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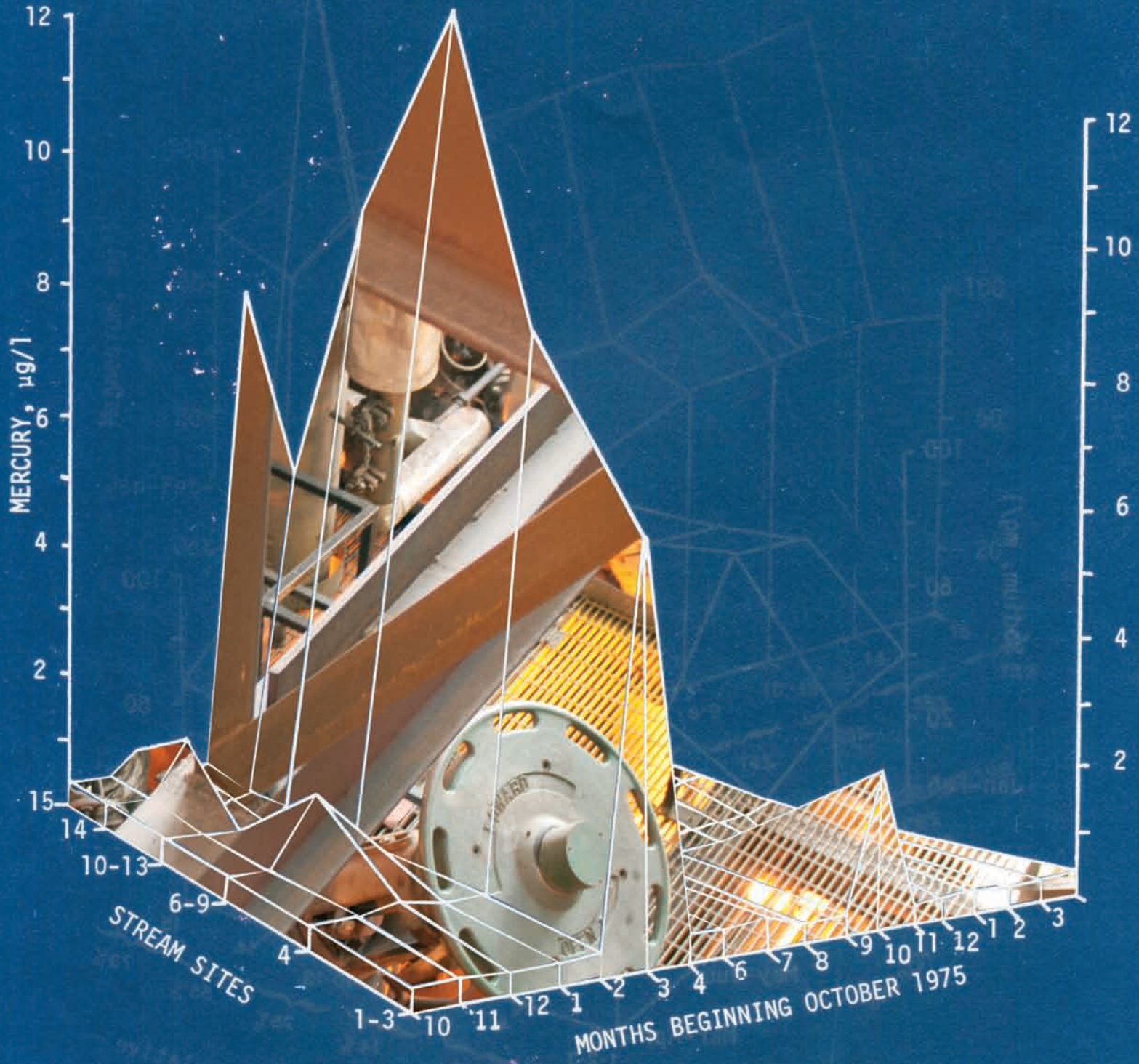

Figure 14. Spatial and temporal changes in mercury.

The Journal of Undergraduate Research is an annual publication by the Center for Undergraduate Research that features the scholarship of undergraduates at the University of Kansas.

