (Cryan 2003; Kunz et al. 2007a). Because of the inefficiency of traditional approaches, such as the mark-recapture method and the limitations of such methods in inferring the demographics of bat populations, the use of molecular markers to estimate population parameters and demographic trends may be the best option for monitoring migratory tree-roosting bat populations and assessing the long-term importance of fatalities at wind power facilities. Our analyses will allow us to determine which marker type, loci, and analyses provide the most power for detecting recent population declines, such as those hypothesized in eastern red bats, and to make educated recommendations as to which methods should be pursued in future monitoring of this species. The immediate research objectives of the project were to:

- Assess the utility of genetic data as a monitoring tool for tracking population declines.

- Model genetic data and examine changes caused by manipulating population size, mortality rates, time since onset of decline, type of molecular marker used, and degrees of population structure.

Methods

Modeling of Lasiurus borealis *populations*

We used coalescent-based simulations to determine the efficacy of genetic data as a monitoring tool for short-term changes in population size. Simulations were parameterized based on DNA sequence data from the mitochondrial D-loop of the eastern red bat, *Lasiurus borealis* (Vonhof & Russell, unpublished data). To evaluate the utility of DNA sequence data, we modelled a haploid locus of 408 bp with a mutation rate $\mu = 2 \times 10\text{-}5$ substitutions/gene/generation and a generation interval of 5 years. To evaluate microsatellite data, we modelled a dataset of 20 diploid loci with a mutation rate $\mu = 10\text{-}5$ substitutions/locus/generation and the same generation interval of 5 years. To mimic population decline in *L. borealis* due to genetically-random mortality from wind turbines, we used a demography in which a single population initially sized at 3.3 x 106 individuals decreases by 1% per year with samples (n = 150) taken after 0, 5, 10, 50, 100, 500, and 1000 years (Fig. 2A). To examine the impact of population structure on the loss of genetic diversity in a declining population, we also considered a model in which a single population initially sized at 3.3 x 106 individuals first splits into two subpopulations of 1.65 x 106 connected by gene flow at a rate m = 0.01% Each subpopulation then decreases in size by 1% per year with samples (n = 150) taken after 0, 5, 10, 50, 100, 500, and 1000 years (Fig. 2B). Coalescent datasets (10,000 replicate datasets per demographic scenario) were simulated according to these demographic models using the software ms (Hudson 2002). For microsatellite data, variation simulated in ms was converted to microsatellite genotypes using the software microsat (M. Cox, unpublished code). Genetic variation was summarized as the number of segregating sites S, nucleotide diversity π, and Tajima's (1989) *D* using the software *ms_stats* (Hudson 2002) for DNA sequence data. For microsatellite data, genetic variation was summarized as average heterozygosity, ϑP, and Cox's Δ using the software *microstat* (M. Cox, unpublished code).

Results

Effect of marker type

We considered two types of molecular markers commonly used in studies of conservation genetics: mitochondrial DNA sequence data and autosomal microsatellite genotype data. These marker types vary in both mode of inheritance and in mutation rate, with mitochondrial DNA being maternally inherited and having a slower mutation rate than the biparentally inherited microsatellite loci. Our results indicate that microsatellite data are more effective than mitochondrial DNA sequence data for detecting population declines over relatively short time scales (Fig. 3-5).

Even though microsatellites appear to be markedly more responsive to demographic population declines, even these quickly evolving loci require hundreds of generations to manifest significant losses of genetic diversity (Fig. 3A). For example, average heterozygosity values remain relatively constant for at least 500 generations following the onset of population decline before declining significantly between 500 and 1000 generations. For mitochondrial DNA sequence data, we start to see a significant decline in simple diversity statistics (number of segregating sites, Fig. 3B) by 1000 generations following the onset of population decline.

Effect of summary statistic

We used multiple summaries of the data to evaluate which statistic(s) were most responsive to simulated population declines. These summary statistics fell into two general classes: direct measures of genetic diversity and neutrality tests. The former includes statistics such as average heterozygosity (Fig. 3A) and θP (Fig. 5A) for microsatellites and the number of segregating sites (Fig. 3B) and nucleotide diversity (Fig. 5B) for DNA sequence data, while the latter class includes Cox's Δ (Fig. 4A) for microsatellites and Tajima's *D* (Fig. 4B) for DNA sequence data.

Simple measures of genetic diversity such as average heterozygosity or segregating sites emerge as the most useful metrics for assessing population declines (Fig. 3). Although the simulated populations retained high levels of variation for long periods of time following the onset of population decline (on the order of 102 generations), average heterozygosity or segregating sites proved quite responsive to population losses totaling at least 60% of the initial population size. Statistics such as θP and nucleotide diversity (Fig. 5) represent the same direct measures of genetic diversity, but are scaled by the mutation rate; as such, they show the same overall pattern as heterozygosity and segregating sites.

Neutrality tests such as Cox's Δ and Tajima's *D* appear to be ineffective for detecting or monitoring population declines over the time scales considered in this study (Fig. 4). These test statistics are expected to approach 0 for neutral loci in a very large population, such as was simulated in our constant population size scenario (i.e., time since the onset of population decline = 0). This expected pattern was observed in our simulations, with variation around the expected average test statistic value of 0. With increasing time since the onset of population decline, we observed little change in the neutrality test statistics except for a notable but statistically insignificant increase at 1000 generations.

Effect of population structure

Eastern red bats show no evidence of genetic population structure throughout their range (Vonhof & Russell, unpublished data). Although not true for eastern red bats, population structure is a common phenomenon among species of conservation concern; therefore, we evaluated the impact of a simple island model of structured populations on the rate of loss of genetic diversity (Fig. 3). These structured populations maintained comparable levels of genetic diversity for similar periods of time as unstructured panmictic populations. When population declines persisted for >500 generations, however, unstructured populations lost diversity at a significantly higher rate than structured populations.

Discussion

Previous research has supported genetic data as an effective means for monitoring population declines (Hedrick & Miller 1992; Luikart et al. 1998; Garza & Williamson 2001). However, these studies were limited in a number of ways, particularly in the demographic models and genetic markers that were evaluated. For large populations experiencing a relatively low rate of population decline such as the eastern red bat, our results indicate that genetic monitoring is not likely to be effective for time spans of <500 generations.

We found that direct measures of genetic diversity (segregating sites and average heterozygosity) are much more informative for detecting population declines than neutrality tests such as Tajima's *D* and Cox's Δ. Direct measures of diversity remained high for hundreds of generations, but they proved responsive to population losses above 60% of the initial population size. Tajima's *D* and Cox's Δ varied around an average of zero with statistically insignificant changes even after 1000 generations. Neutrality tests are often used in demographic studies as indications of population growth; the overabundance of singleton mutations associated with population growth tends to cause significantly negative values for these analyses (Russell et al. 2005). Our analyses suggest that the same test statistics are not useful for detecting population declines. One caveat to this conclusion stems from the particular neutrality tests that were examined in our study. Tajima's *D* has previously been shown to be lacking in statistical power for detecting population growth, whereas statistics such as Fu's (1997) *Fs* proved powerful enough to detect sudden population growth (Ramos-Onsins & Rozas 2006). Such differences leave open the possibility that our analyses with Tajima's *D* (and its microsatellite analog, Cox's Δ) were ineffective because we examined an inappropriate neutrality test. Future analyses should evaluate other neutrality tests to determine the true utility of neutrality tests as a measure of population declines.

Between the two types of markers, microsatellites provided more power to detect population declines over shorter timescales (hundreds of generations for microsatellites as opposed to thousands of generations for sequence data). Microsatellite data are highly variable and are commonly used for the assessment of short-term trends in population sizes (Hedrick 2001). Our study supports the conclusion that haploid DNA sequence data possess significantly less power for detecting population declines than microsatellite data; however, neither marker type appears to be useful for monitoring population declines on the yearly timescales typically required by monitoring agencies.

If the observed and projected growth of wind energy facilities are coupled with the estimates of bat fatalities at wind turbine facilities, it is expected that population decline in the eastern red bat is an immediate problem for conservationists (Pasqualetti et al. 2004; Kunz et al. 2007b). Given that our method is only significant on the order of 102 generations, these methods of genetic evaluation do not prove useful. We conclude that genetic data do not appear to be a valid metric for monitoring red bat population declines due to wind turbine-associated deaths.

For population declines persisting longer than 500 generations, structured population retained diversity to a greater extent than unstructured populations. Although this may seem counter-intuitive, a review of genetic analyses in plant studies has shown that small structured populations tend to maintain higher levels of diversity in total than large panmictic populations (Ellstrand & Elam 1993). As the total population size decreases, subpopulations in a structured population may individually function as refugia for different samples of alleles, allowing a larger amount of genetic information to be preserved in total than in a single unstructured population. We emphasize that the simple island model of population structure evaluated in our study is probably not realistic for most species; unequal subpopulation sizes or asymmetric migration rates may alter these results.

We further emphasize that these conclusions are limited to the population parameters examined in this study, specifically those for eastern red bats facing population declines from wind turbines. The specific evolutionary history and population parameters of a species provide invaluable information when assessing the utility of a proposed conservation genetic study (Hedrick 2001). Similar questions in other species (e.g., little brown bats facing local extirpation from white-nose syndrome) should be addressed using models appropriately parameterized for those systems.

Acknowledgements

We thank Dr. Murray Cox, Massey University, for invaluable advice and access to unpublished code used in simulating and analyzing microsatellite data. Dr. Maarten Vonhof, Western Michigan University, provided access to unpublished DNA sequence data from *Lasiurus borealis*.

Appendix

Simulation code for single-population model
./ms 150 500000 -t 13.068 -eN 0 1
./ms 150 500000 -t 13.068 -eN 0 0.95099005 -eG 0 -33166.108317 -eN 1.51515E-06 1
./ms 150 500000 -t 13.068 -eN 0 0.904382075 -eG 0 -33166.108317 -eN 3.0303E-06 1
./ms 150 500000 -t 13.068 -eN 0 0.605006067 -eG 0 -33166.108317 -eN 1.51515E-05 1
./ms 150 500000 -t 13.068 -eN 0 0.366032341 -eG 0 -33166.108317 -eN 3.0303E-05 1
./ms 150 500000 -t 13.068 -eN 0 0.006570483 -eG 0 -33166.108317 -eN 0.000151515 1
./ms 150 500000 -t 13.068 -eN 0 4.31712E-05 -eG 0 -33166.108317 -eN 0.00030303 1

Simulation code for structured-population model
./ms 150 500000 -t 13.068 -I 2 75 75 330 -eN 0 1
./ms 150 500000 -t 13.068 -I 2 75 75 313.8267165 -eN 0 0.95099005 -eG 0 -33166.108317 -eN 1.51515E-06 1
./ms 150 500000 -t 13.068 -I 2 75 75 298.4460848 -eN 0 0.904382075 -eG 0 -33166.108317 -eN 3.0303E-06 1
./ms 150 500000 -t 13.068 -I 2 75 75 199.6520022 -eN 0 0.605006067 -eG 0 -33166.108317 -eN 1.51515E-05 1
./ms 150 500000 -t 13.068 -I 2 75 75 120.7906726 -eN 0 0.366032341 -eG 0 -33166.108317 -eN 3.0303E-05 1
./ms 150 500000 -t 13.068 -I 2 75 75 2.168259404 -eN 0 0.006570483 -eG 0 -33166.108317 -eN 0.000151515 1
./ms 150 500000 -t 13.068 -I 2 75 75 0.014246512 -eN 0 4.31712E-05 -eG 0 -33166.108317 -eN 0.00030303 1

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Table 1. Species composition of annual bat fatalities at wind energy facilities. Table reproduced from Kunz 2007b.

Species	Pacific Northwest	Rocky Mountains	South-Central	Upper Midwest	East	Total
Hoary bat	153 (49.8%)	155 (89.1%)	10 (9.0%)	309 (28.9%)	396 (28.9%)	1023 (41.1%)
Eastern red bat	-	-	3 (2.7%)	106 (20.3%)	471 (34.4%)	580 (23.3%)
Western red bat	4 (1.3%)	-	-	-	-	4 (0.2%)
Seminole bat	-	-	-	-	1 (0.1%)	1 (0.1%)
Silver-haired bat	94 (30.6%)	7 (4.1%)	1 (0.9%)	35 (6.7%)	72 (5.2%)	209 (8.4%)
Eastern pipistrelle	-	-	1 (0.9%)	7 (1.3%)	253 (18.5%)	261 (10.5%)
Little brown myotis	2 (0.7%)	6 (3.5%)	-	17 (3.3%)	120 (8.7%)	145 (5.8%)
Northern long-eared myotis	-	-	-	-	8 (0.6%)	8 (0.4%)
Big brown bat	2 (0.7%)	2 (1.1%)	1 (0.9%)	19 (3.6%)	35 (2.5%)	59 (2.4%)
Brazilian free-tailed bat	48 (15.6%)	-	95 (85.5%)	-	-	143 (5.7%)
Unknown	4 (1.3%)	4 (2.2%)	-	30 (5.7%)	15 (1.1%)	53 (2.1%)
Total	307	174	111	523	1371	2486

Figure 1. Bat carcass specimens collected at wind turbine sites. Species names are given in text: BigBr = big brown bat (Eptesicus fuscus), Myotis = Myotis spp., Hoary = hoary bat (Lasiurus cinereus), Red = red bat (L. borealis), and SilvH = silver-haired bat (Lasionycteris noctivagans). Figure reprinted from Howe et al. (2002).

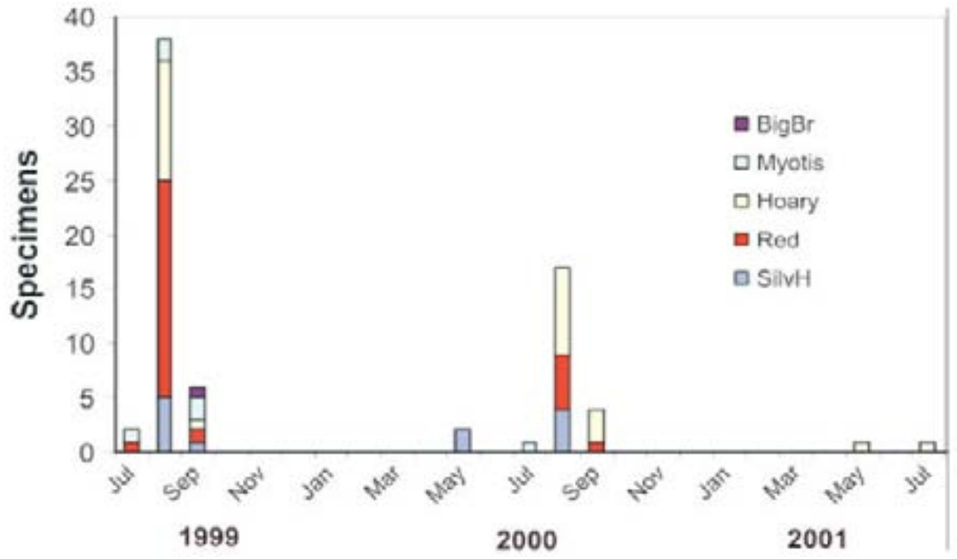

Figure 2. Demographic models of population decline. **A.** Single panmictic population. **B.** Structured population.

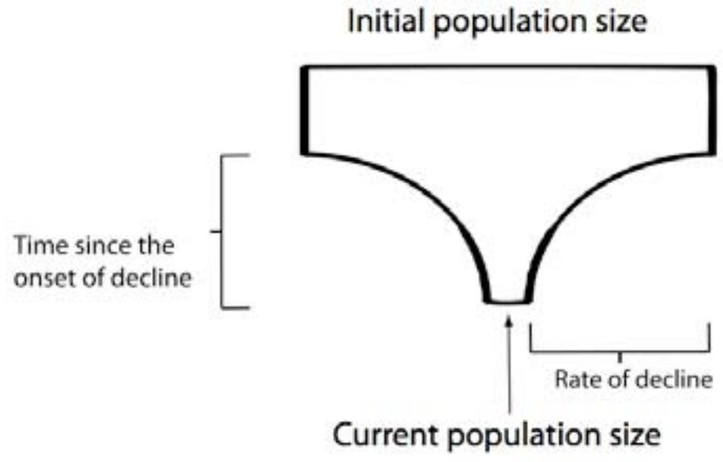

Figure 2A.

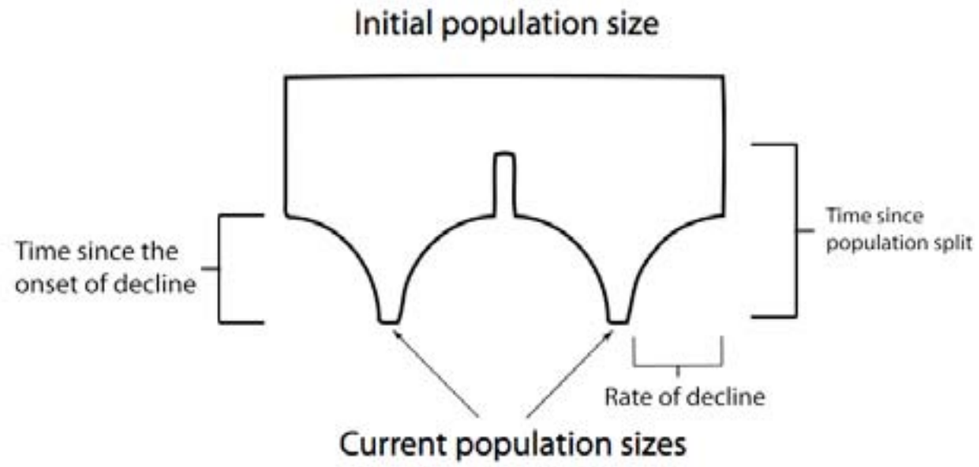

Figure 2B.

Figure 3. Decline in genetic diversity with increasing time since the onset of population size reduction. Data were simulated under demographies with (black) and without (blue) population structure. Average diversity statistics are shown with 95% CI (dashed lines). **A.** Diversity measured as average heterozygosity for 20 autosomal microsatellite loci. **B.** Diversity measured as the number of segregating sites in haploid (mitochondrial) DNA sequence data.

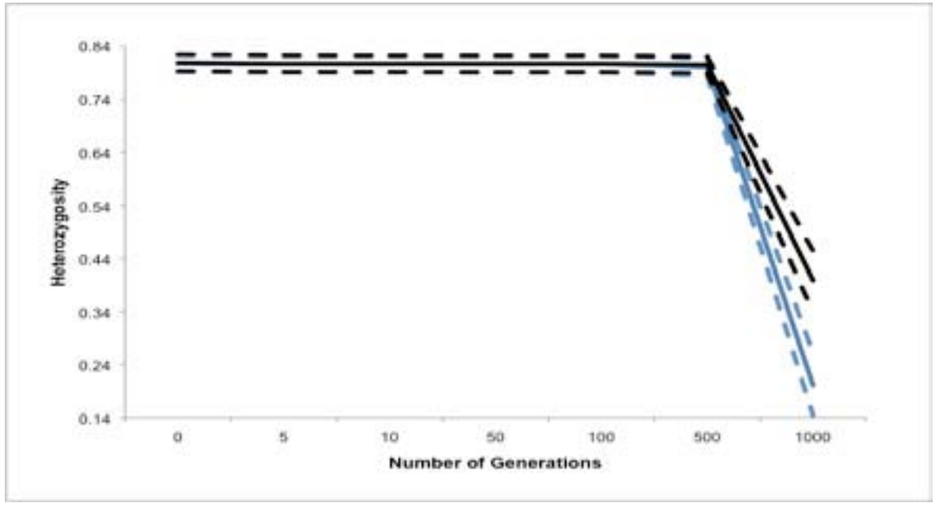

Figure 3A.

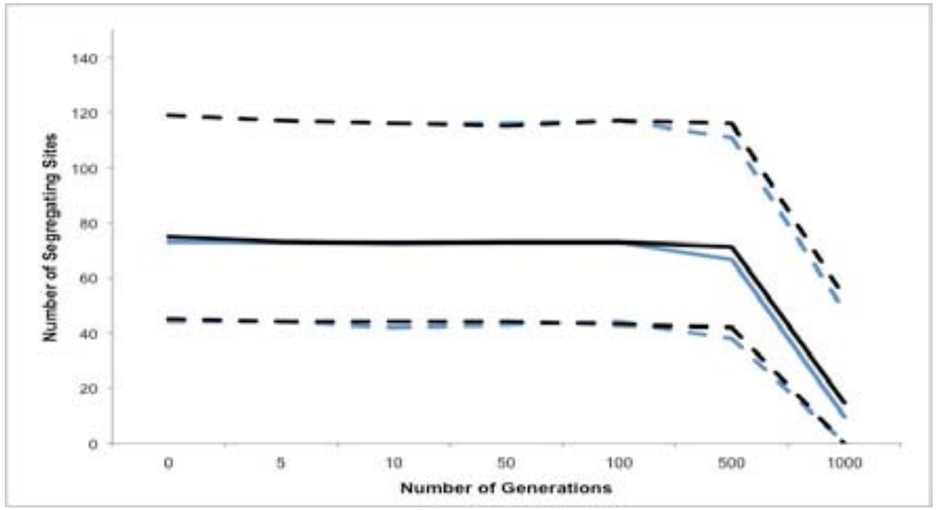

Figure 3B.

Figure 4. Change in neutrality tests with increasing time since the onset of population size reduction. Data were simulated under demographies with (black) and without (blue) population structure. Average test results are shown with 95% CI (dashed lines). **A.** Neutrality measured as Cox's Δ for 20 autosomal microsatellite loci. **B.** Neutrality measured as Tajima's D for haploid (mitochondrial) DNA sequence data.