COVER
Erin Dvorak, "Figure 14," Senior in Photo Media;
Mentor: Bryon Darby, Assistant Professor of Photo Media

Photography has changed the public's perception of various social and political issues since the medium's conception. By exploring a topical subject, the photographer makes the issue accessible on a personal level and promotes awareness of said topic. Photography is significant in this sense as it fosters an understanding accessible by all viewers. By creating work centered on energy production and consumption, viewers have the opportunity to connect with our current state of energy in order to create a higher level of cognizance of this complex subject. Most consumers are disconnected with the environmental, political, and social issues that our source of livelihood creates, and spending time with the various layers of energy production will educate the community about these realities.

After touring the Westar Energy Center in Lawrence, KS, I was inspired to create images that reflected the complex process of coal energy production. This image was created using strictly documentary photography as well as excerpts from research conducted in the 1970's about the various emissions released with coal fired energy production. Juxtaposing these various mediums of research from the past and present gives viewers a new perspective and an outlet to pursue their own curiosities.

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Q&A

How did you become involved in doing research?
I started working in a research lab as a Research Assistant during my sophomore year of college when my professors encouraged me to get involved with academic activities on campus. I gradually grew more and more interested in it, and finally decided to do my own independent project: a senior honors thesis.

How is the research process different from what you expected?
I didn't expect that there would be so many administrative aspects to running a study, such as getting IRB approval and applying for grants. However, I think it was really good that I could get that experience during my undergraduate career.

What is your favorite part of doing research?
I enjoy coming up with a research hypothesis and design based on prior studies in the literature.

Evaluating body dissatisfaction as a moderator between physical self-concept and physical activity

Stephanie Chen

ABSTRACT
Physical activity has been shown to be an important behavior, central to long-term physical, social, and mental health benefits. Unfortunately, recent research has also demonstrated that most American adults fall short of the ideal 150 minutes of moderate-intensity exercise and muscle training per week, often leading to serious health implications. The current study seeks to better understand the psychosocial predictors of physical activity (PA), such as physical self-concept (PSC) and body dissatisfaction (BD) in women. Participants (n=102, mean age = 19.45, SD = 1.91) completed self-report measures of the Physical Self-Description Questionnaire (PSDQ) and the Body Shape Questionnaire (BSQ), with PA being objectively measured through archival data from the student fitness center. It was hypothesized that PSC would positively predict PA and that BD would have a curvilinear moderating effect on the relationship between PSC and PA. Results supported the relationship between PSC and PA, but no moderating effect was found for BD, showing that further research is needed to evaluate the replication of such an effect.

The overall deficiency in physical activity has had an impact on the general health of the population in the United States.

Physical activity has been shown to be an important behavior for general health promotion and maintenance (Haskell et al., 2007; U.S. Department of Health and Human Services [HHS], 2008). Regular exercise for people of all ages produces long-term health benefits; these include sustaining optimum metabolism and body weight, improving bone and muscle density, preventing chronic illnesses such as heart disease or type 2 diabetes, reducing the risk of certain cancers, and promoting overall cardiovascular and muscular fitness (Schnor, Lange, Scharling & Jensen, 2006; Folsom, Arnett, Hutchinson, Liano, Clegg & Cooper, 1997). Beyond these purely physical reasons, physical activity also encourages healthy social opportunities with friends and family, improves mood and mental health, and increases both quality of life and the chances of living a longer life (Osei-Tutu & Campagna, 2005; Wennlof, Yngve, Nilsson, & Sjostrom, 2005; Biddle & Mutrie, 2008). The Centers for Disease Control and Prevention (CDC; 2010) recommends that American adults need at least 150 minutes of moderate-intensity aerobic exercise (i.e. water aerobics, fast walking, bike riding on level ground) or 75 minutes of vigorous-intensity exercise (i.e. jogging or running, swimming laps, playing basketball) in addition to muscle training activities on two or more days per week. In terms of amount of activity per day, the recommended guideline is about 30 minutes on most days of the week.

Unfortunately, studies show that physical activity among adults is lacking. Troiano, Berrigan, and Dodd (2008) indicated that, on average, adults (aged 20-60 years) obtained about 12 minutes combined of moderate and vigorous activity per day. When counting only vigorous physical activity, the mean time dropped to less than two minutes. Given that physical inactivity affects those of all ages, of particular prominence is the lack of activity among the cohort of college undergraduates (King, 1994; Caspersen, Pereira, & Curran, 2000). Studies have shown that this group of individuals exhibits the most dramatic decline in physical activity during the transition from adolescence to early adulthood (Gordon-Larsen, Nelson, & Popkin, 2004; Kwan, Cairney, Faulkner, & Pullenayegum, 2012). As lack of physical activity is one of the most pressing health concerns, interventions targeted at this specific age group could potentially prevent the decrease in regular exercise, thereby carrying health benefits into later life stages.