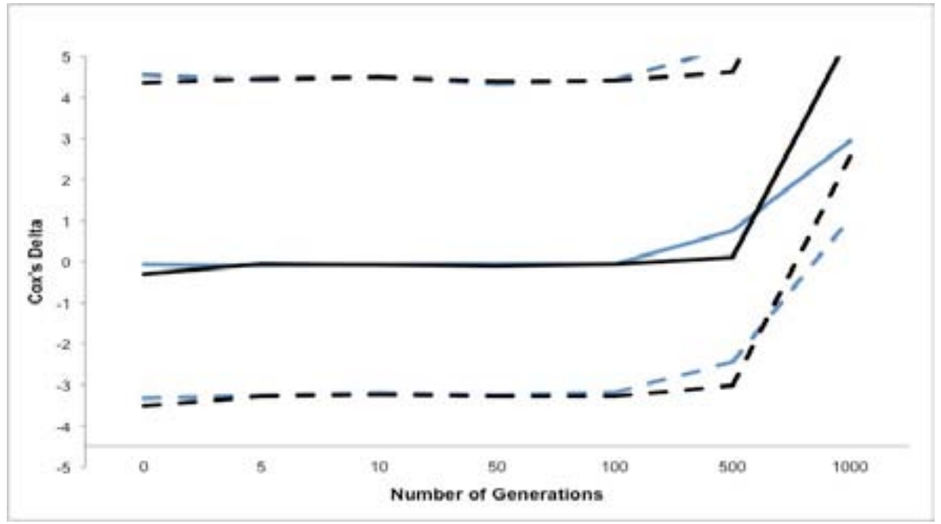

Figure 4A.

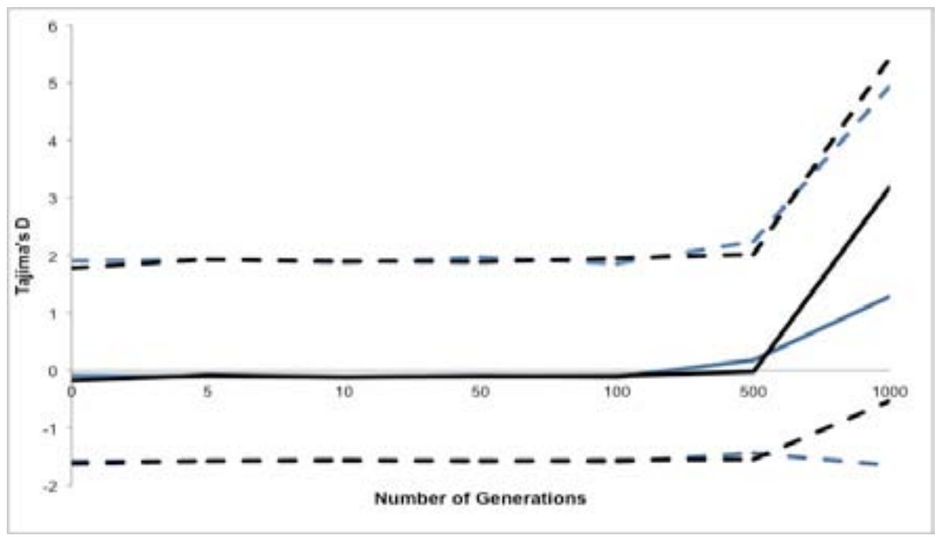

Figure 4B.

Figure 5. Decline in genetic diversity with increasing time since the onset of population size reduction. Data were simulated under demographies with (black) and without (blue) population structure. Average diversity statistics are shown with 95% CI (dashed lines). **A.** Diversity measured as average θP for 20 autosomal microsatellite loci. **B.** Diversity measured as average π for haploid (mitochondrial) DNA sequence data.

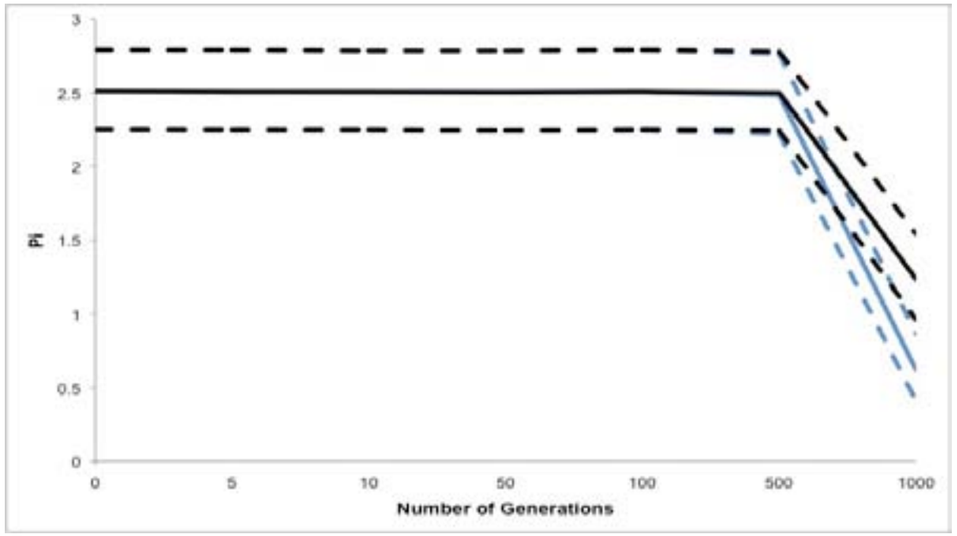

Figure 5A.

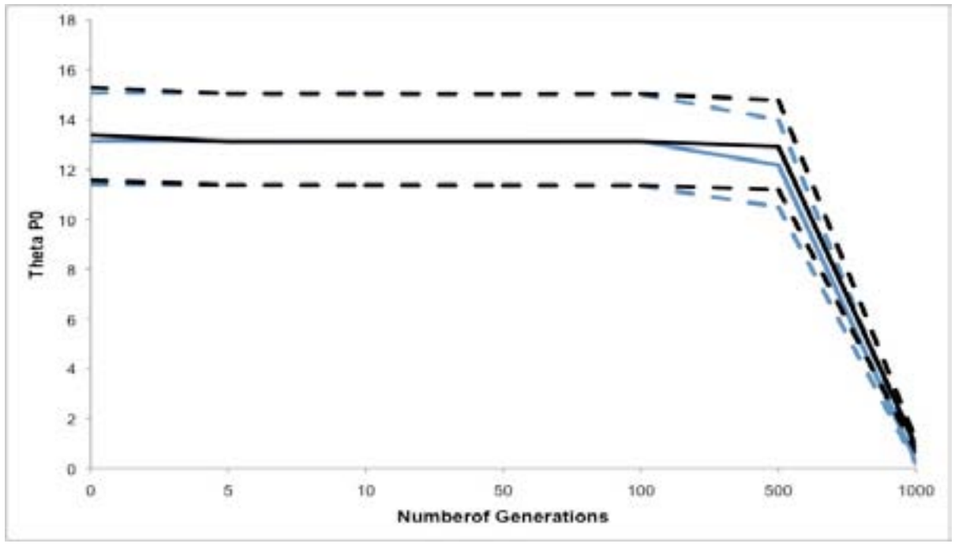

Figure 5B.

Quaternary Geology, Toco, Trinidad, West Indies

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Introduction

The island of Trinidad sits in the boundary zone between the Caribbean and South American plates. According to Global Positioning System data (GPS), the Caribbean Plate is currently moving N86°E ± 2° at ~20mm/yr to the east in relation to the South American plate (Figure 1) (Weber et al., 2001). This motion is accommodated along the trace of the east-to-west striking El Pilar fault zone in eastern Venezuela, which has an average right lateral slip of 1.3 m, as the Caribbean plate moves east in relation to South American plate (Baumbach et al., 2004). In contrast to the single active El Pilar fault trace in Venezuela, several widely spaced, east-west to northeast striking strike-slip traces have been mapped in Trinidad (Soto et al. 2004; Robertson and Burke, 1989), but GPS data show that most transform motion is currently concentrated on the Central Range Fault (Weber et al. 2009). Flinch et al. (1999) demonstrated that the Gulf of Paria pull-apart basin connects the El Pilar fault system and the Central Range fault of Trinidad at a major right step-over. This pull-apart basin is critically related to the geomorphic features seen on the island of Trinidad, which suggests that the island is sinking to the west into the Gulf of Paria pull-apart basin. Weber (2005) explains these features in detail, and many are illustrated in Figure 1. The coastline becomes highly scalloped, drowned and submergent in western Trinidad along the northern coast, with many sunken islands trailing off from the Northern Range into the Gulf of Paria towards Venezuela. Some other features that illustrate westward sinking are subaerial coastal terraces and alluvial fan systems around Northern Range. The subaerial coastal terraces are mainly present along the northeastern coast, with a few outcrops present as far west as Blanchisseuse along the northern coast, but not beyond. The alluvial fans along the southern margin of the Northern Range may also reflect westward sinking into the pull-part basin. They change systematically in morphology from east to west. In the east they are raised and cut by streams, and in the west they are buried. This sinking probably reflects vertical tectonic motions acting over the duration of the pull-apart, approximately the past few million years (Weber, 2005). These features and the idea of long-term subsidence lead Weber (2005) to propose a hypothesis that we test here: northwestern Trinidad may be sinking into the pull-apart basin via a see-saw tectonic mechanism, causing the entire island to tip down to the west and up to the east. We conducted a detailed investigation of the coastal terrace deposits along the northeastern coast. An understanding of the processes leading to the formation of coastal deposits could provide a clearer picture of tectonism affecting the region. Measuring vertical active tectonic motion directly is a challenge, but defining a long-term rate of uplift for the northeastern coastal terraces may be estimated by dating the terrace sediments and then comparing their age and elevation to a reliable global sea level curve (Chapelle et al. 1996).

Previous research on the subaerially exposed coastal terraces found along the northeastern coast of the island was done primarily by Barr (1963). Barr described the unit as coarse quartz sand and quartzose gravels with boulder beds containing rounded cobbles up to 15 in (38 cm) across of pure vein-quartz, and less commonly, quartzite. The units he included in his terrace deposits ranged in thickness from a few inches to about 20 ft (6 m) and lie approximately 30 to 55 ft (9 to 17 m) above sea level. These descriptions compare well with what we saw in the field. Barr also stated that the terraces are likely the result of sub-Recent positive (or upward) movements, a claim that correlates with the hypothesis we tested in our study. Barr also tried to correlate these terraces to what he referred to as the Lower Caroni terraces, which lie along the southern margin of the Northern Range. Based on field observations (Ritter and Weber, 2007), it is known that these range-front deposits are actually alluvial fan deposits. Barr also inferred a second older set of morphometric terraces that he claimed lie about 150 ft (45 m) above sea level, but he added that this higher terrace set is sparse and difficult to see because of the thick cover of tropical vegetation.

Barr's (1963) coastal terrace mapping was part of his more comprehensive geologic

map of the Toco district and was the first ever made. On it, the terraces are labeled simply as "Quaternary terraces." This unit has been shown on all geologic maps of Trinidad/Toco made since Barr's work, including the Kugler (1961) map, the Saunders (1997) map, and the Latinum (2002) map, which is the most recent geologic map created during a hydrogeological assessment of Trinidad by Earthwater Technology Trinidad and Tobago, LLC. Though these newer maps did not change the location or extent of Barr's mapped terrace deposits, they changed their name. For example, Kugler (1961) correlated the age of the terrace deposit with other Quaternary deposits found in the southwestern corner of the island and grouped the two units together, calling them the Cedros Formation after the young sediments exposed on the Cedros Peninsula (Fig. 1). This is a bit of a stretch because the units are not genetically related. More recent mapping of the terraces, such as that on the Latinum (2002) map, has simply labeled the units as Quaternary Deposits or Quaternary Terrace Deposits, which may be a more descriptive way to show them but is also somewhat vague.

The Quaternary age of these terraces has been inferred indirectly since Barr's (1963) work and is based on the sediment character and stratigraphic relationships. These unconsolidated terrace deposits sit on top of Northern Range metamorphic bedrock, therefore they are the youngest unit mapped in this area. Determining absolute ages for the terrace deposits would enable us to know sea level when they were forming by plotting their age on a reliable global sea level curve (Chapelle et al. 1996). The greatest challenge in dating these deposits is that they lack fossils. We overcame this limitation using Optically Stimulated Luminescence (OSL) dating. The deposits are made almost entirely of quartz and feldspar, and they are estimated to be Quaternary in age. Both characteristics made this technique seem promising (Lian, 2007). Samples which give the most reliable OSL ages typically come from arid environments, as this technique was initially developed to date eolian deposits. However, OSL dating has been used in other climates as well. Choi et al. (2003a) had some success dating terrace deposits along the coast of Korea, but adjustments to the test-dose cut-heat temperature had to be made. Even after making this adjustment, there was still one unit that gave a stratigraphically inconsistent age, but in a later publication Choi et al. (2003b) were able to resolve this inconsistency. This gave us hope that even though Trinidad's tropical climate may be working against us by weathering the feldspar, this technique still had potential.

Methods

Base Mapping Methods

Before going out in the field, we created a series of field base maps referenced to the WGS84 datum and with UTM grid lines in meters using ArcGIS®. We started by using 1:10,000 detailed preliminary topographic maps scanned from paper copies that were obtained from the Trinidad and Tobago Lands and Surveys Division. We used the topographic map layer as an overlay to georectify scans of the Barr (1963) map and the Latinum map (2002). After visiting the field in May 2009, we used ArcGIS® to create point files of the studied terrace locations. By overlaying these points on a digital elevation model (DEM) of the island (Latinum, 2002), we were able to determine the height of the terraces we studied in meters above sea level. Aerial photographs (1994) of the Blanchisseuse region were also obtained from the Trinidad and Tobago Lands and Survey Division, scanned, and georeferenced.

Field Methods

From May 26th through June 9th of 2009, Morell and Weber used hand-held GPS units and preliminary topographic and geologic maps to examine the coastal terrace deposits in the Toco region. Field data were collected by measuring, describing, and photographing stratigraphic sections of the terrace deposits. Information collected at each site included the deposits' thickness, sedimentary structures, and sediments' grain size, shape, arrangement, texture, color, etc. The raw field data were then used to create and correlate stratigraphic columns with Adobe Illustrator®. Carefully oriented photographs were also taken. In addition, hand samples of the terrace sediments were also collected, described, labeled, and recorded to be used for later sedimentological analyses and OSL dating.

Sedimentology Methods

We conducted grain size analyses on a representative suite of samples taken from the terrace deposits by sieving to quantify grain size distributions, using the method explained in detail in Folk (1974). This method involved weighing the original samples and the samples left on each sieving screen, and then making tables with the weight percent from each sieve screen and the cumulative weight percent. A histogram and a cumulative percent curve were then created using these percent values. The mode was determined from the histogram, and the values of ϕ (ϕ= -log2d, with d being the diameter of the grain in micrometers) were found using data from the cumulative weight percent curve. We then calculated the mean, median, standard deviation, skewness, and kurtosis following Bogg's (2006) approach. An explanation of the statistical parameters used in the sedimentological analyses is shown in Table 1.

Table 1.

Terms	How defined
Mean	Arithmetic average
Median	The midpoint of grain-size distribution
Mode	Most frequently occurring particle size
Standard deviation	Mathematical expression of sediment sorting, in this case the amount of deviation from the mean sediment size
Skewness	The degree of asymmetry in the sediment size frequency curve or a relative measure of the most abundant particle size ranges in a sample of sediments
Kurtosis	The degree of peakedness of the frequency curve

Hand samples were also studied qualitatively using a binocular microscope, and the gross sphericity, roundness, mineralogy, and surface textures were noted.

To quantify grain shape, a caliper was used to measure the dimensions of 50 random pebbles collected at field location T-09-38 (see Figure 2). This location was chosen because it was easily accessible; 50 pebbles were chosen because this is the smallest number required for a sample to be considered random. The longest, intermediate, and shortest dimensions of each pebble were measured, and these data were plotted onto a graph in the form given by Zingg (1935), which permits one to plot 3-dimensional shapes in 2-dimensions.

X Ray Diffraction Methods

After it became obvious that there was a small but significant fraction of fines from the sieved samples, we became interested in finding the composition of this fine material, which might enable us to discriminate the fines as primary (clastic) or secondary (e.g., pedogenic or diagenetic cement) material. This composition was found by taking samples from sieve 325 or size 4.50ϕ, which is the smallest screen used, from each of the sieved samples and analyzing them using X Ray Diffraction. This was done at Hope College using a Rigaku Miniflex with a copper (Cu Kα1; λ = 1.54059 A) source tube, that was run at 30 kV, at a scanning speed of 2° per minute, and using a range of 2θ between 10° and 80°. The program MDI Jade 7® was used to search internal databases and to determine the mineralogy of the sample fines. Jade 7® uses Bragg's Law to determine mineralogy. The Bragg equation is:

$\theta = \sin^{-1}(\lambda / 2\, n/dhkl)$

where θ is ½ the measured angle of X-ray reflection, λ is the X-ray wavelength (constant for each given source, in our case CuK α 1), n is an integer(constant), and dhkl is the plane (e.g., Azároff, 1958).

Dating Methods

Five quartz-rich coastal terrace deposits (samples 07-MT-6, 07-MT-7a, 07-MT-7b, 07-MT-8a, 07-MT-8b; Figure 2) were dated using Optically Stimulated Luminescence (OSL) at The Luminescence Dating Research Laboratory in the Department of Geological Sciences at the University of Illinois at Chicago. OSL measures the last time a quartz grain was exposed to sunlight. When a grain is exposed to sunlight it becomes "bleached," which means that its latent signal, or stored ionized energy which is gained from radiation emitted from radioisotopes within the mineral grain, from its immediate surroundings, and from cosmic rays (Lian, 2007), is set to zero, or lost. When a grain becomes buried, the latent signal begins to build up again through its exposure to a weak flux of ionizing radiation provided by Thorium, Uranium, and Potassium-40 predominantly from radiometric decay of unstable isotopes in feldspar in the surrounding sediments. This energy stimulates electrons, which get caught in electron traps, or impurities or structural defects within the crystal lattice. The OSL age of the sample is determined by dividing the equivalent dose by the dose-rate. The equivalent dose is the laboratory dose of nuclear radiation needed to induce luminescence equal to that acquired subsequent to the most recent bleaching event. The dose-rate is the rate at which the energy is absorbed from the flux of nuclear radiation (Aitkens, 1998).

Results

Mapping Results

Figure 4a shows the locations of all the terrace deposits studied in the field in 2009. Figure 4b shows terrace elevations calculated from the DEM for each field location; these fall between 7.12 - 26.71 m above sea level. Notice that three of the four locations near Blanchisseuse (shaded in Fig. 4b) have terrace elevations that are almost 10 m higher than any of the terraces near Toco. Figure 4c is the graphic representation of the UTM easting vs. terrace elevation. The Blanchisseuse terraces are higher than those near Toco but also show a much greater elevation scatter.

Field Results

The majority of the terraces, both near Toco and in Blanchisseuse, fell near the edges of, or within, the Quaternary terrace units as mapped by Barr (1963). Nine stratigraphic columns, three in Blanchisseuse and six in Toco, were created from our field measurements and organized based on their locations (Figures 5, 7). Sub-units are correlated based on texture, composition and thickness, and the correlated column sections illustrate how the terrace deposits change in thickness and composition with horizontal distance. In addition, figures 6 and 8 are photographs of one terrace deposit from each of the stratigraphic column sets.

Sedimentology Results

Tables 2 and 3 summarize the sieving data. The mean and median put the gravel samples in the very coarse sand to granule size grains. Two of the samples, 05-Toco-1 and T-09-37, are bimodal. The sample 05-Toco-1 has two very coarse modes, whereas T-09-37 has one mode that is very coarse sand and another that is very fine sand. Taking the sieving values at face value, the samples appeared to be poorly sorted (Table 2). This is not characteristic of beach sediments. The histograms (Appendix C) indicate that two of the five samples were strongly bimodal. We hypothesize that the fines in these samples could be secondary (e.g., cement between primary grains, pedogenic material transported downward in pore spaces between primary grains, and/or spallations of fines from intense tropical physical weathering of primary grains) and not primary (e.g., matrix). This idea still needs to be tested and fleshed out. Table 3 presents the adjusted sieving results with the fine tails revised (also see XRD Results). This improves the sample sorting and brings them more in line with what is expected for typical beach sediments. Samples should be epoxied, dyed, and studied in thin-section to test and better flesh out this approach.

The Zingg diagram made from the caliper calculations illustrates that 52% of the pebbles are prolate, 20% are bladed, 4% are oblate, and 24% are equant. The samples also seem to cluster to the right side of the diagram, illustrating that they are not flat, which is a characteristic that we saw in the field and is typical of the modern beaches in the area.

XRD Results

The XRD results made it clear that the fines in all five samples studied are made primarily of quartz. These graphs show the XRD curves for two samples with overlays of the quartz curve.

OSL Dating Results

Of the five samples sent in to be dated, only three had calculable ages, 07-MT-6, 07-MT-8, and 07-MT-7. These ages were found to be 40,090±3000, 74,020±5650, and 137,500±10,880 years respectively. Ages for the other two samples were considered incalculable because the equivalent dose was too low. When the equivalent dose approaches zero, it makes the age impossible to define. This also occurs when the equivalent dose approaches the top of the dose response curve, which is exponential in nature. The wide range in the ages obtained could be present because of the tropical weathering that the sediments have experienced. The age difference is caused primarily by the variation in the dose rate. The dose rate that created the oldest age is unusually low and was caused by an extremely low level of Potassium in the

sample. Weathering or leaching of feldspar from the unit most likely caused this low level of Potassium. This was the main compositional difference in the 40,000 year old sample and the 137,000 year old sample, and it is also the reason that we consider the oldest age to be the least reliable/representative.

Discussion

We began our study testing the hypothesis put forth by Weber (2005), which states that the terraces in eastern Trinidad may have been tectonically lifted out of the sea as the western side of the island sunk into the Bay of Paria pull-apart. A second hypothesis, which was also developed as we began gathering data in the field, stated that the Toco terraces have remained horizontally constant in relation to changing sea level and that we do not see them in the western part of the island because they have sunk into the Gulf of Paria. Comparing our field maps to Barr's map (Figure 2), we believe that the distribution of these terraces have been reliably mapped. Our XRD analyses show that the fine material in the samples is quartz. The texture of the hand samples leads us to call the fines a quartz silt. This silt could have filled in around the larger quartz sand and gravel grains through the extensive weathering, which could have broken down the larger grains and transported the tiny fragments away from their parent grains. This observed textural relationship could thus be interpreted as the weathering of a gravelly beach sediment. Weathering has also probably influenced the OSL age data we obtained. The OSL ages have such a large spread because of the lack of feldspar in some of the samples; the feldspar has most likely been removed by weathering processes. The oldest OSL age is considered unreliable because it is greatly exaggerated by the lack of Potassium. Neither of the two remaining ages fall near the last global sea level high stand cut, ~120 ka, so sea level was probably never high enough to form these terraces at the elevations where we currently find them. So, provisionally, we accept the see-saw hypothesis as reasonable. The terraces at Blanchisseuse pose an interesting challenge for future work. They are clearly at higher elevations than the Toco terraces. Are they older? Are they the same age (if so, they would falsify the see-saw hypothesis)? It is clear that we need more reliable ages for both the Toco terraces as well as the Blanchisseuse terraces to answer the questions that remain.

Acknowledgements:
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Professor Jon Peterson, Hope College

Figure 1. The Caribbean plate moves approximately east at ~20 mm/yr in relation to the South American plate. Trinidad's geology reflects this by islands and gravels that are sinking into the active Gulf of Paria pull-apart basin to the west and unsunken and exposed gravels and terraces to the east. We studied terrace exposures near the village of Toco in the northeast corner of the island and near the village of Blanchisseuse along the north coast.

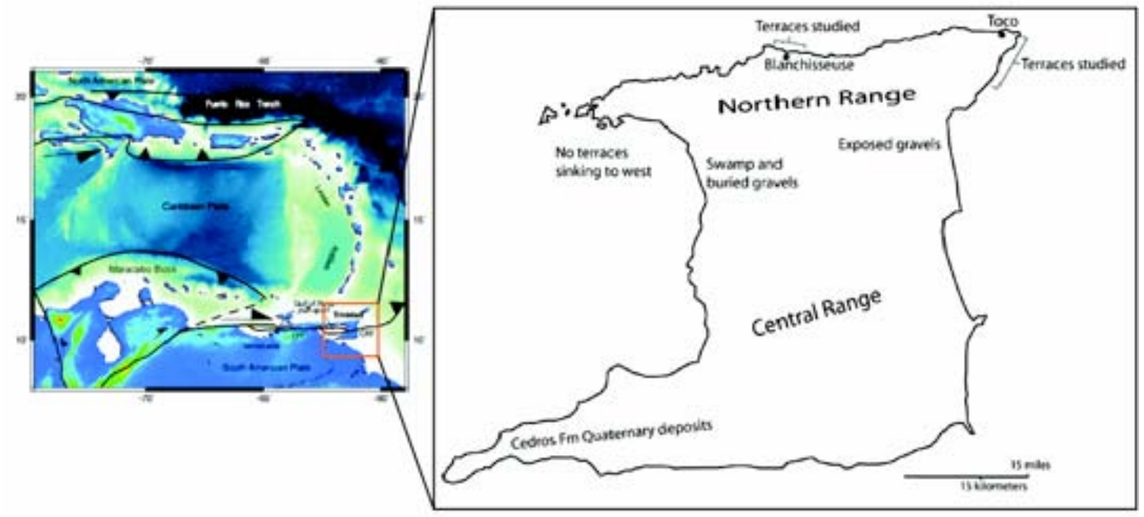


Figure 2. Quaternary terrace deposits near Toco taken from Barr (1963) and field locations studied here shown (dots). These are typically quartz-rich, sand-gravel, and flat-lying deposits that sit unconformably on metamorphic bedrock.

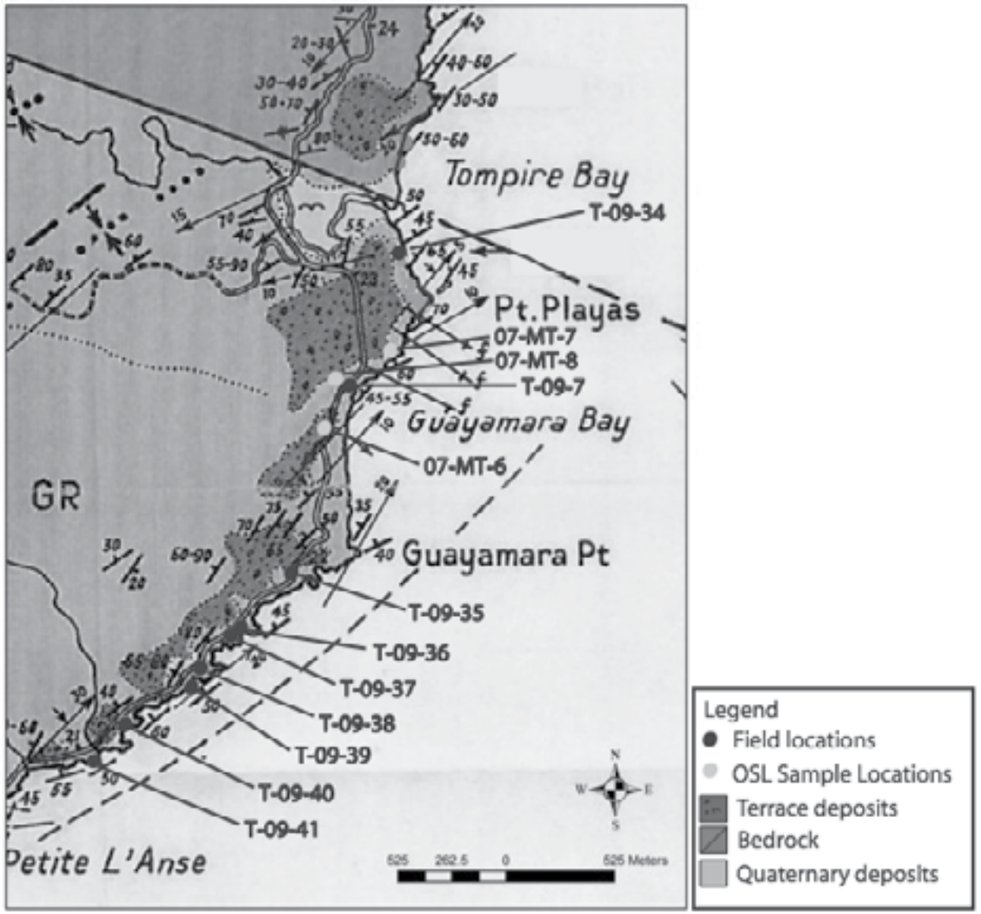


Figure 3. Aerial photographs (1994) from the Blanchisseuse region, georeferenced using ArcGIS©, showing terraces studied here (white dots). These coastal terraces appear to be narrower and approximately 10 m higher than those near Toco. Arima-Blanchisseuse road and the village of Blanchisseuse labeled for geographic reference.

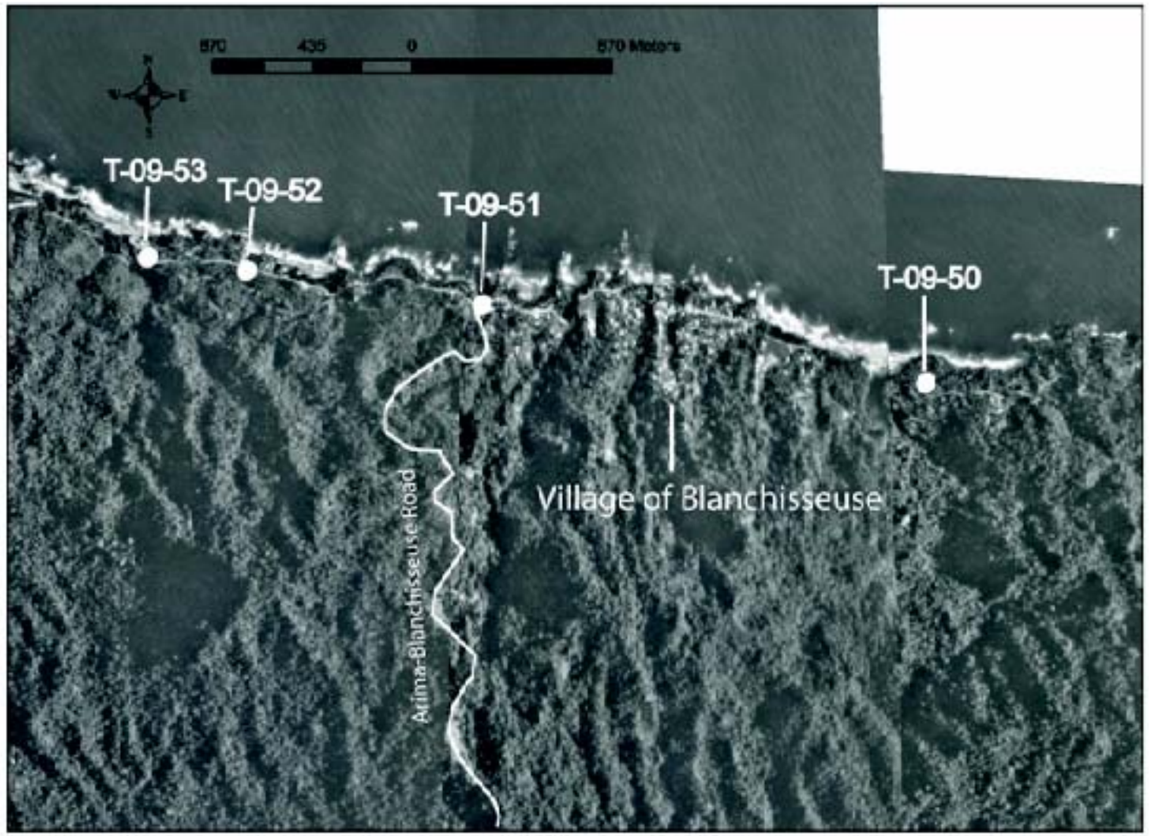
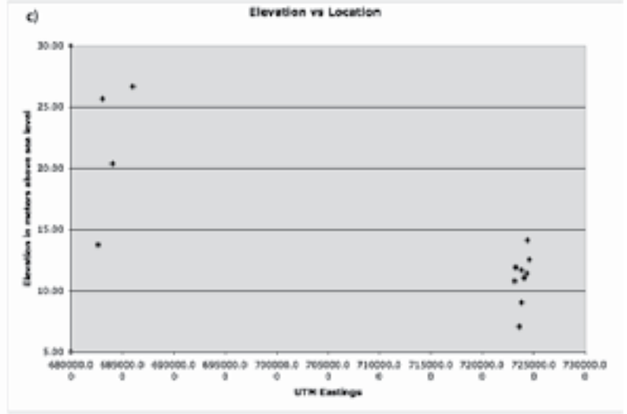


Figure 4 (**a**) DEM with all (Toco and Blanchisseuse) field locations shown (dots), (**b**) table with terrace elevations taken from DEM, and (**c**) a graph of terrace elevations in meters above sea level plotted against their UTM easting. (Zone 20 ,WGS 84) The shaded boxes in **Figure 4b** are the field locations near Blanchisseuse.



b) ID	Elevation (m above sea level)	UTM Easting	UTM Northing
09-T-34	12.57	724597.00	1192340.00
09-T-35	11.09	724098.00	1190749.00
09-T-36	9.06	723850.00	1190486.00
09-T-37	11.73	723808.00	1190447.00
09-T-38	7.12	723657.00	1190282.00
09-T-39	7.12	723604.00	1190197.00
09-T-40	11.92	723288.00	1190017.00
09-T-41	10.81	723138.00	1189841.00
09-T-50	26.71	686012.00	1193875.00
09-T-51	20.43	684043.00	1194220.00
09-T-52	25.69	683010.00	1194370.00
09-T-53	13.77	682578.00	1194426.00
09-T-54	14.14	724385.00	1191674.00
09-T-9	11.46	724304.00	1191488.00

Figure 5. Quaternary coastal terrace stratigraphic sections measured near Toco. Horizontal scale based on UTM Northing component (WGS 84) of measured section locations. Each column is subdivided into units that are described in detail in Appendix A. Three main units (cover, coastal terrace sediments, and metamorphic bedrock) are shown here. Thicknesses in cm in or on sides of stratigraphic sections represent sub-unit thicknesses.

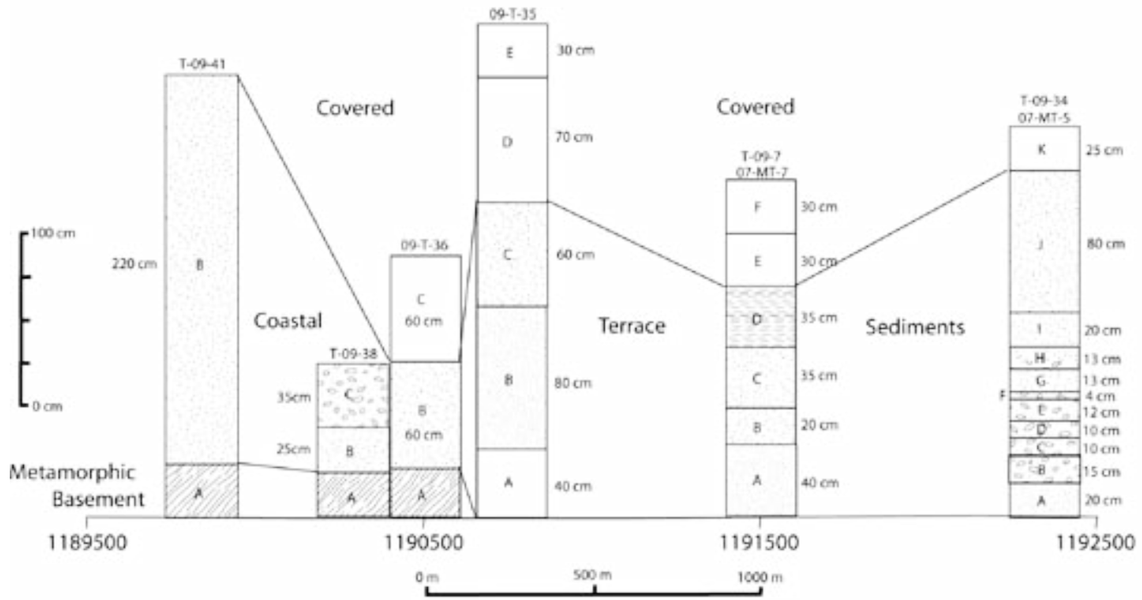


Figure 6. Quaternary coastal terrace at location 09-T-36 (facing northwest). See Figure 8 for location and see Appendix A for additional details and detailed unit (A, B, C) descriptions.

Figure 7. Quaternary coastal terrace stratigraphic sections measured near Blanchisseuse. Horizontal scale based on UTM Easting component (WGS 84) of measured section locations. Each column is subdivided into units that are described in detail in Appendix A. Three main units (cover, coastal terrace sediments, and metamorphic bedrock) are shown here.

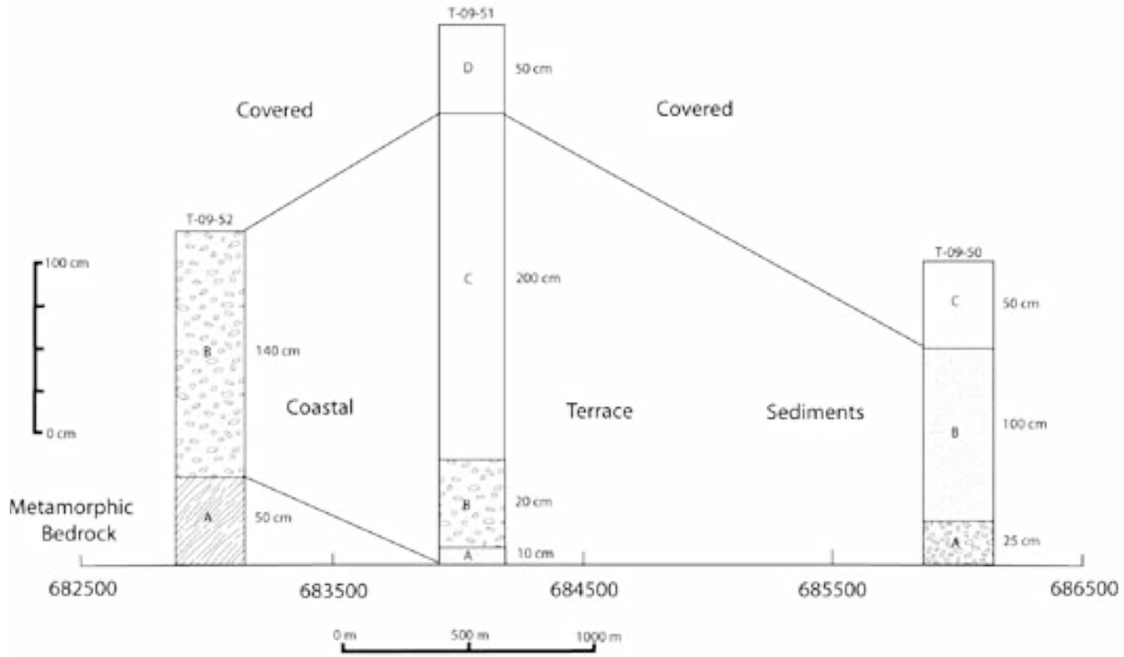


Figure 8. Quaternary coastal terrace at location 09-T-52 (pictures both facing northwest). (a) Terrace in outcrop view and (b) close-up of unit B to show grain size and texture. See Figure 8 for location and see Appendix A for additional details and detailed unit (A, B) descriptions.

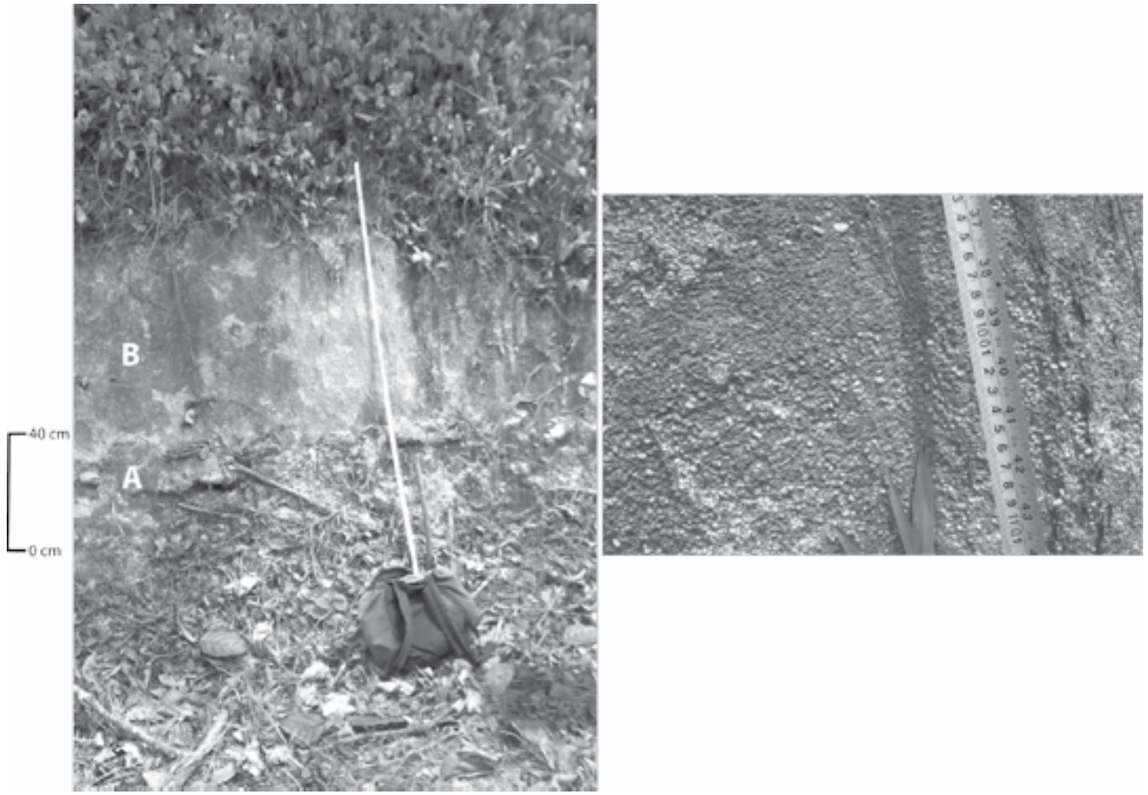


Table 2.
Raw Sieve Data

Sample	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
T-09-37	0.23ϕ v. coarse sand	-0.45ϕ v. coarse sand	-0.75- -0.50ϕ v. coarse sand 4.00-4.25ϕ v. fine sand	1.82ϕ v. well sorted	0.53 Strongly finely skewed	1.29
T-09-34-7	-0.29 ϕ v. coarse sand	-0.26 ϕ granule	-2.00- -1.75 ϕ pebble	1.28 ϕ poorly sorted	0.16 finely skewed	0.93
T-09-52	-0.84 ϕ granule	-1.20 ϕ granule	-1.25--1.00 ϕ granule	1.02 ϕ poorly sorted	0.71 strongly finely skewed	1.00
05-Toco-1	-0.61ϕ v. coarse sand	-0.90 ϕ granule	0.25-0.50 ϕ coarse sand -1.75- -1.50ϕ granule	1.14 ϕ poorly sorted	1.05 strongly finely skewed	1.05
T-09-34-1	2.18 ϕ medium sand	2.60 ϕ fine sand	2.75-3.00 ϕ fine sand	1.83 ϕ	0.39	1.57

Table 3
Adjusted Sieve Data

Sample	Mean	Median	Mode	Standard deviation	Skewness	Kurtosis
T-09-37	-0.80 ϕ v. coarse sand	-0.77 ϕ v. coarse sand	-0.75- -0.50 ϕ v. coarse sand	0.65 ϕ v. well sorted	0.08 Near symmetrical	0.99
T-09-34-7	-1.15 ϕ granule	-1.21 ϕ granule	-2.00- -1.75 ϕ pebble	0.48 ϕ v. well sorted	0.05 Near symmetrical	0.07
T-09-52	-1.56 ϕ granule	-1.57 ϕ granule	-1.25--1.00 ϕ granule	0.23 ϕ well sorted	-0.01 Near Symmetrical	1.00
05-Toco-1	-0.69 ϕ v. coarse sand	-0.59 ϕ v. coarse sand	-1.75- -1.50 ϕ granule	0.84 ϕ v. well sorted	-0.14 coarse skewed	0.57
T-09-34-1	2.18 ϕ medium sand	2.60 ϕ fine sand	2.75-3.00 ϕ fine sand	1.83 ϕ	0.39	1.57

Figure 10. Zingg diagram illustrating quantitative data analysis which classifies particle shape with reference to triaxial ellipsoids. DL, DI, and DS represent the longest axis, intermediate axis, and shortest axis measured of the sample respectively. The horizontal axis of the graph illustrates the ratio DS/DI, and the vertical axis illustrates the ratio DI/DL. See Appendix B for the list of each DS, DI, and DL.