The overall deficiency in physical activity has had an impact on the general health of the population in the United States. Lack of exercise is a risk factor for obesity and obesity is, in turn, a risk factor for many other negative psychological and physiological health conditions (Stroebe, 2008). In light of the current obesity epidemic in the U.S., these discrepancies between ideal and actual exercise levels are particularly alarming. In 2004, 32.2% of American adults were obese—defined as having a BMI (body mass index) of 30 or higher (Ogden et al., 2006). Compared to the most recent measure of 35.7% in 2009, the prevalence of obesity in American adults is clearly on the rise (Ogden et al., 2012). Recently, due to marked efforts by the scientific and health communities, the rate of obesity prevalence has slowed. However, the level of physical inactivity in the United States remains high and there is a need for systemic change (Knuth & Hallal, 2009).

The psychosocial predictors of physical activity are not as clearly understood as the aforementioned health implications. Baker and Brownell (2000) theorized a social cognitive model hypothesizing that improvements in psychological factors (i.e. mood, body image, self-esteem, self-concept, and coping) would lead to an improved overall psychological climate, thereby increasing motivation and commitment. This change would, in turn, positively affect adherence to regular physical activity (Baker & Brownell, 2000). Physical activity has been correlated with positive effects on psychological constructs such as mood, vigor, self-esteem, physical self-concept, overall feeling of well-being, and a decrease in depression (Biddle & Mutrie, 2008). A study by Annesi (2006) found that changes in self-efficacy and physical self-concept, specifically, accounted for a significant amount of voluntary physical activity in pre-adolescent children. Since then, physical self-concept—a complex domain including perceived appearance and physical competence—has been studied as a predictor of physical activity (Rodriguez & Audrain-McGovern, 2005). Recent research has suggested that physical self-concept is the most significant predictor of adherence to exercise regimens when compared to other factors such as self-efficacy, mood disturbance, and body satisfaction (Annesi et al., 2011). The current study seeks to replicate this positive association between physical self-concept and physical activity while additionally investigating the possible moderator of body dissatisfaction.

Defined as the negative associations with perceived body weight, shape, or image, body dissatisfaction (BD) is a valuable measure of attitudes toward one's body (Cash et al., 2012). The current literature provides evidence of associations between BD and social anxiety, self-esteem, eating disorders, and depression (Russel & Cox, 2003; Grilo & Masheb, 2005; Barker & Galambos, 2007). In a recent study, its weight dissatisfaction facet was also seen to be a moderator of the outcome of weight loss, based on the Yerkes-Dodson law (Johnston, Moreno, Regas, Tyler, & Foreyt, 2012). As postulated by the Yerkes-Dodson law, studies have shown that there is an optimal level of stress or arousal that is beneficial to performance in various tasks, including learning, test scores, and grades (Yerkes & Dodson, 1908; Kuczmarski et al., 2002; Childress, Brewerton, Hodges & Jarrell, 1993). In Johnston et al.'s study, the Yerkes-Dodson law was applied to the hypothesis that weight dissatisfaction was an arousing stressor among children enrolled in a weight management program and it would impact their weight loss (Yerkes & Dodson, 1908, Johnson & Wardle, 2005, Johnston et al., 2012). Support was found for a parabolic association when participants with only moderate dissatisfaction lost significantly more weight than children who had extremely high or low measures of dissatisfaction (Johnston et al., 2012). Based on this research, we speculate that body dissatisfaction will operate similarly in a sample of college-aged females, with those experiencing relatively high or low levels of body dissatisfaction participating in less regular physical activity.

In the current study, we investigate physical self-concept as a predictor of physical activity and hypothesize that body dissatisfaction will play a moderating role in that relationship. Although the sample consists of young adult females, we expect to see the same Yerkes-Dodson phenomenon from Johnston et al.'s study (2012); effectively, after controlling for BMI, those with extremely low or high BD will be less physically active than participants in the more moderate categories of this measure. Also, we hypothesize that subjects with higher measures of physical self-concept will also participate in more regular physical activity.

METHODS

Participants

One group of participants (n=71) was recruited from the online Service Oriented Network Architecture (SONA) system through the author's institution and compensated with course credit to fulfill a research requirement. Another group (n=31) was directly recruited from the student fitness center where data was collected. An information table was set up and participants were invited to participate in a study on "physical activity and health" for no compensation. The sample was comprised of 102 female undergraduates who fulfilled the inclusion criteria of being fluent in English and using the student fitness center to exercise.

Measures

All subjects were given questionnaires, including self-report measures of body dissatisfaction and physical self-concept. Objective measures of BMI and physical activity were also obtained. Analyses included recruitment group and BMI as potential control variables, body dissatisfaction and physical self-concept as IVs (independent variables), and physical activity as the DV (dependent variable).

The Body Shape Questionnaire (BSQ) was used to assess the participants' attitudes about body image. Participants rated how often they had felt in certain ways about their body within the past month (i.e. "Have you thought that your thighs, hips or bottom are too large for the rest of you?") on a scale with answers ranging from 1-(never) and 6-(always). Individual scores from the 34 items were then summed for a total score, with higher numbers reflecting greater body dissatisfaction. This measure has been shown to have high internal consistency (α=.97) and test-retest reliability (r=.88) among adult populations (Rosen et al., 1996). Internal consistency in the present sample was estimated at α=.97.

Physical self-concept was measured by the Physical Self-Description Questionnaire (PSDQ; Marsh & Redmayne, 1994). This 70-item self-report survey was designed to assess 11 facets of physical self-concept and fitness: strength, body fat, activity, endurance, sports competence, coordination, health, appearance, flexibility, global physical self-concept, and global esteem (Marsh & Redmayne, 1994). In the present study, the 6-item subscale of physical self-concept in physical activity was used. The scale of the items ranged from 1-false to 6-true for how accurate each statement was for the participant (i.e. "I am satisfied with the kind of person I am physically"). Studies have shown acceptable internal consistency (median α=.92) and test-retest reliability (r=.69-.83) scores in nonclinical populations (Marsh, 1996). In the present sample, internal consistency was estimated at α=.95 for the 6-item subscale.

BMI was calculated using the guidelines provided by the Centers for Disease Control and Prevention (CDC 2011, BMI=kg/m2). Participants were measured without shoes and in light clothing using digital scales (model number SECA 813, SECA Corp., Hanover, MD, USA) and a portable stadiometer (model number

SECA 214, SECA Corp.). Participants were measured twice each time, with respect to height and weight, and the average of the two measurements was used for analysis.

The primary measure of physical activity was obtained through archival data from a student fitness center located on the campus of a large Midwestern university. Enrolled students can enter the facilities with their student ID, and there are many available sports and exercise equipment, such as basketball or tennis courts, weight machines, free weights, and machines intended to promote cardiovascular exercises (i.e. treadmills, ellipticals, exercise bikes, etc.). Whenever a participant "checked in" at the front desk with their ID, that information was recorded in the fitness center's database. For the current study, we obtained permission from the director and staff for the access and usage of this information pertaining only to the consented participants in our study; participants' "check-in" data were monitored for the period of 28 days.

Procedures

Participants recruited through the SONA system were informed of this study through the university's online recruiting center, where they were first screened for the inclusion criteria of 1) female gender, 2) English fluency, and 3) using the fitness center to workout. After signing up for the study, participants were scheduled to meet in a large classroom with researchers to give informed consent and complete study questionnaires. Directly recruited participants volunteered for this study at an information table in the fitness center. Afterwards, they were directed upstairs to the data collection classroom to complete the surveys. All were informed that participation was voluntary and that they were free to withdraw at any point during the study. Full informed consent for the use of their data from the fitness center was obtained. The first time point of data collection was administered in person and included the self-reported physical self-concept and body dissatisfaction surveys. Objective BMI measures were also taken in a private, adjacent classroom. Archival data were gathered at the end of data collection and assessed the number of check-ins for the period of 28 days. All study procedures were approved by the Human Subjects committee of the author's institution.