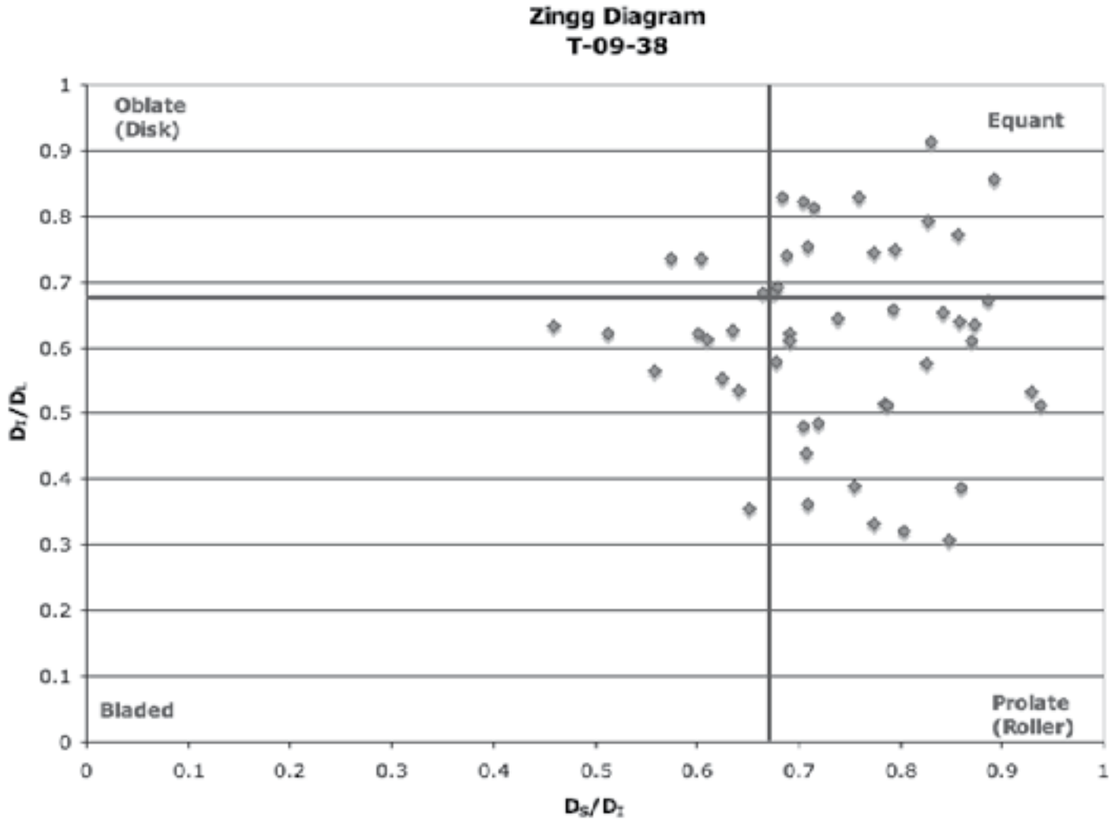
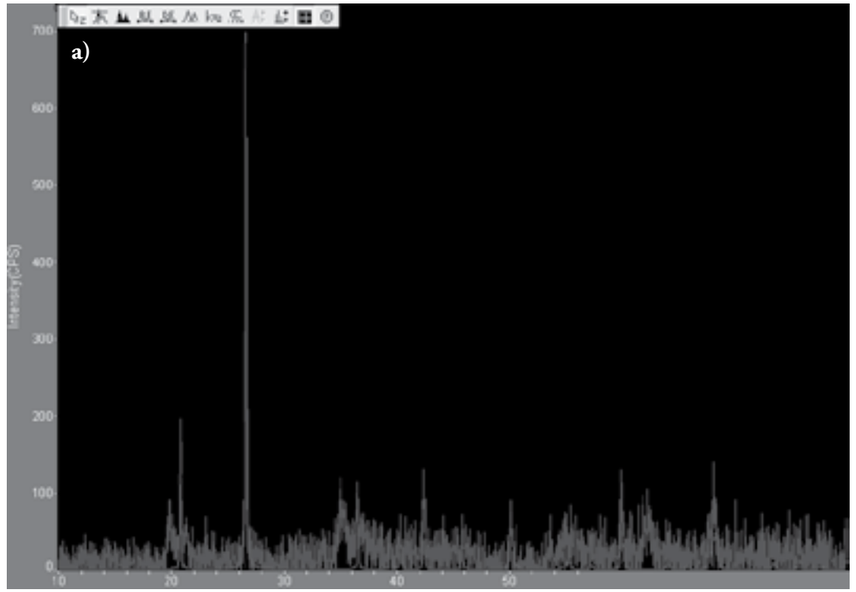


Figure 11. X-ray diffraction (XRD) graphs created by the Rigaku Miniflex with the horizontal axis displaying degrees within the range of 2θ between 10° and 80° and the vertical axis displaying the intensity in CPS. The graphs were overlaid with the standard graph of quartz, which was found to match all of the samples. (a) Sample collected at location 09-T-52 near Blanchisseuse and (b) sample collected at location 09-T-37 near Toco.



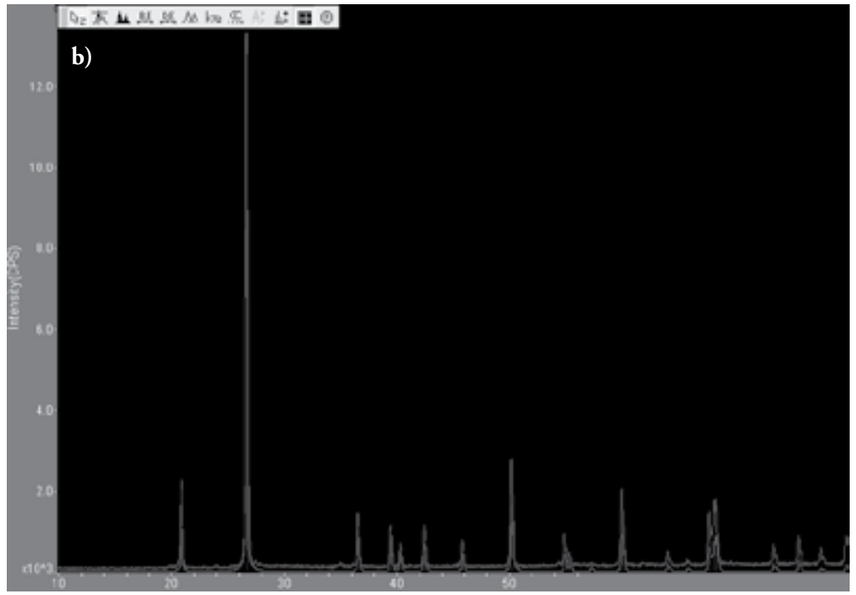
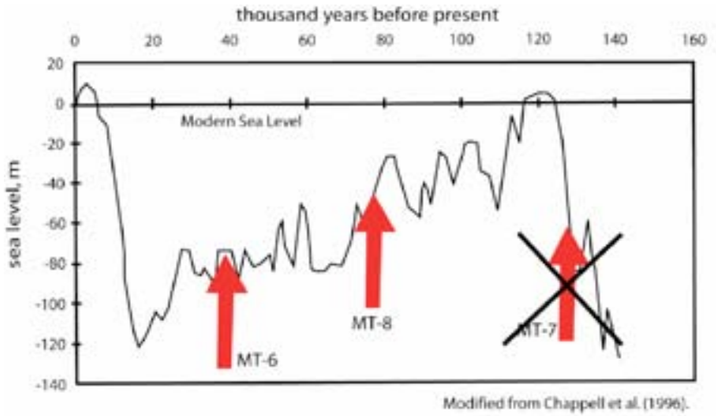


Figure 12. (a) Chart illustrating the change in global sea level from 140 ka to present, with the horizontal line at 0 representing modern sea level. Arrows show our dated samples' ages. The oldest sample has been thrown away because its age is too exaggerated (Sea level curve modified from Chappell et al. 1996). (b) Data table of all relevant information related to the dating process.



Modified from Chappell et al. (1996).

Field Number	UTM Northing	UTM Easting	Equivalent dose (Grays)	U (ppm)[b]	Th (ppm)[b]	K_2O (%)[b]	H_2O (%)	Cosmic (mGrays/yr)[c]	Dose Rate (mGrays/yr)	OSL age (yr)
07-MT-6	1191819	0724596	34.15±0.70[d]	1.4±0.1	3.7±0.1	0.520±0.01	15±5	0.18±0.04	0.84±0.04	**40,090±3000**
07-MT-8	1191484	0724310	83.564±2.59	1.3±0.1	4.0±0.1	0.59±0.01	15±5	1.13±0.07	1.13±0.07	**74,020±5650**
07-MT-8	1191484	0724310	Low emissions	1.3±0.1	4.0±0.1	0.59±0.01	15±5	1.13±0.07	1.13±0.07	incalculable
07-MT-7	1191688	0724380	69.77±0.78	0.9±0.1	1.9±0.1	0.09±0.01	20±5	0.51±0.03	0.51±0.03	**137,500±10,880**
07-MT-7	1191688	0724380	Low emissions	0.9±0.1	1.9±0.1	0.09±0.01	20±5	0.51±0.03	0.51±0.03	incalculable

Appendix A
Descriptions of units in Figures 5,6,7, and 8

T-09-7 (07-MT-7) – (A) 40 cm of med-fine sand limonite- and hematite-stained, (B) 20 cm of material similar to unit above, but more limonite, **sample 07-MT-7** taken here, (C) 35 cm of quartz granules to sand-sized sandy gravel, weathered, buff colored, (D) 35 cm of mottled, chocolate brown/limonite yellow, brown appears to be clay-rich unit, (E) 30 cm of weathered sand and gravel = A soil horizon, (F) 30 cm of organic rich, weathered sand and gravel = A soil horizon

T-09-34 (07-MT-5) – (A) 20 cm of fine-sand, medium yellowish-brown, limonite-stained and cemented, **sample T-09-34-1** taken here, (B) 15 cm of gravel, metamorphic rock fragments and vein quartz ~13 cm or less in diameter, subrounded, hint of imbrication, short dimension of pebbles sub-perpendicular to contact, (C) 10 cm of mostly subrounded vein quartz and most grains touching each other with sand matrix (sand is fine to very fine and orange), ~1cm diameter, the top contact is gradational, (D) 10 cm of gravel, mostly metamorphic Northern Range rock fragments ~5 cm or less in diameter, pebbles roughly equidimensional, top contact sharp, grains touching each other but have a sand matrix, (E) 12 cm of gravel less than 1 cm in diameter and sand mixture, gravels mostly rounded vein quartz, orange, top contact sharp, (F) 4 cm of gravel, Northern Range metamorphic rock fragments and vein quartz pebbles ~5 cm or less in diameter, hint of imbrication within axes of rock fragments sub-perpendicular to bedding, (G) 13 cm of coarse-sand and ~2 mm or less in diameter gravel mix, orange, **sample T-09-34-7** taken here, (H) 13 cm of blocky metamorphic rock fragments and subrounded vein quartz, to 3-4 mm vein quartz gravels and coarse-sand mix, fines upward from 3-4 cm diameter pebbles at base stained orange, (I) 20 cm of coarse-sand, highly weathered and limonite stained, gradational contact on top, (J) 80 cm of poorly sorted coarse-sand, 2-3 mm gravel made of vein quartz and occasional rounded vein quartz pebbles ~5 cm or smaller, (K) 25 cm is organic rich modern soil, A soil horizon, roots

T-09-35 – (A) 40 cm of covered material probably sand underneath soil, (B) 80 cm of medium grained sand, weathered orange with goethite and limonite bands, (C) 60 cm of coarse to very coarse sand, subangular, gray, weathered orange, (D) 70 cm of light gray, rooted and weathered material, (E) 30 cm of possible well covered A soil horizon

T-09-36 – (A) metamorphic bedrock, (B) 60 cm of very coarse to coarse sand with fine sand matrix, **sample 09-T-36** taken here, (C) 60 cm covered with vegetation

T-09-38 – (A) metamorphic bedrock, (B) 25 cm of coarse sand with few granules, layered, highly weathered, limonite stained and cemented, (C) 35 cm of subrounded vein quartz and Northern Range metamorphic pebbles in grain-to-grain contact, moderately sorted, grains greater than 5 cm in diameter

T-09-41 – (A) weathered bedrock, (B) 220 cm of coarse sand with a few millimeter sized granules in grain-to-grain contact cemented, **sample T-09-41** taken here

T-09-50 – (A) 25 cm of colluvium and poorly sorted vein quartz and clasts up to 16 cm, (B) 100 cm of very fine sand, (C) 50 cm of cover

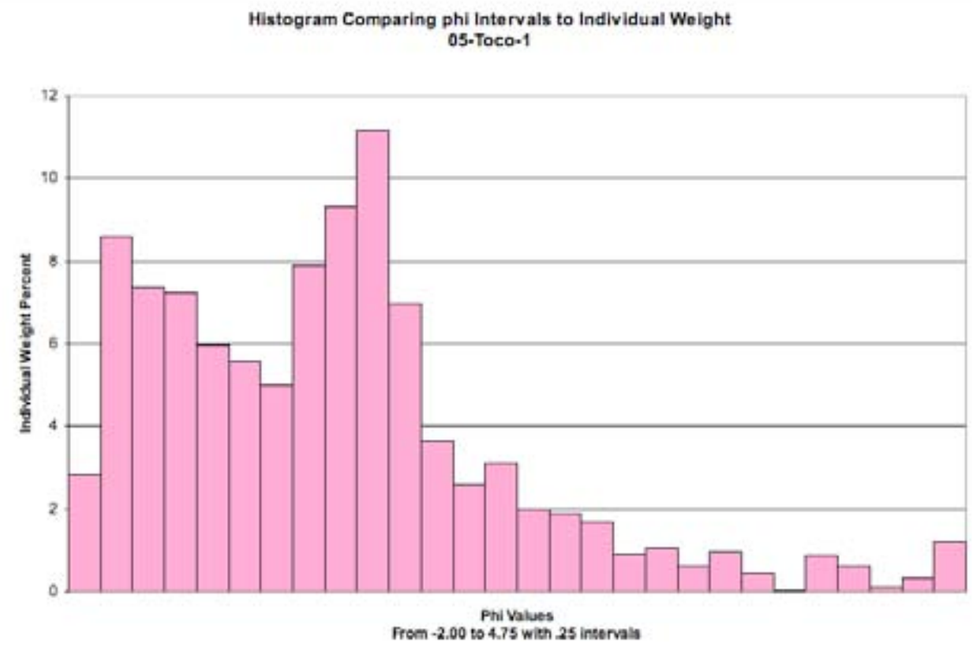
T-09-51 – (A) 10 cm of sand, **sample T-09-51-1** taken here, (B) 20 cm of gravel with rounded clasts, (C) 200 cm of covered, highly weathered material, (D) 50 cm are covered and grassy

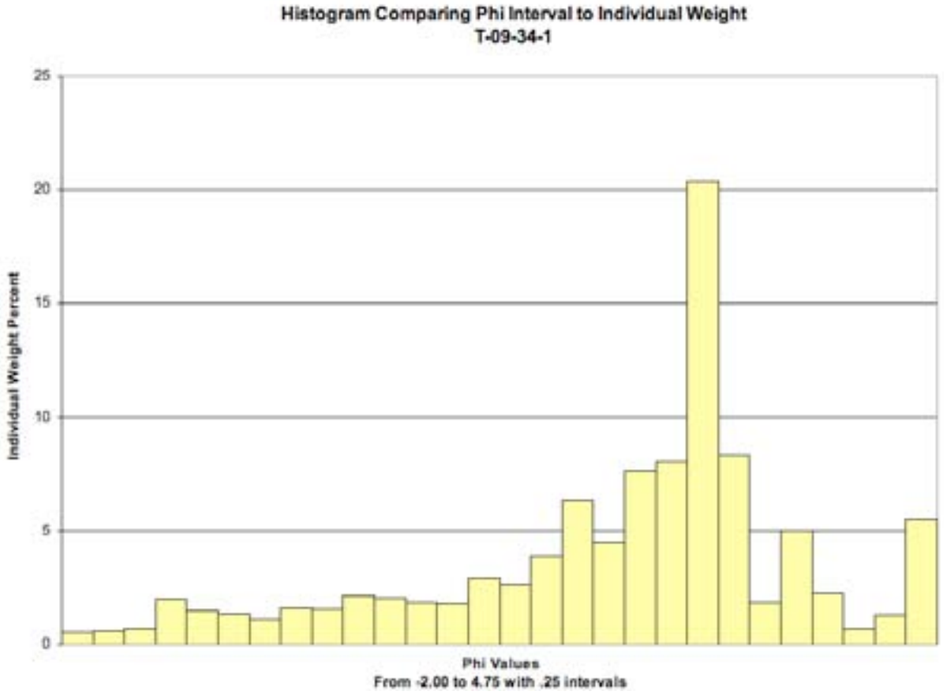
T-09-52 – (A) 50 cm of metamorphic bedrock, (B) 140 cm of rounded very fine gravel, ~.5 cm in diameter

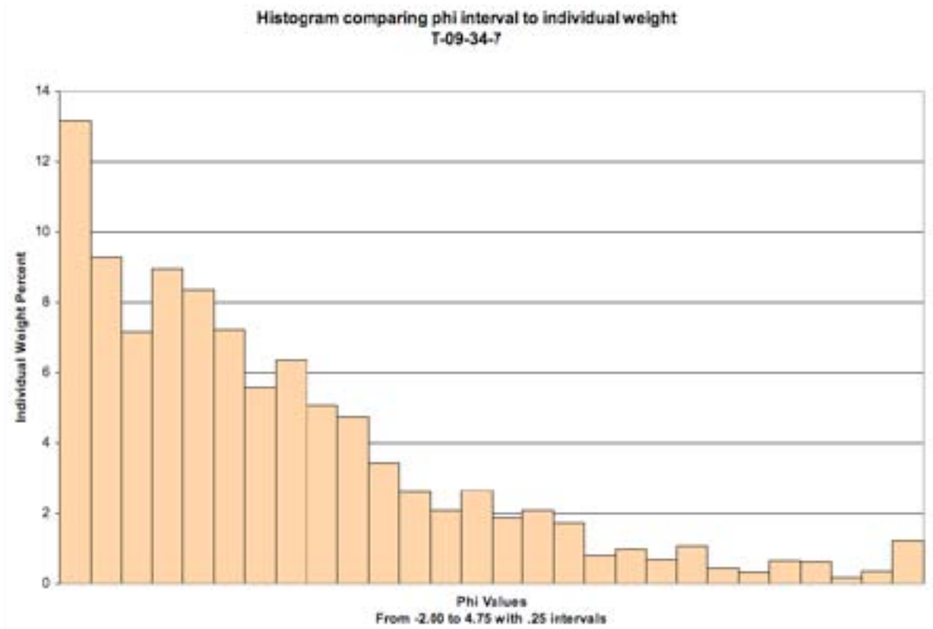
Appendix B
Lengths of the long, intermediate, and short dimensions of the 50 pebbles used to create the Zingg diagram in Figure 10.