RESULTS

Descriptive Statistics

A total of 102 participants were enrolled in the study, two of which were excluded because of failure to obtain the entirety of the surveys and/or measure of physical activity. Specifically, one was omitted for incomplete physical self-concept measures and one was omitted for missing physical activity measures. Of the 100 remaining, all participants were female students enrolled in a large Midwestern university, and age ranged from 17-31 years. As shown in Table 1, 71 participants were recruited online through the SONA system and received credit in return for participation (labeled as SONA). The other 29 participants were recruited directly from the student fitness center either before or after working out (labeled as DIRECT). This group of subjects fulfilled all aforementioned inclusion criteria and participated on a strictly voluntary basis.

Preliminary Analyses

A correlation matrix was used to evaluate the inclusion of the variables of recruitment process and BMI in the hierarchical regression. Since there were two different methods of participant recruitment, SONA and DIRECT, they were dummy-coded and correlated with the dependent variable of physical activity to see if there was significant association among the variances. Neither recruitment process ($r = 0.08$) nor BMI ($r = -0.01$) had a significant correlation with amount of physical activity; therefore they were both excluded as covariates from the later analysis.

Multiple Polynomial Regression with Interaction Term

To evaluate our hypothesis of physical self-concept positively predicting physical activity, we included it as the first term in the model. To further test the hypothesis of a curvilinear moderation of body dissatisfaction between physical self-concept and physical activity, the covariates included both the individual and squared terms of body dissatisfaction, along with the linear and curvilinear terms of the interaction. The full model included physical self-concept, body dissatisfaction, and

TABLE 1. Means and standard deviations of study variables by recruitment group

Variable	SONA (n=71)	DIRECT (n=29)	Total (n=100)
Age (yrs)	19.47(1.91)	19.96(2.31)	19.45(1.91)
BMI	23.51(3.67)	25.79(6.04)	24.17(4.63)
PSC	25.11(1.05)	24.38(0.73)	26.59(8.62)
BD	88.26(1.0)	85.66(0.97)	87.51(33.25)
PA	4.92(5.82)	5.93(5.7)	5.21(5.87)

Notes: BMI, body mass index; PSC, physical self-concept; BD, body dissatisfaction; PA, physical activity.

the interaction terms as independent variables predicting the objective measure of physical activity from archival data. Results of the regression are depicted in Table 2.

TABLE 2. Z-scored simultaneous regression model with curvilinear interaction term

Predictor Variables	Parameter estimates				
	β	SE	t	p	Partial η2
Intercept	5.6	0.68	8.18	<.001	
PSC	3.04	0.7	4.36	<.001	0.26
BD	1.3	0.56	2.3	0.02	0.05
BD^2	-0.4	0.5	-0.8	0.43	0.01
PSC X BD	0.42	0.57	0.74	0.46	0.01
PSC X BD^2	-0.2	0.49	-0.42	0.68	0

Notes: F(5, 94)=7.62, p<.001, Adjusted R2=0.25. PSC, physical self-concept; BD, body dissatisfaction.

The overall model fit was acceptable with the ANOVA test, indicating that the amount of variance in physical activity predicted by the two independent variables was significantly different from zero ($F(2, 97)=18.83$, $p<.001$). Also, the coefficient of multiple determination demonstrated that the variance among the levels of physical self-concept and body dissatisfaction in this sample predicted about 26% of the variance in physical activity ($R2=0.2648$).

As demonstrated, PSC and BD both predicted a significant part of the variance in physical activity, as measured by the number of times participants visited the fitness center in a one month period. However, the other three coefficients representing the linear and curvilinear interactions were not significant. Analysis established support for the hypothesis of PSC as a positive predictor of PA. However, there was no evidence for the hypothesized curvilinear moderation of BD on the prior relationship and the Yerkes-Dodson phenomenon was not observed in this sample. BD was shown to be positively related to PA, with higher levels of BD significantly predicting higher levels of regular PA.

DISCUSSION

The current study was a correlational design investigating the relationships between physical self-concept, body dissatisfaction, and physical activity among a group of female undergraduates. It was hypothesized that participants reporting higher physical self-concept would also adhere to a more regular exercise regimen. Also, self-reported body dissatisfaction was hypothesized to have a curvilinear moderating effect between physical self-concept and physical activity, with those in lower or higher categories exhibiting lower amounts of regular exercise than those in moderate categories. As physical activity, or the lack thereof, is an important issue affecting the cohort of college undergraduates, it is important to better understand the psychosocial constructs motivating such behavior in this age group (Troiano, Berrigan, and Dodd, 2008). Results of such a study could inform interventions targeted towards increasing adherence to regular physical activity regimens or improving weight loss strategies.

Results of the regression indicated that the physical self-concept term was highly significant and corresponded with our hypothesis that it would positively predict higher levels of physical activity. For every one unit increase in standard deviations on our physical self-concept measure (PSDQ), the model predicted an additional three "check-in" time points during the span of one month at the student fitness center. This demonstrated a strong positive linear relationship between physical self-concept and physical activity, which further supports the findings of earlier studies (Biddle & Mutrie, 2008; Annesi et al., 2011). These conclusions suggest that those who possess stronger concepts of their physical self (i.e. "I do lots of sports, dance, gym, or other physical activities.") adhere to a significantly more regular exercise regimen. However, as this concept was not experimentally manipulated, we have no evidence to presume that physical self-concept affects physical activity or vice versa. Overall, this strengthens the support for the importance of this psychosocial predictor in relation to physical activity; therefore, it might be beneficial to take this into consideration when planning clinical interventions or weight loss/exercise programs.

Contrary to our expectations, the relationship between body dissatisfaction and physical activity was not shown to be curvilinear, and there was not a significant moderation of body dissatisfaction on the relationship between physical self-concept and physical activity. Instead, the analyses suggested that an increase in body dissatisfaction significantly predicted greater levels of physical activity. Specifically, for each unit of increase in standard deviations

on the body dissatisfaction measure, it was predicted that the participant would visit the fitness center one more time within the duration of a month. These results suggest that the more dissatisfied the participants felt about their body shape or size (i.e. "Have you ever felt ashamed of your body?"), the more they were motivated to exercise regularly.

Though they were not what we expected to find, our results do extend conclusions outlined in a study on "aesthetic exercising," defined as exercising with an aesthetic purpose. Adolescent girls who were more active than their peers showed significantly greater amounts of body image dissatisfaction, and the majority of these girls reported a desire for a "slimmer silhouette" (Laus et al., 2013). Together, this evidence could support the idea that young women frequently exercise for the sake of their appearance instead of strictly having physical health or weight loss as the primary goals. This could apply to the findings in the present sample, especially as most of our participants had BMIs in the normal ranges and only 10% were obese (defined as BMI>30).

The present results on body dissatisfaction did not conform to expectations for several possible reasons. In the Johnston et al. article, a curvilinear relationship reminiscent of the Yerkes-Dodson law of arousal was found between body dissatisfaction and weight loss over a several week-long intervention (2012). It is possible that this parabolic association was largely due to facets other than exercise in the intervention, such as diet and health education. Also, the sample in this article was comprised of young adolescents (11-14 years), pertaining to a different population from the present sample (17-31 years). Even though the ages are similar, we cannot rule out the possibility that young adults have different thought processes and priorities than teens regarding body dissatisfaction or physical activity. Young adults may regard body dissatisfaction as more of a motivator than an arousal-inducing stressor; therefore those with higher levels of dissatisfaction are not discouraged from working out.

In the future, studies extending this line of research should address some of the present limitations. There may have been a lack of power to detect either the second-order body dissatisfaction or curvilinear interaction term. Also, the convenience sample was drawn from a population of female students at a large Midwestern university, limiting the generalizability to other demographic groups. However, as lack of physical activity is particularly prominent among the cohort of college undergraduates, the results found could still hold some practical implications (King, 1994; Caspersen, Pereira, & Curran, 2000). Furthermore, the sample focused on young adult females who are typically shown to be particularly concerned about body image and have high risks for harmful health behaviors such as eating disorders (Laus et al., 2013). Future studies should also take multiple measures of body dissatisfaction into account. Even though the BSQ (Body Shape Questionnaire) is a clinically validated measure, it may not have adequately captured the construct of body dissatisfaction in the current sample (Rosen et al., 1996). Finally, in order to more thoroughly explore the present constructs and strengthen the conclusions found, a study should be conducted utilizing a manipulated decrease of body dissatisfaction (i.e. through an intervention or other means) and measuring the impact on regular physical activity.

The present study was a correlational examination evaluating the relationships between physical self-concept, body dissatisfaction, and physical activity in a convenience sample of college-age females. Given our original hypotheses, the data showed support for the expected positive relationship between physical self-concept and physical activity. However, the hypothesized curvilinear interaction of body dissatisfaction was not significant within our sample, suggesting that further research is needed to assess the replication of a Yerkes-Dodson effect among the population of young adult females. If future studies confirm the nature of these psychosocial predictors of physical activity, they would both fill a gap in the literature and hold practical implications for the design of interventions looking to promote physical activity or weight loss.