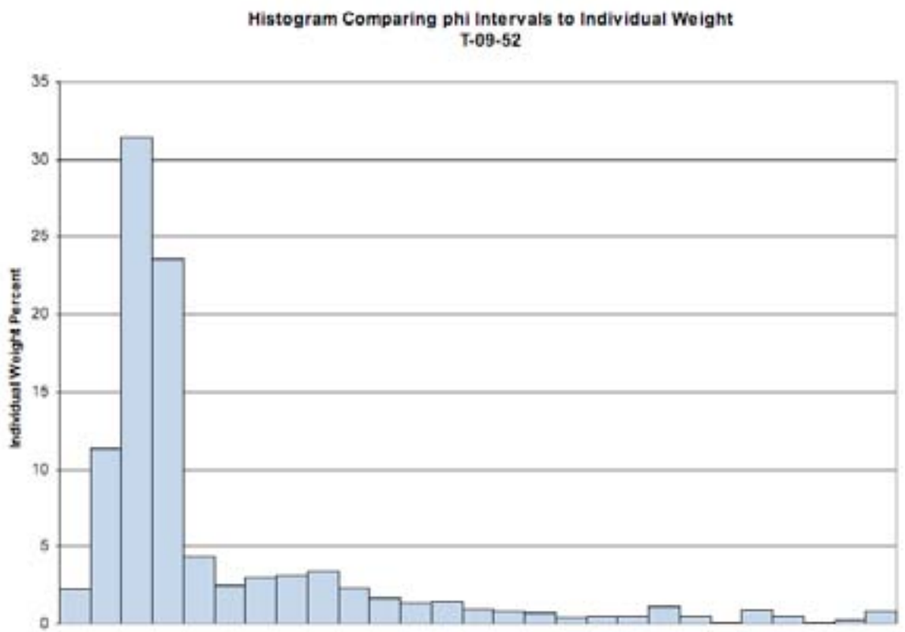
Pebble #	D_L	D_I	D_S
1	0.732	0.516	0.424
2	0.85	0.702	0.404
3	0.856	0.764	0.654
4	0.874	0.694	0.52
5	0.914	0.608	0.416
6	1.024	0.878	0.678
7	1.112	0.706	0.442
8	1.128	0.856	0.71
9	1.132	0.738	0.262
10	1.158	0.918	0.604
11	1.182	1.014	0.648
12	1.184	0.84	0.634
13	1.188	1	0.654
14	1.194	0.924	0.688
15	1.198	0.824	0.61
16	1.262	1.118	0.752
17	1.268	0.856	0.584
18	1.32	1.096	1.002
19	1.364	0.832	0.51
20	1.448	1.07	0.69
21	1.502	1.074	0.874
22	1.522	1.29	0.398
23	1.598	0.818	0.508
24	1.654	1.034	0.572
25	1.658	0.952	0.7
26	1.706	1.206	0.53
27	1.758	1.36	0.452
28	1.804	1.55	0.6
29	1.814	1.5	1.19
30	1.858	0.854	0.54
31	1.864	1.288	0.8
32	1.89	1.644	1.002
33	1.912	1.5	0.772
34	1.974	1.42	0.69
35	2.002	1.118	0.632
36	2.074	1.252	0.922
37	2.118	1.988	1.018
38	2.288	1.466	0.786
39	2.456	1.664	0.964
40	2.5	1.7	1.178
41	2.524	2.204	1.402
42	2.774	1.896	1.572
43	2.826	2.224	1.138
44	2.826	2.624	1.4
45	3.078	2.184	0.79
46	3.358	2.364	1.138
47	3.744	2.824	1.1
48	4.218	3.39	1.086
49	4.52	2.72	1.692
50	4.726	3.268	1.996

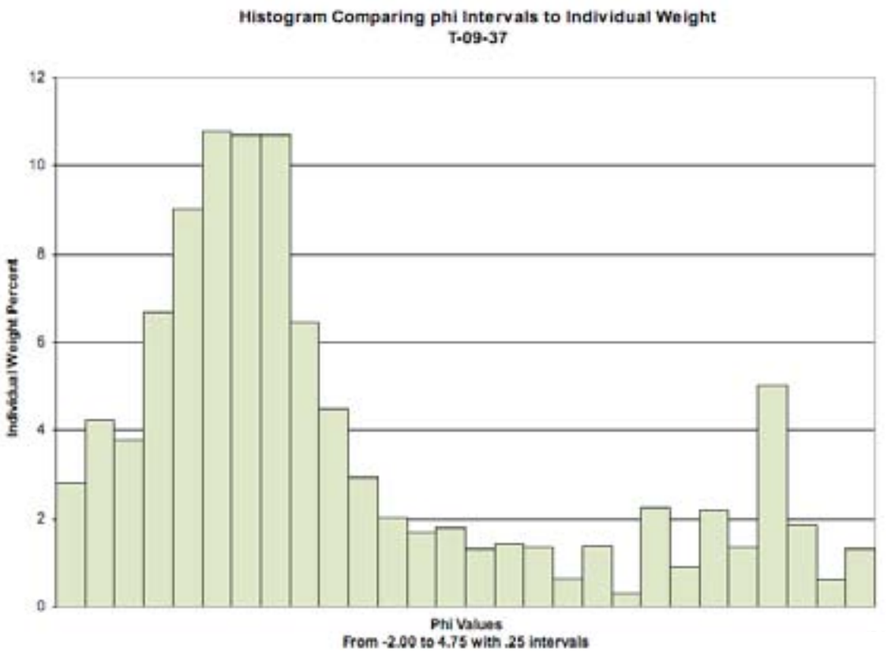
Appendix C
Histograms for each of the samples sieved.






Histogram comparing phi interval to individual weight
T-09-34-7
Individual Weight Percent
0
2
4
6
8
10
12
14
Phi Values
From -2.00 to 4.75 with .25 intervals


Histogram Comparing phi Intervals to Individual Weight
T-09-52
Individual Weight Percent
0
5
10
15
20
25
30
35
Phi Values
From -2.00 to 4.75 with .25 intervals


Histogram Comparing phi Intervals to Individual Weight
T-09-37
Individual Weight Percent
0
2
4
6
8
10
12
Phi Values
From -2.00 to 4.75 with .25 intervals

Computer-Aided Student Study Group Formation

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Abstract

Students thrive in a variety of collaborative learning environments. Furthermore, research has shown student study groups are especially effective methods to promote learning. Our research project developed an artificially intelligent, Internet-based system that aids in formation of study groups outside the classroom setting. The system utilized a HTML/PHP/CSS web interface with a MySQL database backend for the system design. Analysis of student feedback following system demonstration revealed significant support on viability and potential usage. A formal study will be conducted during the fall 2009 semester at Grand Valley State University and analysis of results will follow.

1 Introduction

Students thrive in a variety of collaborative learning environments, especially through the use of study groups [1], [4], [6]. However, the typical means by which students form study groups remains problematic. The nature of the problems stems from randomly or pseudo-strategically selecting study-mates amongst students in a class. This approach does not typically yield top-notch study groups. Consequently, students face challenges such as arranging meeting times around busy schedules, not knowing highly-compatible study-mates, and limiting study-mate selection to one's class. To overcome these problems, we have developed an autonomous group formation system utilizing the Internet.

1.1 Background

Our system operates on the foundation that collaborative learning is an effective means of learning. In his paper, Zoltán Dörnyei [1] asserts that collaborative learning is "a highly effective classroom intervention, superior to most traditional forms of instruction in terms of producing learning gains and student achievement, higher-order thinking, positive attitudes toward learning, increased motivation, better teacher-student and student-student relationships accompanied by more developed interpersonal skills and higher self-esteem on the part of students." Study groups utilize the principles of collaborative learning, and, therefore, retain many of these benefits. Dörnyei continues on to state "group characteristics and group processes significantly contributed to success or failure in the classroom and directly affect the quality and quantity of learning within the group." While our system does not control what group processes are used in study groups, it does determine what characteristics a group is composed of in order to boost group cohesiveness and success. Phyllis C. Blumenfeld et al. [2] asserts that group composition should be of similar knowledge levels to best promote learning. Phil Kelly [3] expands the list of characteristics to include group size, gender, ability, personality, nationality, age, and experience. The focus of this research is to form effective study groups using the principles of collaborative learning. Currently, the goal of this stage in the research is to develop an artificially intelligent, Internet-based system that aids in the formation of study groups. Our system looks at the individual characteristics of age, gender, knowledge level in a subject, gender group preference, and available study times when forming groups.

1.2 Paper Outline

This paper presents our approach to developing a group formation system and analyzing viability and potential usage of our system. Section 2 outlines and describes our system operation procedures and components for facilitating their procedures. Section 3 describes our evaluation of our system prototype in terms of viability and potential usage. Analysis of the data shows that our computer system is viable, usable, and well-received by students. The final section outlines future research refinements to our prototype for a formal study and deployment.

2 System Components and Operation Procedures

The system was designed with the following components: user and administrator interfaces (see section 3.1.1 and 3.1.2) and a MySQL database. The interfaces consist of HTML with embedded PHP web pages styled by CSS. These components operate on four procedural steps (see section 3.2).

2.1 System Components

2.1.1 User Interface
The user interface consists of three web pages: the user account login page, the user customization page, and user information processing page, accessed in this order. The user account login page facilitates user access to the system. The user must enter his or her username and password into a PHP form in order to input information into the system. The user customization page possesses the purpose of obtaining user information needed to form cohesive groups which promote learning (see section 1.1). This information also is entered into PHP forms. By inputting information, the user becomes part of the selection pool under consideration when forming study groups, and, therefore, becomes eligible to be selected to be in a study group. The user information processing page displays a message confirming the information has been correctly entered into the database and ended the user task of entering information. Finally, PHP code on this page retains the user information in a MySQL database for later processing (see section 3.2).

2.1.2 Administrator Interface

The administrator interface also consists of three web pages: administrator account login page, administrator function selection page, and administrator function output page, accessed in this order. The administrator account login is identical to the user account login page, with username and passwords required for access. The administrator function selection page allows the administrator to perform the following actions:

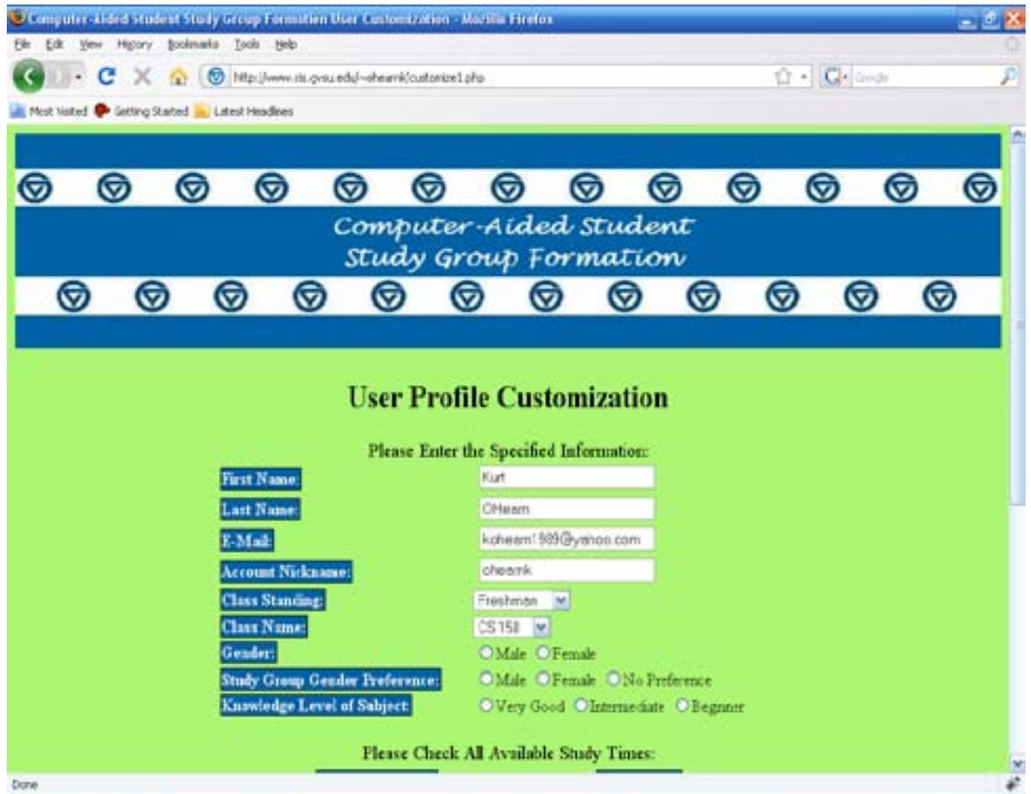
- Manually insert data into the MySQL database
- Manually delete information from the MySQL database
- Search and display information stored in the database
- Execute the group formation algorithm

Once the administrator selects and executes an option, the third page, the administrator function output page, displays the result of the action.

2.2 System Operation Procedures

The system resolved current problems in group formation by using three methods: scheduling study group meeting times and locations; expanding the number of study-

Figure 1: User Customization Page User Data Entry



mate selections, especially across sections of the same class; and selecting "best-matching" group members to maximize meaningful learning from the new possibilities. In order to accomplish these actions, we developed four cyclical operational procedures. These procedures can be summed up in the following four steps:

1. Users enter data via the user interface
2. User data are stored in a MySQL database
3. An AI program is run via the administrator interface to form groups
4. The system communicates to users that groups have been formed

In the first step of the procedure, the user accesses our system via the user interface component (i.e., a series of web pages with PHP forms). In Figure 1 the user enters data into our system. Data entered include user identification information, user contact information, and user characteristics. One unique item contained in the user characteristics is the available study times in Figure 2. A series of check boxes collects the available study times by hour, then that information is concatenated into a string for processing. In step two, all the user data is stored in a MySQL database. PHP code in the user interface web pages accesses the MySQL database and stores all the user data in a single table. This table is sorted by user data categories (e.g., first name, last name, e-mail) so that one entry in the database corresponds to one person. A concatenation of the user e-mail and the class name abbreviation serves as the primary key for accessing information. In step three, an administrator logs onto an administrator Internet interface, which is a series of web pages similar to the user interface, and runs the group formation algorithm to form groups.

The group formation algorithm is made up of PHP code that accesses the MySQL database and temporarily copies all the data into PHP variables. These variables in conjunction with loops and conditional statements evaluate all the information and found possible groups. The current algorithm utilizes a filtering approach by time-increment and characteristics for determining groups [5], [7], [8], [9], [10]. This approach uses the following sequence: first, the system finds all students who can meet at a certain hour and have not yet been assigned a group (i.e., the system started at 9 AM for convenience and incremented until 7 PM). Next, this pool is filtered down further by other characteristics (see section 1.2). Finally, the system forms groups out of users left with matching characteristics. The system then increments to the next hour and repeats the process. In the fourth step, the system takes the output of the group formation algorithm (i.e., a list of groups) and sends e-mails to the users containing the date, time, and location of the meeting and the nicknames of the members in the group.

4 Results

We analyzed data collected through demonstrations to four summer classes in 2009 at Grand Valley State University. Following the demonstration, students were asked to complete an anonymous survey on the project viability and potential usage. A total of 76 students were surveyed.

Figure 2: User Customization Page Available Study Times

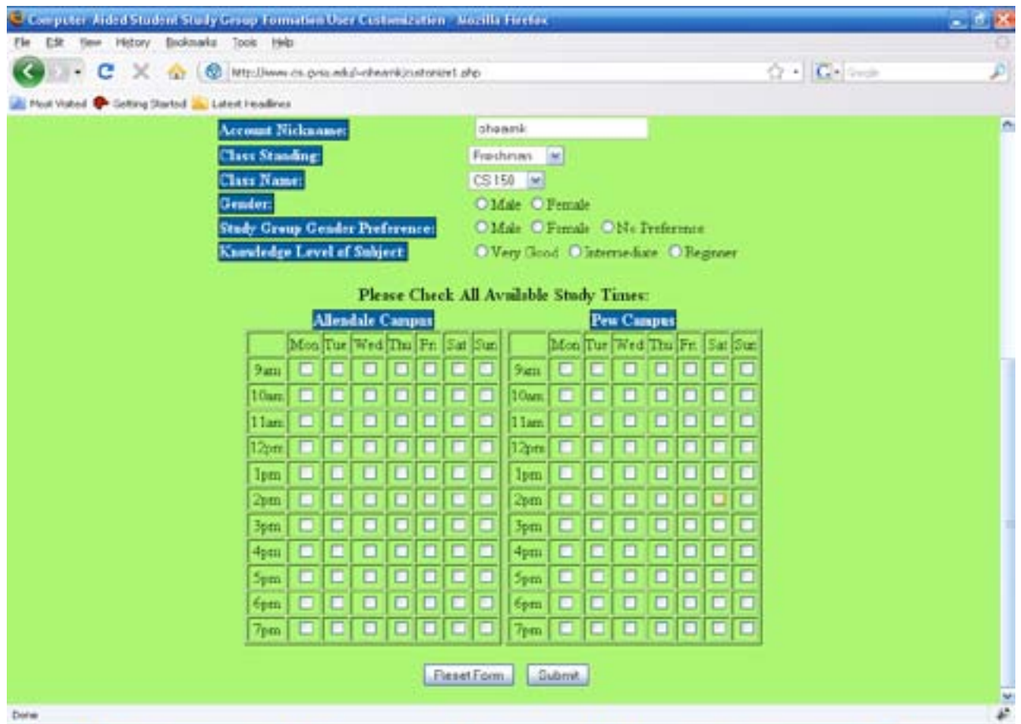


Figure 3: Viability Responses

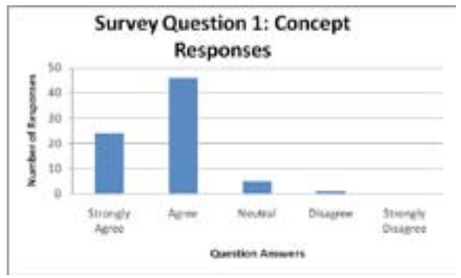


Figure 3 shows responses to the following statement: "The concept of a program that facilitates forming study groups is a 'good' idea." Statistics in Figure 3 reveal that student response was overwhelmingly positive: over ninety percent of students thought our system that formed student study groups was a feasible, worthy idea.

Figure 4: Potential Usage Responses

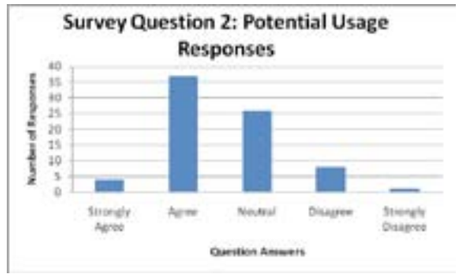


Figure 4 shows responses to the following statement: "If the program presented today was available at Grand Valley State University, I would use it." Statistics in Figure 4 on potential usage of our system are also supportive: approximately half of the students said they would use our system if it was available. Analysis confirms that our computer system is viable, usable, and well-received by students.

5 Future Research

With promising statistics on viability and usability of our current system, the direction of future research is to refine and deploy our system during the fall 2009 semester here at Grand Valley State University. Two sections of CS 162 (Computer Science I) are the intended targets for testing. Additionally, refinements to the system for future deployments include user feedback mechanisms, additional communication methods, group confirmations/cancellations, and improvement of the group formation algorithm.

The first idea for future deployment is a user feedback mechanism. This mechanism would function similarly to eBay's rating system for sales feedback. Following a study group meeting, users could log into the system and rate fellow group mates. Negative ratings would indicate little group cohesion, thus, incompatible members could not be grouped together in the future. Likewise, strong ratings would signify strong group cohesion, thus, group members with positive feedback would likely be grouped together again.

Another feature to be developed is new communication methods. Additional communication methods beyond e-mails to users may include text messages to cell phones, voice messages, and integration into existing online applications such as Facebook.

A mechanism that allows users to confirm or cancel attendance for a group meeting is another possible addition. Users could log into the system and indicate their plans on attending a group. The system could then contact other members and inform them of a group member's attendance plans. If enough people confirm or cancel, the system would confirm or cancel a group meeting. Besides the confirmation/cancelation feature, the group formation algorithm could be improved to form more cohesive groups and maximize learning. The fall 2009 deployment will provide information on system performance as well as group cohesiveness through simple surveys. This information could be used to change which characteristics the group formation algorithm uses to form groups.

Appendix A: Source Code

```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This page is the user login
    to the user interface.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"
"http://www.w3.org/TR/html4/loose.dtd">
<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Computer-Aided Student Study Group Formation Login</title>
<link rel="stylesheet" type="text/css"
href="style1.css" />
</head>

<body>

<!--header-->

<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<h2>This Program is for Demonstration Purposes ONLY<br />
This program is not yet fully operational</h2>
<h2>Welcome to Our Website!</h2>

<div align="center">

<big>Please log in below to edit information on your account</big><br />
<form method="post" action="customize1.php">
<table><tbody>
<tr><td id="loginlabel"><label align="left">Username: </label></td>
<td id="pdata"><input type="text" name="username" value=""
   size="25" maxlength="50" /></td></tr>
<tr><td id="loginlabel"><label>Password: </label></td>
<td id="pdata"><input type="password" name="password" value=""
   size="25" maxlength="50" /></td></tr></tbody></table>
<input type="submit" value="Confirm" />
</form>

</div>

<br /><br /><br /><br />
<p class="group" align="center">We Form Groups to Promote Learning</p>

<!--end main content-->

</body>

</html>
```



```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This page is the user data entry page.
    All characteristics used in the group formation
    algorithm are entered in by the user in forms
    and then stored in the database in process.php.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"

"http://www.w3.org/TR/html4/loose.dtd">

<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Computer-Aided Student Study Group Formation User Customization</title>
<link rel="stylesheet" type="text/css"
href="style1.css" />
</head>

<body>

<!--header-->

<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<?php

   //Process information from username/password form
   if(array_key_exists("username", $_POST))
      $username = $_POST['username'];
   if(array_key_exists("password", $_POST))
      $password = $_POST['password'];
   //Error checking for username/password combination
   if ($password != "admin" || !$username) {
      print "<error>Error: Incorrect Username/" .
        "Password Combination</error><BR>";
      exit(0);
   }
?>
<h2 align="center">User Profile Customization</h2>

<div align="center">

<form method="post" action="process1.php">
<big>Please Enter the Specified Information:</big>
<table><tbody>
<tr><td id="label"><label>First Name:</label></td>
<td id="data"><input type="text" value="Kurt" name="fname" size="25"
   maxlength="50" /></td></tr>
```

```
<tr><td id="label"><label>Last Name:</label></td>
<td id="data"><input type="text" value="OHearn" name="lname" size="25"
   maxlength="50" /></td></tr>
<tr><td id="label"><label>E-Mail:</label></td>
<td id="data"><input type="text" value="kohearn1989@yahoo.com" name="email"
size="25"
   maxlength="50" /></td></tr>
<tr><td id="label"><label>Account Nickname:</label></td>
<td id="data"><input type="text" value="ohearnk" name="nickname" size="25"
   maxlength="50" /></td></tr>
<tr><td id="label"><label>Class Standing:</label></td>
<td id="data"><select name="classstanding">
<option value="freshman">Freshman</option>
<option value="sophomore">Sophomore</option>
<option value="junior">Junior</option>
<option value="senior">Senior</option></select></td></tr>
<tr><td id="label"><label>Class Name:</label></td>
<td id="data"><select name="classname">
<option value="cs150">CS 150</option>
<option value="sta215">STA 215</option></select></td></tr>
<tr><td id="label"><label>Gender:</label></td>
<td id="data"><input type="radio" name="gender"
   value="M" />Male
<input type="radio" name="gender" value="F" />Female</td></tr>
<tr><td id="label"><label>Study Group Gender Preference:</label></td>
<td id="data"><input type="radio" name="genderpref" value="M" />Male
<input type="radio" name="genderpref" value="F" />Female
<input type="radio" name="genderpref" value="N" />No Preference</td></tr>
<tr><td id="label"><label>Knowledge Level of Subject:</label></td>
<td id="data"><input type="radio" name="level" value="E" />Very Good
<input type="radio" name="level" value="I" />Intermediate
<input type="radio" name="level" value="B" />Beginner</td></tr>
</tbody></table>
<br />

<table>
<thead><big>Please Check All Available Study Times:</big></thead>
<tbody><tr><td>
<label>Allendale Campus</label>
<table id="times" border="1"><tbody>
<tr><td> </td><td>Mon</td><td>Tue</td><td>Wed</td>
   <td>Thu</td><td>Fri</td><td>Sat</td><td>Sun</td></tr>
<tr><td>9am</td>
<td><input type="checkbox" name="ma9" value="t" /></td>
<td><input type="checkbox" name="ta9" value="t" /></td>
<td><input type="checkbox" name="wa9" value="t" /></td>
<td><input type="checkbox" name="tha9" value="t" /></td>
<td><input type="checkbox" name="fa9" value="t" /></td>
<td><input type="checkbox" name="saa9" value="t" /></td>
<td><input type="checkbox" name="sua9" value="t" /></td></tr>
<tr><td>10am</td>
<td><input type="checkbox" name="ma10" value="t" /></td>
<td><input type="checkbox" name="ta10" value="t" /></td>
<td><input type="checkbox" name="wa10" value="t" /></td>
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<td><input type="checkbox" name="sua10" value="t" /></td></tr>
<tr><td>11am</td>
<td><input type="checkbox" name="ma11" value="t" /></td>
<td><input type="checkbox" name="ta11" value="t" /></td>
<td><input type="checkbox" name="wa11" value="t" /></td>
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<td><input type="checkbox" name="fa11" value="t" /></td>
<td><input type="checkbox" name="saa11" value="t" /></td>
<td><input type="checkbox" name="sua11" value="t" /></td></tr>
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<td><input type="checkbox" name="ta12" value="t" /></td>
<td><input type="checkbox" name="wa12" value="t" /></td>
<td><input type="checkbox" name="tha12" value="t" /></td>
<td><input type="checkbox" name="fa12" value="t" /></td>
<td><input type="checkbox" name="saa12" value="t" /></td>
<td><input type="checkbox" name="sua12" value="t" /></td></tr>
<tr><td>1pm</td>
<td><input type="checkbox" name="ma13" value="t" /></td>
<td><input type="checkbox" name="ta13" value="t" /></td>
<td><input type="checkbox" name="wa13" value="t" /></td>
<td><input type="checkbox" name="tha13" value="t" /></td>
<td><input type="checkbox" name="fa13" value="t" /></td>
<td><input type="checkbox" name="saa13" value="t" /></td>
<td><input type="checkbox" name="sua13" value="t" /></td></tr>
<tr><td>2pm</td>
<td><input type="checkbox" name="ma14" value="t" /></td>
<td><input type="checkbox" name="ta14" value="t" /></td>
<td><input type="checkbox" name="wa14" value="t" /></td>
<td><input type="checkbox" name="tha14" value="t" /></td>
<td><input type="checkbox" name="fa14" value="t" /></td>
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<td><input type="checkbox" name="wa15" value="t" /></td>
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<td><input type="checkbox" name="fa15" value="t" /></td>
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<td><input type="checkbox" name="wa17" value="t" /></td>
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```

```
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</tbody>
</table>
</td>

<td>
<label>Pew Campus</label>
<table id="times" border="1"><tbody>
<tr><td> </td><td>Mon</td><td>Tue</td><td>Wed</td>
   <td>Thu</td><td>Fri</td><td>Sat</td><td>Sun</td></tr>
<tr><td>9am</td>
<td><input type="checkbox" name="mp9" value="t" /></td>
<td><input type="checkbox" name="tp9" value="t" /></td>
<td><input type="checkbox" name="wp9" value="t" /></td>
<td><input type="checkbox" name="thp9" value="t" /></td>
<td><input type="checkbox" name="fp9" value="t" /></td>
<td><input type="checkbox" name="sap9" value="t" /></td>
<td><input type="checkbox" name="sup9" value="t" /></td></tr>
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<td><input type="checkbox" name="mp10" value="t" /></td>
<td><input type="checkbox" name="tp10" value="t" /></td>
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<td><input type="checkbox" name="wp11" value="t" /></td>
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<td><input type="checkbox" name="fp14" value="t" /></td>
<td><input type="checkbox" name="sap14" value="t" /></td>
<td><input type="checkbox" name="sup14" value="t" /></td></tr>
```



```
<tr><td>3pm</td>
<td><input type="checkbox" name="mp15" value="t" /></td>
<td><input type="checkbox" name="tp15" value="t" /></td>
<td><input type="checkbox" name="wp15" value="t" /></td>
<td><input type="checkbox" name="thp15" value="t" /></td>
<td><input type="checkbox" name="fp15" value="t" /></td>
<td><input type="checkbox" name="sap15" value="t" /></td>
<td><input type="checkbox" name="sup15" value="t" /></td></tr>
<tr><td>4pm</td>
<td><input type="checkbox" name="mp16" value="t" /></td>
<td><input type="checkbox" name="tp16" value="t" /></td>
<td><input type="checkbox" name="wp16" value="t" /></td>
<td><input type="checkbox" name="thp16" value="t" /></td>
<td><input type="checkbox" name="fp16" value="t" /></td>
<td><input type="checkbox" name="sap16" value="t" /></td>
<td><input type="checkbox" name="sup16" value="t" /></td></tr>
<tr><td>5pm</td>
<td><input type="checkbox" name="mp17" value="t" /></td>
<td><input type="checkbox" name="tp17" value="t" /></td>
<td><input type="checkbox" name="wp17" value="t" /></td>
<td><input type="checkbox" name="thp17" value="t" /></td>
<td><input type="checkbox" name="fp17" value="t" /></td>
<td><input type="checkbox" name="sap17" value="t" /></td>
<td><input type="checkbox" name="sup17" value="t" /></td></tr>
<tr><td>6pm</td>
<td><input type="checkbox" name="mp18" value="t" /></td>
<td><input type="checkbox" name="tp18" value="t" /></td>
<td><input type="checkbox" name="wp18" value="t" /></td>
<td><input type="checkbox" name="thp18" value="t" /></td>
<td><input type="checkbox" name="fp18" value="t" /></td>
<td><input type="checkbox" name="sap18" value="t" /></td>
<td><input type="checkbox" name="sup18" value="t" /></td></tr>
<tr><td>7pm</td>
<td><input type="checkbox" name="mp19" value="t" /></td>
<td><input type="checkbox" name="tp19" value="t" /></td>
<td><input type="checkbox" name="wp19" value="t" /></td>
<td><input type="checkbox" name="thp19" value="t" /></td>
<td><input type="checkbox" name="fp19" value="t" /></td>
<td><input type="checkbox" name="sap19" value="t" /></td>
<td><input type="checkbox" name="sup19" value="t" /></td></tr>
</tbody></table>
</td></tr></tbody></table>

<p><input type="reset" value="Reset Form" />
<input type="submit" value="Submit" /></p>
</form>

</div>

<!--end main content-->

</body>

</html>
```

```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This page takes the user data entered
    into forms on the customize.php page and inserts
    that information into the database for later
    processing by the group formation algorithm.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"

"http://www.w3.org/TR/html4/loose.dtd">

<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Processor</title>
<link rel="stylesheet" type="text/css"
href="style1.css" />
</head>

<body>

<!--header-->

<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<?php

   //Process infromation from data entry form
   if(array_key_exists("fname", $_POST))
      $fname = $_POST['fname'];
   if(array_key_exists("lname", $_POST))
      $lname = $_POST['lname'];
   if(array_key_exists("email", $_POST))
      $email = $_POST['email'];
   if(array_key_exists("nickname", $_POST))
      $nickname = $_POST['nickname'];
   if(array_key_exists("gender", $_POST))
      $gender = $_POST['gender'];
   if(array_key_exists("genderpref", $_POST))
      $genderpref = $_POST['genderpref'];
   if(array_key_exists("classstanding", $_POST))
      $classstanding = $_POST['classstanding'];
   if(array_key_exists("classname", $_POST))
      $classname = $_POST['classname'];
   if(array_key_exists("level", $_POST))
      $level = $_POST['level'];

   $atime = "";
   $ptime = "";
```



```
   //Allendale Campus Times
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("ma$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("ta$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("wa$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("tha$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("fa$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("saa$i", $_POST) ? $atime .= '1' : $atime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("sua$i", $_POST) ? $atime .= '1' : $atime .= '0');
   //Pew Campus Times
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("mp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("tp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("wp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("thp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("fp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("sap$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   for($i = 9; $i <= 19; $i++)
      (array_key_exists("sup$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
   $time = $atime.$ptime;

   if (!$fname || !$lname || !$email || !$nickname || !$gender || !$genderpref
   || !$classstanding || !$classname || !$level ) {
      print "<error>Error: Incorrect Data Entry</error><BR>";
      print "<error>Please Fill In All Areas Before Submitting</error><BR>";
      exit(0);
   }

   if ($ptime == "000000000000000000000000000000000000" .
   "000000000000000000000000000000000000"
   && $atime == "000000000000000000000000000000000000" .
   "000000000000000000000000000000000000") {
        print "<error>Error: Incorrect Data Entry</error><BR>";
        print "<error>Please Fill In At Least 1 Available Study</error>”;
        print "<error> Time Before Submitting</error><BR>";
      exit(0);
}

   //1st Database Testing Code
   mysql_connect("localhost", "mcnairdb", "mcnairdb1579") or die ("<error>" .
   "No Connection. Please Try Again Later.</error><BR>");

//   mysql_query ("CREATE TABLE mcnairdb.table1(email CHAR(40) PRIMARY KEY, " .
//   "fname CHAR(30), lname CHAR (30), nickname CHAR (30), gender CHAR (1), " .
//   "genderpref CHAR (1), classstanding CHAR (9), classname CHAR (6), level" .
//   " CHAR (1), time CHAR (154))");

   //Delete similar entries before inserting to prevent duplicate entries
   $temp = "DELETE FROM mcnairdb.table1 WHERE email = '$email' && classname =
'$classname'";
   mysql_query ($temp) or die (mysql_error());
   //Insert form data
```

```
   $temp = "INSERT INTO mcnairdb.table1(email, fname, lname, nickname, gender,
   genderpref, classstanding, classname, level, time) VALUES ('$email', '$fname',
  '$lname', '$nickname', '$gender', '$genderpref', '$classstanding', '$classname',
  '$level', '$time')";
   mysql_query ($temp) or die (mysql_error());

   mysql_close();

?>
<h2>Thank you!<br />You are now signed out<br />
   <br />You will receive e-mail notification(s) of groups forming soon.</h2>
<h3><a href="http://www.cis.gvsu.edu/~ohearnk/index1.html">Return to
Homepage</a></h3>

<!--end main content-->

</body>

</html>
```



```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This page is the administrator login
    to the debugger/testing system.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"

"http://www.w3.org/TR/html4/loose.dtd">

<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Computer-Aided Student Study Group Formation Login</title>
<link rel="stylesheet" type="text/css"
href="style.css" />
</head>

<body>

<!--header-->

<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<h2>Welcome to Our Website!<br />This is the Administrator Login Page</h2>

<div align="center">

<big>Please log in below</big><br />
<form method="post" action="option.php">
<table><tbody><tr><td id="loginlabel"><label align="left">Username: </label></td>
<td id="pdata"><input type="text" name="username" value=""
   size="25" maxlength="50" /></td></tr>
<tr><td id="loginlabel"><label>Password: </label></td>
<td id="pdata"><input type="password" name="password" value=""
   size="25" maxlength="50" /></td></tr></tbody></table>
<input type="submit" value="Confirm" />
</form>

</div>

<br /><br /><br /><br />
<p class="group" align="center">We Form Groups to Promote Learning</p>

<!--end main content-->

</body>

</html>
```

```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This debugger/testing page contains four forms
    pertaining to four different functions to execute:
    search database entries and display, insert new entry into the
    database and display, delete existing entries from the database
    and display, and run the study group formation algorith to form
    a listing of study groups.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"

"http://www.w3.org/TR/html4/loose.dtd">

<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Search</title>
<link rel="stylesheet" type="text/css"
href="style1.css" />
</head>

<body>

<!--header-->
<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<div align = "center">

<?php

   if(array_key_exists("username", $_POST))
      $username = $_POST['username'];
   if(array_key_exists("password", $_POST))
      $password = $_POST['password'];

   if ($password != "admin" || $username != "administrator") {
      print "<error>Error: Incorrect Username/" .
        "Password Combination</error><BR>";
      exit(0);
   }

?>
</div><br />

<div align="center">
<p><big><big>Choose One of the Four Options Below</big></big></p>
<form method="post" action="data.php">
<p><big>Specify Category and Keyword to Search the Database For:</big></p>
```



```
<table><tbody>
<tr><td id="searchlabel"><label>Category:</label></td>
<td id="searchlabel"><label>Keyword:</label></td></tr>
<tr><td id="search"><select name="category">
<option value="all">Display All</option>
<option value="email">E-Mail</option>
<option value="fname">First Name</option>
<option value="lname">Last Name</option>
<option value="nickname">Nickname</option>
<option value="gender">Gender</option>
<option value="genderpref">Gender Preference</option>
<option value="classstanding">Class Standing</option>
<option value="classname">Class Name</option>
<option value="level">Knowledge Level</option></select></td>
<td id="search"><input type="text" name="keyword"
   size="15" maxlength="50" /></td></tr>
</tbody></table>
<p><input type="submit" value="Search" /></p>
</form></div><br />

<div align="center">
<form method="post" action="data.php">
<p><big>Enter Data to Insert into the Database:</big></p>
<table><tbody>
<tr><td id="label"><label>First Name:</label></td>
<td id="data"><input type="text" name="fname"
   size="25" maxlength="50" /></td></tr>
<tr><td id="label"><label>Last Name:</label></td>
<td id="data"><input type="text" name="lname"
   size="25" maxlength="50" /></td></tr>
<tr><td id="label"><label>E-Mail:</label></td>
<td id="data"><input type="text" name="email"
   size="25" maxlength="50" /></td></tr>
<tr><td id="label"><label>Account Nickname:</label></td>
<td id="data"><input type="text" name="nickname"
   size="25" maxlength="50" /></td></tr>
<tr><td id="label"><label>Class Standing:</label></td>
<td id="data"><select name="classstanding">
<option value="freshman">Freshman</option>
<option value="sophomore">Sophomore</option>
<option value="junior">Junior</option>
<option value="senior">Senior</option></select></td></tr>
<tr><td id="label"><label>Class Name:</label></td>
<td id="data"><select name="classname">
<option value="cs150">CS 150</option>
<option value="sta215">STA 215</option></select></td></tr>
<tr><td id="label"><label>Gender:</label></td>
<td id="data"><input type="radio" name="gender" value="M" />Male
<input type="radio" name="gender" value="F" />Female</td></tr>
<tr><td id="label"><label>Study Group Gender Preference:</label></td>
<td id="data"><input type="radio" name="genderpref" value="M" />Male
<input type="radio" name="genderpref" value="F" />Female
<input type="radio" name="genderpref" value="N" />No Preference</td></tr>
<tr><td id="label"><label>Knowledge Level of Subject:</label></td>
<td id="data"><input type="radio" name="level" value="E" />Very Good
<input type="radio" name="level" value="I" />Intermediate
<input type="radio" name="level" value="B" />Beginner</td></tr>
<input type="hidden" name="category" value="all" />
<input type="hidden" name="insert" value="yes" />
<input type="hidden" name="delete" value="yes" />
</tbody></table>
<table><thead><big>Please Check All Available Study Times:</big></thead>
<tbody><tr><td>
```

```
<label>Allendale Campus</label>
<table id="times" border="1"><tbody>
<tr><td> </td><td>Mon</td><td>Tue</td><td>Wed</td>
   <td>Thu</td><td>Fri</td><td>Sat</td><td>Sun</td></tr>
<tr><td>9am</td>
<td><input type="checkbox" name="ma9" value="t" /></td>
<td><input type="checkbox" name="ta9" value="t" /></td>
<td><input type="checkbox" name="wa9" value="t" /></td>
<td><input type="checkbox" name="tha9" value="t" /></td>
<td><input type="checkbox" name="fa9" value="t" /></td>
<td><input type="checkbox" name="saa9" value="t" /></td>
<td><input type="checkbox" name="sua9" value="t" /></td></tr>
<tr><td>10am</td>
<td><input type="checkbox" name="ma10" value="t" /></td>
<td><input type="checkbox" name="ta10" value="t" /></td>
<td><input type="checkbox" name="wa10" value="t" /></td>
<td><input type="checkbox" name="tha10" value="t" /></td>
<td><input type="checkbox" name="fa10" value="t" /></td>
<td><input type="checkbox" name="saa10" value="t" /></td>
<td><input type="checkbox" name="sua10" value="t" /></td></tr>
<tr><td>11am</td>
<td><input type="checkbox" name="ma11" value="t" /></td>
<td><input type="checkbox" name="ta11" value="t" /></td>
<td><input type="checkbox" name="wa11" value="t" /></td>
<td><input type="checkbox" name="tha11" value="t" /></td>
<td><input type="checkbox" name="fa11" value="t" /></td>
<td><input type="checkbox" name="saa11" value="t" /></td>
<td><input type="checkbox" name="sua11" value="t" /></td></tr>
<tr><td>12pm</td>
<td><input type="checkbox" name="ma12" value="t" /></td>
<td><input type="checkbox" name="ta12" value="t" /></td>
<td><input type="checkbox" name="wa12" value="t" /></td>
<td><input type="checkbox" name="tha12" value="t" /></td>
<td><input type="checkbox" name="fa12" value="t" /></td>
<td><input type="checkbox" name="saa12" value="t" /></td>
<td><input type="checkbox" name="sua12" value="t" /></td></tr>
<tr><td>1pm</td>
<td><input type="checkbox" name="ma13" value="t" /></td>
<td><input type="checkbox" name="ta13" value="t" /></td>
<td><input type="checkbox" name="wa13" value="t" /></td>
<td><input type="checkbox" name="tha13" value="t" /></td>
<td><input type="checkbox" name="fa13" value="t" /></td>
<td><input type="checkbox" name="saa13" value="t" /></td>
<td><input type="checkbox" name="sua13" value="t" /></td></tr>
<tr><td>2pm</td>
<td><input type="checkbox" name="ma14" value="t" /></td>
<td><input type="checkbox" name="ta14" value="t" /></td>
<td><input type="checkbox" name="wa14" value="t" /></td>
<td><input type="checkbox" name="tha14" value="t" /></td>
<td><input type="checkbox" name="fa14" value="t" /></td>
<td><input type="checkbox" name="saa14" value="t" /></td>
<td><input type="checkbox" name="sua14" value="t" /></td></tr>
<tr><td>3pm</td>
<td><input type="checkbox" name="ma15" value="t" /></td>
<td><input type="checkbox" name="ta15" value="t" /></td>
<td><input type="checkbox" name="wa15" value="t" /></td>
<td><input type="checkbox" name="tha15" value="t" /></td>
<td><input type="checkbox" name="fa15" value="t" /></td>
<td><input type="checkbox" name="saa15" value="t" /></td>
<td><input type="checkbox" name="sua15" value="t" /></td></tr>
<tr><td>4pm</td>
<td><input type="checkbox" name="ma16" value="t" /></td>
<td><input type="checkbox" name="ta16" value="t" /></td>
<td><input type="checkbox" name="wa16" value="t" /></td>
<td><input type="checkbox" name="tha16" value="t" /></td>
<td><input type="checkbox" name="fa16" value="t" /></td>
<td><input type="checkbox" name="saa16" value="t" /></td>
<td><input type="checkbox" name="sua16" value="t" /></td></tr>
<tr><td>5pm</td>
<td><input type="checkbox" name="ma17" value="t" /></td>
<td><input type="checkbox" name="ta17" value="t" /></td>
<td><input type="checkbox" name="wa17" value="t" /></td>
<td><input type="checkbox" name="tha17" value="t" /></td>
<td><input type="checkbox" name="fa17" value="t" /></td>
<td><input type="checkbox" name="saa17" value="t" /></td>
<td><input type="checkbox" name="sua17" value="t" /></td></tr>
<tr><td>6pm</td>
<td><input type="checkbox" name="ma18" value="t" /></td>
<td><input type="checkbox" name="ta18" value="t" /></td>
<td><input type="checkbox" name="wa18" value="t" /></td>
<td><input type="checkbox" name="tha18" value="t" /></td>
<td><input type="checkbox" name="fa18" value="t" /></td>
<td><input type="checkbox" name="saa18" value="t" /></td>
<td><input type="checkbox" name="sua18" value="t" /></td></tr>
<tr><td>7pm</td>
<td><input type="checkbox" name="ma19" value="t" /></td>
<td><input type="checkbox" name="ta19" value="t" /></td>
<td><input type="checkbox" name="wa19" value="t" /></td>
<td><input type="checkbox" name="tha19" value="t" /></td>
<td><input type="checkbox" name="fa19" value="t" /></td>
<td><input type="checkbox" name="saa19" value="t" /></td>
<td><input type="checkbox" name="sua19" value="t" /></td></tr>
</tbody>
</table>
</td>