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Q&A

How did you become involved in doing research?
I applied to join the McNair Scholars Program and was accepted in my junior year. A major component of McNair is that all scholars complete at least one significant research project prior to graduation. I had always enjoyed finding out why people and things were the way they were when I was a child, so I was excited about this program that gave me the opportunity to do that as an adult. At KU, there were several other organizations and professors who encouraged me along the way.

How is the research process different from what you expected?
I was surprised by how enjoyable and rewarding it can be. I know research in any field is a lot of work, but the end result is well worth the effort. It was surprising to see how many different parts go into the books on our library's shelves and how long it can take to have a single question answered. I also didn't expect I could spend so much on coffee.

What is your favorite part of doing research?
I enjoy opportunities to explore new ways of looking at the past, which has influenced the world around us. I am also extremely fascinated with the way in which our present shapes our view of the past. The history of any topic evolves as the times and historians themselves do, which is exciting for me. The opportunity to research and share my findings with others has been a lifelong goal.

Breaking ground in Canaan: African-American community in Lawrence, 1870–1920

Paul E. Fowler III

ABSTRACT
This article chronicles the migration of African-Americans to Lawrence, Kansas from the South, and their creation and maintenance of a black community in a small Midwestern town in the wake of three major migration periods. African-Americans identified Kansas as a bastion of abolitionism and a place they could exchange the harsh economic and racial conditions of the post-bellum South for the opportunity to realize the full panoply of citizenship rights in the "free state." The realities experienced by the black population in Lawrence seldom lived up to their ideal. Black migrants experienced similar forms of Jim Crow in Lawrence they had fled the South to escape, such as economic depression, segregation, and violence. Despite this racial animus, African-Americans in Lawrence found ways to carve out a viable community that featured churches, benevolent organizations, schools, and a class of entrepreneurs that helped African-Americans cope with the realities of Jim Crow in their land of Canaan.

EARLY COMMUNITY & INITIAL MIGRATION

The African-American community of Lawrence, Kansas began formation in earnest as early as the beginning of the U.S. Civil War (1861-1865). The black population of Kansas reached its highest proportion to whites by the end of the war because of the confiscations and escapes of Missouri and Arkansas slave property. Former slaves supplemented the lack of available farm labor in the state because of troop enlistments for the war. By 1865, Lawrence represented the second highest concentration of urban blacks in the state, following Leavenworth. This initial black population of Lawrence was composed mostly of able-bodied men capable of escaping slavery.

Several Kansas towns served as stations along the Underground Railroad during the state's territorial period (1854-1861), including Leavenworth, Quindaro, Osawatomie, Topeka, and the abolitionist stronghold of Lawrence.[1] Escaped slaves came to Lawrence because it offered protection against slave-catchers from those who sought to return them to slavery—Lawrence further offered the possibility of paid employment and, in the eyes of many blacks, the chance for social equality.[2]

Once in Kansas, a primary concern for blacks and whites became where and how to house large numbers of former slaves in urban and rural areas. Former slaves clustered in contraband camps—neighborhoods that blacks maintained themselves.[3] Despite often-deplorable living conditions, these camps provided a sense of community for African-Americans and the opportunity to seek liberty and self-improvement in Kansas.[4] The contraband camp in Lawrence was located on Massachusetts Street. Despite the abolitionist sentiments of the townspeople, the sudden concentration of blacks within city limits alarmed many whites. Despite their unease with large numbers of blacks then residing in Lawrence, whites believed that education would help to make blacks responsible enough to enjoy citizenship rights and promote the safety of Kansas towns.[5]

Schools and churches were often located in these camps or close by. Most blacks believed the only way to attain full citizenship was through education. Whites shared this belief and most citizens in the state were willing to assist in the education of former slaves. An abolitionist named S.N. Simpson founded the first school for blacks in Lawrence, which held classes in the courthouse.[6] The charity of whites helped keep the school open through the donation of a meeting place, bibles to teach reading and writing, and monetary assistance. Whites expected that education for blacks would instill a self-helping nature in former slaves to reduce reliance on charity. The Kansas State Journal observed of Simpson's school, "Indeed this school may be regarded as an experiment, and much that affects the negro race is to be settled by its success or failure," and ""…they will be living exponents of the doctrine of the race to own itself."[7]