<td>
<label>Pew Campus</label>
<table id="times" border="1"><tbody>
<tr><td> </td><td>Mon</td><td>Tue</td><td>Wed</td>
   <td>Thu</td><td>Fri</td><td>Sat</td><td>Sun</td></tr>
<tr><td>9am</td>
<td><input type="checkbox" name="mp9" value="t" /></td>
<td><input type="checkbox" name="tp9" value="t" /></td>
<td><input type="checkbox" name="wp9" value="t" /></td>
<td><input type="checkbox" name="thp9" value="t" /></td>
<td><input type="checkbox" name="fp9" value="t" /></td>
<td><input type="checkbox" name="sap9" value="t" /></td>
<td><input type="checkbox" name="sup9" value="t" /></td></tr>
<tr><td>10am</td>
<td><input type="checkbox" name="mp10" value="t" /></td>
<td><input type="checkbox" name="tp10" value="t" /></td>
<td><input type="checkbox" name="wp10" value="t" /></td>
<td><input type="checkbox" name="thp10" value="t" /></td>
<td><input type="checkbox" name="fp10" value="t" /></td>
<td><input type="checkbox" name="sap10" value="t" /></td>
<td><input type="checkbox" name="sup10" value="t" /></td></tr>
<tr><td>11am</td>
<td><input type="checkbox" name="mp11" value="t" /></td>
<td><input type="checkbox" name="tp11" value="t" /></td>
<td><input type="checkbox" name="wp11" value="t" /></td>
<td><input type="checkbox" name="thp11" value="t" /></td>
<td><input type="checkbox" name="fp11" value="t" /></td>
<td><input type="checkbox" name="sap11" value="t" /></td>
<td><input type="checkbox" name="sup11" value="t" /></td></tr>
<tr><td>12pm</td>
```

```
<td><input type="checkbox" name="mp12" value="t" /></td>
<td><input type="checkbox" name="tp12" value="t" /></td>
<td><input type="checkbox" name="wp12" value="t" /></td>
<td><input type="checkbox" name="thp12" value="t" /></td>
<td><input type="checkbox" name="fp12" value="t" /></td>
<td><input type="checkbox" name="sap12" value="t" /></td>
<td><input type="checkbox" name="sup12" value="t" /></td></tr>
<tr><td>1pm</td>
<td><input type="checkbox" name="mp13" value="t" /></td>
<td><input type="checkbox" name="tp13" value="t" /></td>
<td><input type="checkbox" name="wp13" value="t" /></td>
<td><input type="checkbox" name="thp13" value="t" /></td>
<td><input type="checkbox" name="fp13" value="t" /></td>
<td><input type="checkbox" name="sap13" value="t" /></td>
<td><input type="checkbox" name="sup13" value="t" /></td></tr>
<tr><td>2pm</td>
<td><input type="checkbox" name="mp14" value="t" /></td>
<td><input type="checkbox" name="tp14" value="t" /></td>
<td><input type="checkbox" name="wp14" value="t" /></td>
<td><input type="checkbox" name="thp14" value="t" /></td>
<td><input type="checkbox" name="fp14" value="t" /></td>
<td><input type="checkbox" name="sap14" value="t" /></td>
<td><input type="checkbox" name="sup14" value="t" /></td></tr>
<tr><td>3pm</td>
<td><input type="checkbox" name="mp15" value="t" /></td>
<td><input type="checkbox" name="tp15" value="t" /></td>
<td><input type="checkbox" name="wp15" value="t" /></td>
<td><input type="checkbox" name="thp15" value="t" /></td>
<td><input type="checkbox" name="fp15" value="t" /></td>
<td><input type="checkbox" name="sap15" value="t" /></td>
<td><input type="checkbox" name="sup15" value="t" /></td></tr>
<tr><td>4pm</td>
<td><input type="checkbox" name="mp16" value="t" /></td>
<td><input type="checkbox" name="tp16" value="t" /></td>
<td><input type="checkbox" name="wp16" value="t" /></td>
<td><input type="checkbox" name="thp16" value="t" /></td>
<td><input type="checkbox" name="fp16" value="t" /></td>
<td><input type="checkbox" name="sap16" value="t" /></td>
<td><input type="checkbox" name="sup16" value="t" /></td></tr>
<tr><td>5pm</td>
<td><input type="checkbox" name="mp17" value="t" /></td>
<td><input type="checkbox" name="tp17" value="t" /></td>
<td><input type="checkbox" name="wp17" value="t" /></td>
<td><input type="checkbox" name="thp17" value="t" /></td>
<td><input type="checkbox" name="fp17" value="t" /></td>
<td><input type="checkbox" name="sap17" value="t" /></td>
<td><input type="checkbox" name="sup17" value="t" /></td></tr>
<tr><td>6pm</td>
<td><input type="checkbox" name="mp18" value="t" /></td>
<td><input type="checkbox" name="tp18" value="t" /></td>
<td><input type="checkbox" name="wp18" value="t" /></td>
<td><input type="checkbox" name="thp18" value="t" /></td>
<td><input type="checkbox" name="fp18" value="t" /></td>
<td><input type="checkbox" name="sap18" value="t" /></td>
<td><input type="checkbox" name="sup18" value="t" /></td></tr>
<tr><td>7pm</td>
<td><input type="checkbox" name="mp19" value="t" /></td>
<td><input type="checkbox" name="tp19" value="t" /></td>
<td><input type="checkbox" name="wp19" value="t" /></td>
<td><input type="checkbox" name="thp19" value="t" /></td>
<td><input type="checkbox" name="fp19" value="t" /></td>
<td><input type="checkbox" name="sap19" value="t" /></td>
<td><input type="checkbox" name="sup19" value="t" /></td></tr>
</tbody></table>
</td></tr><tbody></table>
<p><input type="submit" value="Insert" /></p>
</form></div><br />

<div align="center">
<form method="post" action="data.php">
<p><big>Specify E-mail and Class Name to Delete Entry:</big></p>
<table><tbody>
<tr><td id="searchlabel"><label>E-mail:</label></td>
<td id="searchlabel"><label>Class Name:</label></td></tr>
<tr><td id="search"><input type="text" name="email"
   size="15" maxlength="50" /></td>
<td id="search"><input type="text" name="classname"
   size="15" maxlength="50" /></td></tr>
<input type="hidden" name="category" value="all" />
<input type="hidden" name="delete" value="yes" />
</tbody></table>
<p><input type="submit" value="Delete" /></p>
</form></div><br />

<div align="center">
<form method="post" action="data.php">
<p><big>Group Formation Algorithm:</big></p>
<input type="hidden" name="algorithm" value="yes" />
<p><input type="submit" value="Run" /></p>
</form></div><br />

<h3><a href="http://www.cis.gvsu.edu/~ohearnk/adminlogin.html">Log Out</a></h3>

<!--end main content-->

</body>
</html>
```

```
<!--Project: Computer-Aided Student Study Group Formation
    Author: Kurt O'Hearn
    Date: 6/30/2009
    Description: This page displays the result of the selection
    from the option.php page (search, insert, delete, run algorithm).
    The search option queries the database for all or specific
    information and displays that information. The delete and insert
    options change entries in the database and then display the
    newly changed database. The run algorithm option forms study groups
    by copying all entries from the database into temporary arrays
    and manipulating the data.

    The Ronald E. McNair Post-Baccalaureate Achievement Program
    at Grand Valley State University provided funding and
    support to perform this project. Dr. Roger Ferguson mentored
    this project.
-->

<!DOCTYPE html PUBLIC "-//W3C/DTD XHTML 1.0 Transitional//EN"

"http://www.w3.org/TR/html4/loose.dtd">

<html xmlns="http://www.w3.org/1999/xhtml">

<head>
<meta http-equiv="content-type"
content="text/html; charset=utf-8" />
<title>Data</title>
<link rel="stylesheet" type="text/css"
href="style1.css" />
</head>

<body>

<!--header-->

<img src="Computer-Aided_Student_Study_Group_Formation_Webpage_Logo2.JPG"
   width=100% height=200px />

<!--end header-->

<!--main content-->

<div align = "center">

<?php

//This function copies all selected data stored in the database and displays it
function display ($q) {
   print "<table border = '1'> <tbody>";
   print "<tr><td>E-mail</td><td>First Name</td><td>Last
Name</td><td>Nickname</td>" .
   "<td>Gender</td><td>Gender Preference</td><td>Class Standing</td><td>Class
Name</td>" .
   "<td>Knowledge Level</td><td>Study Times</td></tr>";
   while ($r = mysql_fetch_row($q)) {
       print "<tr>";
       foreach ($r as $column)
           print "<td>".$column."</td>";
       print "</tr>";
   }
   print "</tbody> </table>";
}
```



```
//This function copies all data stored in the database to temporary arrays for
manipulation
//to run the group formation algorithm
function transfer () {
   //Copy information from database
   $q = mysql_query ("SELECT email, fname, lname, nickname, gender, genderpref,
classstanding," .
   " classname, level, time FROM mcnairdb.table1") or die (mysql_error());
   $i = 0;
   while ($r = mysql_fetch_row($q)) {
       $emails[$i] = $r[0];
       $fnames[$i] = $r[1];
       $lnames[$i] = $r[2];
       $nicknames[$i] = $r[3];
       $genders[$i] = $r[4];
       $genderprefs[$i] = $r[5];
       $classstanding[$i] = $r[6];
       $classnames[$i] = $r[7];
       $levels[$i] = $r[8];
       $times[$i] = $r[9];
       $i++;
   }

   //Assigned group number. By default, each person is assigned a "0"
   //which means no group is assigned
   for($j = 0; $j <= $i; $j++)
      $gassign[$j] = 0;

   //Temporary time match number used to create a pool of group candidates
   for($j = 0; $j <= $i; $j++)
      $ttemp[$j] = 0;

   //Day of group meeting
   for($j = 0; $j <= $i; $j++)
      $gday[$j] = "";

   //Time of group meeting
   for($j = 0; $j <= $i; $j++)
      $gtime[$j] = "";

   //Storage of all the arrays into another array for easy access to all data
   $data = array(0 => $emails, 1 => $fnames, 2 => $lnames, 3 => $nicknames, 4 =>
$genders,
   5 => $genderprefs, 6 => $classstandings, 7 => $classnames, 8 => $levels, 9 =>
$times,
   10 => $gassign, 11 => $ttemp, 12 => $gday, 13 => $gtime);

   return $data;
}

//This function counts the number of entries in the database
function dbSize () {
   $size = 0;
   $q = mysql_query ("SELECT email FROM mcnairdb.table1") or die (mysql_error());
   while ($r = mysql_fetch_row($q))
       foreach ($r as $column)
           $size++;

   return $size;
}

//This function determines the meeting day of a group
//in the group formation algorithm
```

```
function assignGroupDay ($k) {
   if(((int)($k / 11)) == 0 || ((int)($k / 11)) == 7)
      return "Monday";
   else if(((int)($k / 11)) == 1 || ((int)($k / 11)) == 8)
      return "Tuesday";
   else if(((int)($k / 11)) == 2 || ((int)($k / 11)) == 9)
      return "Wednesday";
   else if(((int)($k / 11)) == 3 || ((int)($k / 11)) == 10)
      return "Thursday";
   else if(((int)($k / 11)) == 4 || ((int)($k / 11)) == 11)
      return "Friday";
   else if(((int)($k / 11)) == 5 || ((int)($k / 11)) == 12)
      return "Saturday";
   else
      return "Sunday";
}

//This function determines the meeting time of a group
//in the group formation algorithm
function assignGroupTime ($k) {
   if($k % 11 == 0)
      return "9AM";
   else if($k % 11 == 1)
      return "10AM";
   else if($k % 11 == 2)
      return "11AM";
   else if($k % 11 == 3)
      return "12PM";
   else if($k % 11 == 4)
      return "1PM";
   else if($k % 11 == 5)
      return "2PM";
   else if($k % 11 == 6)
      return "3PM";
   else if($k % 11 == 7)
      return "4PM";
   else if($k % 11 == 8)
      return "5PM";
   else if($k % 11 == 9)
      return "6PM";
   else
      return "7PM";
}

//This function displays the output of the group
//formation algorithm (i.e. groups)
function displayGroups ($gnumber, $size, $data) {
      for ($j = 1; $j < $gnumber; $j++) {
         print "<BR><table><tbody>";
         print "<tr><td><ins>Group#$j</ins></td></tr>";
         print "</tbody></table>";
         for ($i = 0; $i < $size; $i++)
            if($data[10][$i] == $j) {
               print "<table><tbody>";
               print "<tr>";
               print "<td id='algorithm'>".$data[0][$i]."</td>";
               print "<td id='algorithm'>".$data[1][$i]."</td>";
               print "<td id='algorithm'>".$data[2][$i]."</td>";
               print "<td id='algorithm'>".$data[3][$i]."</td>";
               print "<td id='algorithm'>".$data[7][$i]."</td>";
               print "<td id='algorithm' >".$data[12][$i]."</td>";
               print "<td id='algorithm'>".$data[13][$i]."</td>";
               print "</tr>";
               print "</tbody></table>";
            }
      }
}

//This function generates an array containing one entry for
//each unique class name to use in the group formation algorithm
function getClasses () {
   //Copy class names
   $q = mysql_query ("SELECT classname FROM mcnairdb.table1") or die
(mysql_error());
   $i = 0;
   while ($r = mysql_fetch_row($q)) {
       foreach ($r as $column)
          if($i == 0) {
             $cnames[$i] = $column;
             $i++;
          }
          else {
             $flag = 0;
             for($j = 0; $j < $i; $j++)
                if($cnames[$j] == $column)
                   $flag = 1;
             if($flag == 0) {
                $cnames[$i] = $column;
                $i++;
             }
          }
   }

   return $cnames;
}

//This function works identically to the function above
//except it returns the number of unique classes instead
function getNumberOfClasses () {
   //Copy class names
   $q = mysql_query ("SELECT classname FROM mcnairdb.table1") or die
(mysql_error());
   $i = 0;
   while ($r = mysql_fetch_row($q)) {
       foreach ($r as $column)
          if($i == 0) {
             $cnames[$i] = $column;
             $i++;
          }
          else {
             $flag = 0;
             for($j = 0; $j < $i; $j++)
                if($cnames[$j] == $column)
                   $flag = 1;
             if($flag == 0) {
                $cnames[$i] = $column;
                $i++;
             }
          }
   }

   return $i;
}

   //Process data needed to discern option
   if(array_key_exists("category", $_POST))
```

```
   $category = $_POST['category'];
if(array_key_exists("keyword", $_POST))
   $keyword = $_POST['keyword'];
if(array_key_exists("insert", $_POST))
   $insert = $_POST['insert'];
if(array_key_exists("delete", $_POST))
   $delete = $_POST['delete'];
if(array_key_exists("algorithm", $_POST))
   $algorithm = $_POST['algorithm'];

//Create time string for manipulation
$atime = "";
$ptime = "";
//Allendale Campus Times
for($i = 9; $i <= 19; $i++)
   (array_key_exists("ma$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("ta$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("wa$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("tha$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("fa$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("saa$i", $_POST) ? $atime .= '1' : $atime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("sua$i", $_POST) ? $atime .= '1' : $atime .= '0');
//Pew Campus Times
for($i = 9; $i <= 19; $i++)
   (array_key_exists("mp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("tp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("wp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("thp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("fp$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("sap$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
for($i = 9; $i <= 19; $i++)
   (array_key_exists("sup$i", $_POST) ? $ptime .= '1' : $ptime .= '0');
$time = $atime.$ptime;

//Search input error checking
if ($category != "all" && !$keyword && !$algorithm) {
     print "<error>Error: No Search Term</error><BR>";
     exit(0);
}

//Database connection and manipulationnn
mysql_connect("localhost", "mcnairdb", "mcnairdb1579") or die ("<error>No Connection." .
" Please Try Again Later.</error><BR>");

//Create table
//   mysql_query ("CREATE TABLE mcnairdb.table1(email CHAR(40) PRIMARY KEY, fname " .
//   "CHAR(30), lname CHAR (30), nickname CHAR (30), gender CHAR (1), genderpref " .
//   "CHAR (1), classstanding CHAR (9), classname CHAR (6), level CHAR (1), time " .
//   "CHAR (154))");

//Delete entry
//Before inserting new entry, all similar entries
```



```
//to new entry are deleted to prevent duplications
if ($delete == "yes") {
   $temp = "DELETE FROM mcnairdb.table1 WHERE email = '$email' && " .
   "classname = '$classname'";
   mysql_query ($temp) or die (mysql_error());
}

//Insert new entry
if ($insert == "yes") {
   //Process data needed to insert new entry
   if(array_key_exists("fname", $_POST))
      $fname = $_POST['fname'];
   if(array_key_exists("lname", $_POST))
      $lname = $_POST['lname'];
   if(array_key_exists("email", $_POST))
      $email = $_POST['email'];
   if(array_key_exists("nickname", $_POST))
      $nickname = $_POST['nickname'];
   if(array_key_exists("gender", $_POST))
      $gender = $_POST['gender'];
   if(array_key_exists("genderpref", $_POST))
      $genderpref = $_POST['genderpref'];
   if(array_key_exists("classstanding", $_POST))
      $classstanding = $_POST['classstanding'];
   if(array_key_exists("classname", $_POST))
      $classname = $_POST['classname'];
   if(array_key_exists("level", $_POST))
      $level = $_POST['level'];

   //Insert entry general error checking
   if ((!$fname || !$lname || !$email || !$nickname || !$gender || !$genderpref
   || !$classstanding || !$classname || !$level) ) {
        print "<error>Error: Incorrect Data Entry</error><BR>";
      print "<error>Please Fill In All Areas Before Inserting</error><BR>";
        exit(0);
   }

   //Insert entry study times error checking
   if ($ptime == "000000000000000000000000000000000000000000000000" .
   "000000000000000000000000000" && $atime == "000000000000000000" .
   "000000000000000000000000000000000000000000000000000000000000") {
      print "<error>Error: Incorrect Data Entry</error><BR>";
      print "<error>Please Fill In At Least 1 Available Study Time" .
      " Before Submitting</error><BR>";
        exit(0);
   }

   $temp = "INSERT INTO mcnairdb.table1(email, fname, lname, nickname, " .
   "gender, genderpref, classstanding, classname, level, time) VALUES " .
   "('$email', '$fname', '$lname', '$nickname', '$gender', '$genderpref'," .
   " '$classstanding', '$classname', '$level', '$time')";
   mysql_query ($temp) or die (mysql_error());
}

//Query options by category
//Query db for all data
if ($category == "all")
   $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
   " genderpref, classstanding, classname, level, time" .
   " FROM mcnairdb.table1") or die (mysql_error());

//Query db for matching email entries only
else if ($category == "email")
```

```
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE email = '$keyword'") or die (mysql_error());

   //Query db for matching first name entries only
   else if ($category == "fname")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE fname = '$keyword'") or die (mysql_error());

   //Query db for matching last name entries only
   else if ($category == "lname")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE lname = '$keyword'") or die (mysql_error());

   //Query db for matching nickname entries only
   else if ($category == "nickname")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE nickname = '$keyword'") or die (mysql_error());

   //Query db for matching gender entries only
   else if ($category == "gender")
      $q = mysql_query ("SELECT email, fname, lname, nickname," .
      "gender, genderpref, classstanding, classname, level, time " .
      "FROM mcnairdb.table1 WHERE gender = '$keyword'") or die (mysql_error());

   //Query db for matching gender preferences entries only
   else if ($category == "genderpref")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE genderpref = '$keyword'") or die
(mysql_error());

   //Query db for matching class standing entries only
   else if ($category == "classstanding")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE classstanding = '$keyword'") or die
(mysql_error());

   //Query db for matching class name entries only
   else if ($category == "classname")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE classname = '$keyword'") or die
(mysql_error());

   //Query db for matching knowledge level entries only
   else if ($category == "level")
      $q = mysql_query ("SELECT email, fname, lname, nickname, gender," .
      " genderpref, classstanding, classname, level, time" .
      " FROM mcnairdb.table1 WHERE level = '$keyword'") or die (mysql_error());

   if (!$algorithm) {
      //Display query option
      print "<BR>";
      display($q);
      print "<BR>";
   }

   //Group formation algorithm execution
```



```
if ($algorithm == "yes") {
   //Copy All Data from the Database and Store Temporarily for Algorithm Execution
   $data = transfer();
   //Copy array of class names
   $cnames = getClasses();
   //Determine the number of unique class entries
   $numberofclasses = getNumberOfClasses();
   //Study group formation algorithm
   $size = dbSize(); //Number of entries in db
   $gnumber = 1; //Group assignment number. Increments with each new group.

   //Cycle through study times
   for($m = 0; $m < $numberofclasses; $m++)
      for($k = 0; $k <= 153; $k++) {
         $pool = 0;
         //Cycle through db entries
         for($i = 0; $i < $size; $i++)
            if($k <= 152)
               //Check entry if possible match for pool, then add
               if(strcmp(substr($data[9][$i], $k, -153 + $k), 1) == 0
               && $data[10][$i] == 0 && $data[7][$i] == $cnames[$m]) {
                  $data[11][$i] = 1;
                  $pool++;
               }
               //Remove entry from pool if not possible match
               else
                  $data[11][$i] = 0;

            //To Compare the Last Piece of the String;
            //Couldn't Use strcmp for last element with zero for reverse number
            else
               //Check entry if possible match for pool, then add
               if(strcmp(substr($data[9][$i], -1), 1) == 0
               && $data[10][$i] == 0 && $data[7][$i] == $cnames[$m]) {
                  $data[11][$i] = 1;
                  $pool++;
               }
               //Remove entry from pool if not possible match
               else {
                  $data[11][$i] = 0;
               }

   //Check for large enough pool to form group
   $j = 0;
   if($pool >= 2)
      //Able to form another group
      while($pool != 0) {
         $thisgroup = $pool % 6;
         if($pool == 0)
            $thisgroup == 6;
         while($thisgroup > 0) {
            //Add member to group
            if($data[11][$j] == 1) {
               $data[10][$j] = $gnumber;
               //Assign group day
               $data[12][$j] = assignGroupDay($k);
               //Assign group time
               $data[13][$j] = assignGroupTime($k);
               $thisgroup--;
               $pool--;
            }

            //Next group
```

```
                    if($thisgroup == 0)
                       $gnumber++;
                    $j++;
                 }
              }
        }
      //Display groups
      displayGroups($gnumber, $size, $data);
   }

   //Delete Table
//   mysql_query("DROP TABLE mcnairdb.table1") or print "Failure to drop table" .
//   " -> Table does not exist6<BR>";
   mysql_close();
?>

<br /><form method="post" action="option.php">
<input type="hidden" name="username" value="administrator" />
<input type="hidden" name="password" value="admin" />
<input type="submit" value="Previous Page" />
</form>

</div>

<h3><a href="http://www.cis.gvsu.edu/~ohearnk/adminlogin.html">Log Out</a></h3>

<!--end main content-->

</body>

</html>
```

```
<!--CSS-->

body
   {background: #AEFA73}
h2
   {font-size: 28px;
    text-align: center;}
h3
   {text-align: center;}
error
   {font-size: 28px;
    color:red;
    width: 100%;
    text-align: center;}
label
   {color: white;
    background: #0561A5;
    font-weight: bold;
    border: 1px solid black;}
input
   {margin-left: .5em;
    margin-bottom: .2em;
    line-height: 1.4em;}
p.group
   {font-family: "Freestyle Script", sans-serif;
    font-size: 24px;}
td
   {text-align: center;
    width: 25px;}
#loginlabel
   {text-align:left;
    width: 50px;}
#label
   {text-align:left;
    width: 250px;}
#searchlabel
   {text-align:left;
    width: 55px;}
#data
   {text-align:left;
    width: 325px;}
#dpata
   {text-align:left;
    width: 50px;}
#search
   {text-align: left;
    width: 55px;}
#algorithm
   {text-align: center;
    width: 175px;}
a:link
   {font-weight: bold;
    color:red;}
a:visited
   {color:orange;}
a:focus
   {color:purple;}
a:hover
   {color:green;}
a:active
   {color:blue;}
```

References

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Development of the Innate Immune Response in Nestling Tree Swallows (*Tachycineta bicolor*)

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Abstract

The innate immune system provides an immediate, short term, first line of defense from pathogens; its appearance early in development in vertebrates is evidence of its critical importance. Even so, few studies have investigated the development of the immune response as juveniles transition into adults. Ultimately, the ability to respond to pathogens confers fitness benefits in terms of health, survival, and reproductive success, and it follows that functions such as rapid growth cannot be fully met simultaneously since energy is a limiting resource. As a result, defense mechanisms are compromised at an early age due to energy allocation to rapid growth; therefore, immunity should increase as individuals mature. I studied the development of innate immunity in nestling Tree Swallows using microbicidal assays which were conducted in vitro to assess the ability of the immune system to kill E. coli via lysis. This research may provide insight into patterns of disease susceptibility, which in turn influence evolutionary fitness and population dynamics.

Introduction

Ecoimmunology seeks to explore and understand various immune defense strategies observed among species. The ecological study of the development of immune function in birds and other vertebrates is in its infancy [1], and age-specific variation in immune function has been understudied in regard to innate immune development in wild animals [2, 1].

The vertebrate immune system consists of two components: innate and acquired immunity [3]. Innate immunity is the nonspecific response to pathogens through complement, a cascade of proteins acting in sequence to produce biological effects concerned with inflammation and the lysis of cells, and phagocytosis, macrophages that ingest foreign particulate matter by enveloping them into the cell, occurring in the blood. Unlike acquired immunity, which develops over the lifetime of an organism from previous encounters with pathogens, innate immunity is present at birth. Innate immunity provides an immediate, short-term, first line of defense that develops throughout the juvenile stage. Because these components have a genetic basis, they are directly subjected to natural selection, thus favoring the evolution of immune competence, and observations that the components of the innate immune system appear early in development in vertebrates [2, 4], including Tree Swallows, *Tachycineta bicolor* [1], are evidence of its critical importance.

Immune function involves life-history trade-offs influenced by differences in energy allocation to growth, maintenance and reproduction [5], all of which are energetically costly [6]; thus these three processes cannot be fully met simultaneously. Juveniles use energy for growth and maintenance, whereas adults use energy for maintenance and reproduction. Ultimately, the ability to respond to pathogens confers fitness benefits in terms of health, survival, and reproductive success [7]. Selection should favor those individuals that are able to budget their energy so as to balance the demands of growth and maintenance. This demand results in strong selection pressures on developing songbirds, which must grow rapidly to be able to leave the nest and avoid predation [8] while at the same time develop a competent innate immune response.

Most ecoimmunological studies have not focused on the development of innate immunity in immature, wild animals, but rather have used domesticated species such as chickens with precocial development [9, 10] as opposed to altricial development found in wild Tree Swallows and other passerines. Furthermore, chickens have been artificially bred for increased body growth for meat production or egg-laying, which may alter their lifespan, thus possibly altering natural, innate immune defense mechanisms [11, 12]. Additionally, in those studies that do exist on wild species, measurements were primarily taken at one specific age (e.g., 12 days after hatching), neglecting developmental stages as juveniles transition into adults.

Studies on the development of immune defense in nestling Tree Swallows may provide insight into patterns of age-related disease susceptibility, which in turn influences evolutionary fitness and population dynamics [13]. I studied the development of innate

immunity in a free-living, altricial bird, the Tree Swallow. Microbicidal assays [14] were used to examine age-specific variation in the innate immune function of nestlings at different stages of development, and I predicted that immune function would increase over the course of the nestling period.

Methods

Tree Swallows are a common, aerially foraging, passerine species distributed throughout North America that readily accept nest boxes as breeding sites. Females usually lay clutches of 5-6 eggs which hatch after approximately 15 days of incubation displaying. Hatchlings are altricial, and both parents feed the nestlings up until the time they fledge, which is about 20 days [15]. I studied Tree Swallows that nested in wooden nest boxes arranged in grids in an old field on the campus of Grand Valley State University (GVSU) (42º57′N, 85º53′W), Ottawa County, Michigan in June and early July, 2009. Nests were monitored closely to determine clutch completion date, exact hatch date, and, therefore, exact nestling age.

I collected blood samples from 36 nestlings. Due to the small size of Tree Swallows, I obtained only a single blood sample from each individual nestling to prevent jeopardizing its health. Tree Swallow nestlings undergo three basic stages of development: their eyes open 3-4 days after hatching; they develop endothermy 8-9 days after hatching [16]; and, they fledge approximately 20 days after hatching [15]. I examined the innate immune system at nestling days (ND; ND-0 = the day the first egg in a clutch hatched) 6, 12, and 18, which fall in the range of these developmental stages. At ND-3-4, nestlings were too small to obtain blood samples of adequate volume to perform *in vitro* assays, so I began drawing blood from ND-6 nestlings, which weigh 10-12 g, about half as much as adult swallows weigh [15]. At ND-12, Tree Swallow nestlings weighed as much or more than adults and then dropped in weight as they began to allocate their energy into feather growth [16, 15]. In addition, on ND-18 nestlings, I measured nestling mass to the nearest 0.2 g with a Pesola spring, and flattened wing chord of the right wing to the nearest 1 mm using a ruler with a stop fixed to one end.

Blood samples were collected within 3 min. of handling because the stress hormone corticosterone, which can affect immune response, remains at or near baseline levels in birds for up to 3 min. following handling [17]. Blood was collected into sterile heparinized capillary tubes (50-75 µL capacity) directly from the brachial vein in the wing after venipuncture using sterile lancets or needles. Prior to venipuncture, the area on the wing was sterilized with 70% ethanol. Venipuncture and blood collection occurred after the ethanol completely evaporated because ethanol can cause hemolysis, which can complicate immune assays [14]. Capillary tubes were sealed with clay and placed in sterilized containers for transport to the lab. Blood was transported to the laboratory usually within 60 min. of collection for the best results during immune assays [14].

The microbicidal assay produces an index of the capacity of the blood, measuring how rapidly it can thwart an invasion by potential pathogens [14]. This assay is a general *in vitro* measurement of the effectiveness of the innate immune system because it evaluates the ability of multiple elements in the blood (e.g., white blood cells, natural and specific antibodies, lysozimes, and opsonins [molecules that help white blood cells to bind to potential pathogens during phagocytosis]) to kill microbes, and the assay integrates many of the important components of the innate immune system [14].

This assay is ideal for examining innate immunity in small birds for two reasons. First, it was optimized to evaluate the immunocompetence of the innate immune system using very small blood volumes (< 100 µL) with species-non-specific reagents [14]. Second, it was developed to be a rapid, simple, and reliable measure of innate immune function and does not require elaborate training or specialized equipment.

Microbicidal Assay—This assay evaluated the ability of constituents found in whole blood to kill microbes following the methods described in Millet et al. (2007). Assays were performed on samples of less than 100 µL. Briefly, I tested the ability of whole blood to kill microbes *Escherichia coli* (ATCC#8739, Microbiologics Inc., Saint Cloud, MN) supplied as 10 organisms per lyophilized pellet. These are common microbes and did not need special treatment beyond normal microbiological methods. All lab work took place inside laminar flow hoods. Microbe pellets were reconstituted according to manufacturer's instructions in 40 mL of sterile, endotoxin-free Phosphate Buffered Saline (PBS) and held at 4º C. Each day that assays were run, the stock culture was diluted with cold PBS to make a working culture with approx. 50,000 microbes/mL. Working cultures were kept on ice.

Whole blood was diluted to 1:4 with prewarmed (41º C) CO -independent media (#18045; Gibco-Invitrogen, Californai, CA) plus 4mM L-glutamine in a sterile 1.5 mL capped tube. Ten microliters of the working culture (200 microbes) was added per 100 µL of diluted blood, vortexed, and incubated for 45 min. at 40.5 º C. After incubation samples were removed from the incubator, vortexed, and duplicated, 50 µL aliquots were pipetted onto agar plates, spread, inverted, and incubated at 37º C for 24 hours. E. coli colonies were counted after 24 hours. The number of microbes in the initial inoculums were determined by diluting microbes in media alone (10 µL of working culture per 100 µL of media) and then immediately plated. Negative controls in which no microbes were added were also prepared. Microbicidal activity of the blood was defined as the percent of the inoculum killed which equal 1- (viable microbes after incubation/number inoculated) [14].

Responsible Conduct of Research—The methods used in this study were in accordance with suggestions for the ethical handling of wild birds [18]. We obtained permission to conduct this study from the GVSU Institutional Animal Care and Use Committee (IACUC).

Results

Total numbers of agar plated E. coli bacteria were measured in nestlings at ND-6 (n = 10), ND-12 (n = 16), and ND-18 (n = 22). Lysis increased as birds matured; the ability of constituents in the blood to kill this pathogen increased from approximately zero at ND-6 to 22% at ND-12 to 43% at ND-18 (ANOVA, $F = 12.25$, $df = 2,50$, $P < 0.001$, Fig. 1). Neither wing chord nor mass showed any significant correlation in the amount of lysis that occurred in ND-12s and ND-18s (Fig. 2 & 3). Even though ND-18 nestlings became independent when they fledged, their innate immune systems were not fully developed. In comparison, adult Tree Swallows (n = 79) (B. Houdek et al., unpublished data) at my study site displayed significantly greater lysis (mean = 82.6% ± 24.6%) than did nestlings at ND-18 (ANOVA, $F = 62.12$, $df = 3,123$, $P < 0.001$). Though body weight remained nearly the same (ND-18 mean mass = 21.0 g, n = 22; adult mean mass = 20.8g, n = 79), wing length was significantly shorter (second year female = 110.3mm ± 2.6mm, µ ± sd, n = 77; after second year female = 112.3mm ± 3.1mm, µ ± sd, n = 216; second year male = 116.7mm ± 4.0mm, µ ± sd, n = 51; after second year male = 116.2mm ± 3.4mm, µ ± sd, n = 114) and percent lysis (fig. 4) was significantly less in ND-18s than in adults (Mann-Whitney $U = 267.5$, $P < 0.001$).

Discussion

These data show evidence of life-history trade-offs. At ND-6, nestlings possessed little to no immunity (Fig. 1) while presumably expending considerable amounts of energy on body growth [5]. At ND-12, Tree Swallow nestlings showed increased immunity over that of ND-6 nestlings (Fig. 1) and weighed as much or more than adults and then dropped in weight as they began to allocate their energy into feather growth [16, 15]. As they transitioned to ND-18, there was another significant increase in immunity (Fig. 1) while body mass increased to a weight similar to that of adults. Energy allocation to innate immunity appeared to differ between the three stages of development in nestlings as well as between ND-18 nestlings and adults. Though body weight remained nearly the same, percent lysis (Fig. 4) was significantly less in ND-18s than in adults. This suggested that a large amount of energy was still being used by ND-18s for wing growth, thus less was devoted to developing immunity, further suggesting differences in energy allocation with an immunological cost during growth and development, which is consistent with findings in previous studies [19, 5].

In addition to trade-offs between growth and immune development, it has been shown that increased reproductive effort reduces humoral immunocompetence [20] in both adult female Barn Swallows, *Hirundo rustica*, and her nestlings, showing decreased immunity as brood size increases due to lower per capita feeding rate with limited resources [21]. This was supported with the findings of Nordling et al., [22] which showed that female Collared Flycatchers, *Ficedula albicollis*, raising enlarged broods, had lower humoral immunocompetence and increased parasitism, and that parasitism was associated with a reduction in survival probability. Because the immune system is designed to prevent and control infection by pathogens and parasites, a reduction in immunocompetence might lead to an increased risk of infection, thus reduced fitness and chances of survival [7].

Finally, there are data suggesting that leaving the nest upon a predation attempt could be part of the normal behavioral repertoire of altricial nestlings [23] and is associated with adaptations in their ontogenesis and morphology [24]. Research on Meadow Pipits, *Anthus pratensis* [25], suggests patterns of growth in nestlings with directional selection for high growth rates, where the mean growth rate of nestlings in entirely depredated broods was lower than the population mean while that for partially depredated broods was higher. In broods that grew extremely slowly, the number of nestlings was reduced by either nestling competition for food or by predation, or by a combination of both. Magrath [26] showed that the post-fledging survival of slowly growing young is low, suggesting that mortality due to lack of food and by predation were synergistic, yet both acted independently [25] and differed with range. All broods in Halupka's study, with the exception of those birds that grew extremely fast, were susceptible to predation, and only the slowest growing nestlings suffered from mortality associated with the food shortage. Thus, it appears that nest predation is the most important factor selecting for rapid growth in altricial bird species, including Tree Swallows.

In summary, I studied the development of the innate immune response in nestling Tree Swallows at different stages of development via blood samples using microbicidal assays. Since there is strong selection pressure to develop a competent innate immune response, as expected, there was a steady increase in the ability of the innate immune system to kill bacteria as juveniles transitioned into independence along with transitions in energy allocation. Energy is limited, and because of this, there are physiological trade-offs within an energy budget in terms of costs and benefits. Juveniles appeared to allocate more energy to maintenance and rapid growth, with apparently little energy towards immunity, as clearly seen with the ND-6 nestlings. Energy allocation to immunity appeared to increase throughout each subsequent stage of development, with full immune potential not being reached until after fledging. This trade-off may reflect the balance between predation and pathogen pressures on nestlings favoring selection on rapid growth.

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Figure 1. Mean percent lysis (± SE) measuring the ability of the blood to kill bacteria *E. coli* at different stages of development in nestling Tree Swallows (ANOVA, F = 12.25, df = 2,50, P < 0.001).

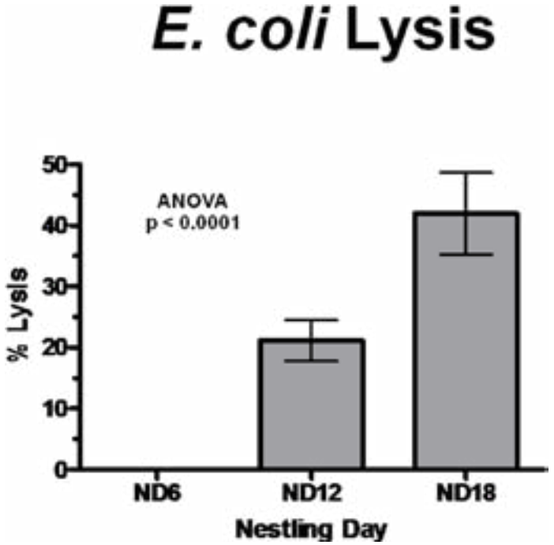


Figure 2. Measurements of wing chord and mass showing percent lysis assessing the ability of the blood to kill bacteria *E. coli* for each nestling day 12 Tree Swallow sampled.

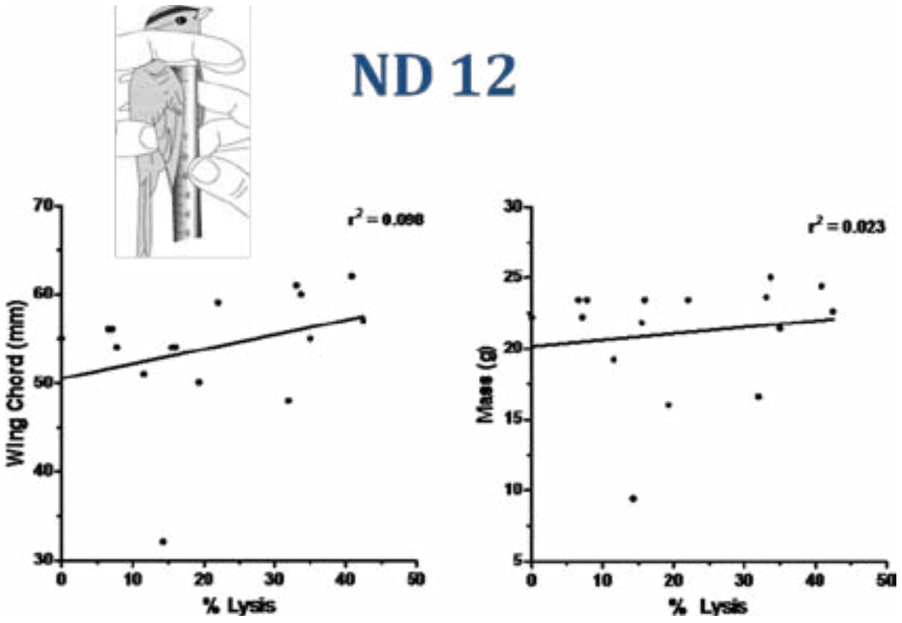


Figure 3. Measurements of wing chord and mass showing percent lysis assessing the ability of the blood to kill bacteria *E. coli* for each nestling day 18 Tree Swallow sampled.

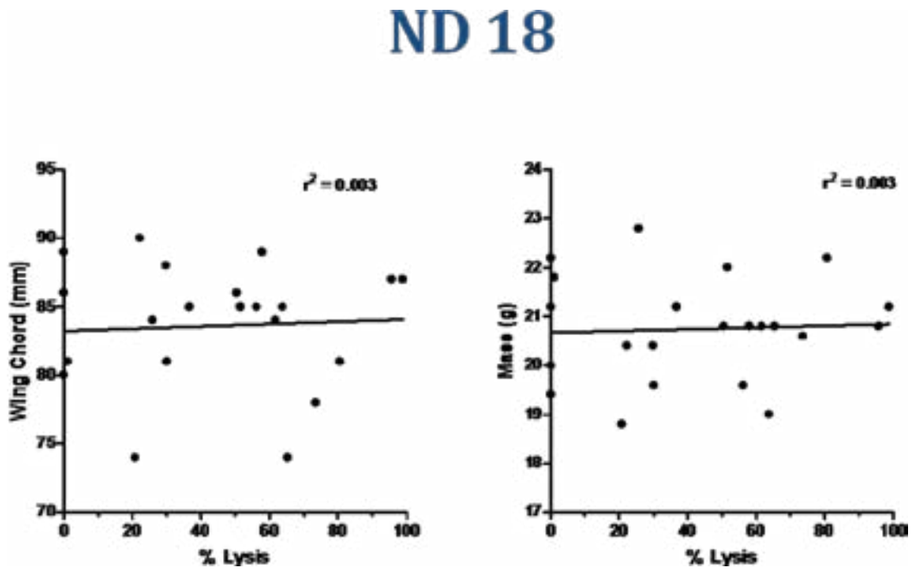
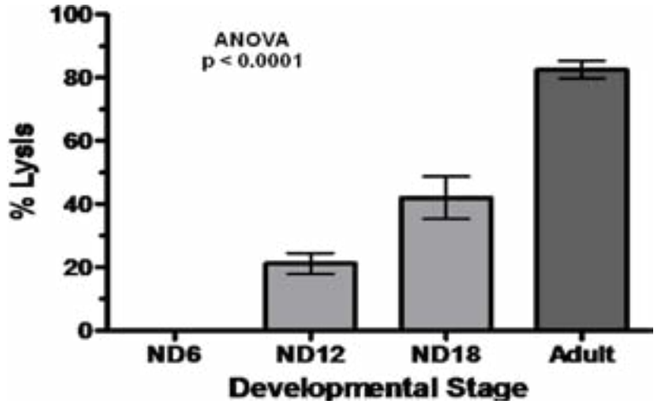


Figure 4. Mean percent lysis (± SE) measuring the ability of the blood to kill E. coli bacteria at different stages of development, including adults, in Tree Swallows (ANOVA, F = 62.12, df = 3,123, P < 0.001).



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