Labor scarcity allowed former slaves to find employment in unskilled and agricultural labor roles. Former slaves gained pay for their work, and the Lawrence community gained a low-cost labor to supplement manpower shortages. Blacks worked in skilled and semi-skilled occupations, as blacksmiths, barbers, stonemasons, carpenters, woodcutters, preachers, and schoolteachers. From 1863 onwards, the largest single employer of blacks in Lawrence and the state was the army. Black women found employment as domestics—as washerwomen, cooks, housekeepers, and servants.[8]

African-Americans from other Northern states migrated to Kansas during this period to help recently freed slaves adjust to their freedom and pursue citizenship rights within the state. John M. Langston and his brother Charles H. Langston came to Kansas from Ohio during the Civil War to assist the transition of blacks to their newfound freedom in Kansas. Through their assistance, the Kansas Emancipation League, founded in 1863, sought increased political inclusion for African-Americans and helped blacks find employment and housing in Kansas.[9]

The initial black population of Lawrence, Kansas arrived in the state dependent on the charity of the white population while fulfilling the labor requirements of the state. Various factors caused blacks to become increasingly independent of the white population and resulted in a heavier reliance on intra-community support—financially and socially. The tradition of Kansas as the "Free Stare" was established by the end of the Civil War. Subsequent decades saw the growth of the African-American community in actual numbers due to

1. Richard B. Sheridan, From Slavery in Missouri to Freedom in Kansas: The Influx of Black Fugitives and Contrabands into Kansas, 1854-1865, Kansas History 12 (Spring 1989): 31.
2. Ibid, 37.
3. Priscilla F. Clement, Growing Pains: Children in the Industrial Age, 1850-1890 (New York: Twayne Publishers, 1997), 24.
4. Ibid.
5. Leavenworth Daily Conservative, February 7, 1862.
7. "The Contraband School," Kansas State Journal (Lawrence, Kansas), March 20, 1862.
7. Ibid.
8. Sheridan, From Slavery in Missouri to Freedom in Kansas, 40.
9. Sheridan, "Charles Henry Langston and the African-American Struggle in Kansas," Kansas History 22, vol. 4 (Spring 1999): 274.

successive waves of migrations from the South to escape the degradations of Jim Crow. Kansas represented a land of promise for many black migrants, who viewed Kansas as an American version of the biblical Land of Canaan.

POST-WAR MIGRATIONS (PRE-EXODUS, EXODUS, & THE GREAT MIGRATION)

During the Reconstruction Era, increasing racial violence and economic insecurity provided the primary "push" impetus for thousands of African-Americans to leave the South in favor of Northern destinations. Lawrence seemingly offered migrants the possibility for economic advancement and social inclusion. Many of the migrants who arrived in Kansas came because of their mythological interpretations of the state's history as the birthplace of the conflict that resulted in their freedom. Similar to the war era migrations of escaped slaves, the migrations of 1870-1920 resulted in the arrival of hundreds of African-Americans in Lawrence who were financially destitute and initially dependent on the charity of the existing white and black communities of Lawrence.

Prior to 1870, Missouri was the primary contributor to the black population of Kansas. By the mid-1870s, Kentucky and Tennessee became the first states to provide sustained migration of African-Americans to Kansas since the Civil War, followed by the Exodus of blacks from Mississippi, Louisiana, and Texas.[10] The pre-Exodus migration of African-Americans to Kansas totaled an estimated 9,500, while the Exodus itself accounts for approximately 4,000.[11] These combined migrations caused the black population of Lawrence to grow from 933 in 1865 to 2,000 by 1880.[12] In slightly more than ten years, the black population of Lawrence more than doubled, which caused strain on the existing population of the town and its resources. Many migrants went to great lengths in preparation for their journey, while others arrived in the state financially destitute and only in possession of what they could carry. Migrants received assistance along their journey from organizations led by Radical Republicans upset by the racial violence perpetrated against blacks by Southern Democrats. One organization was the Colored Refugee Relief Board of St. Louis, Missouri that aided Exodusters with food and shelter as they journeyed to Kansas.[13] Whites and blacks alike wrote to Governor John P. St. John (Gov. 1879-1883) to request advice and assistance with the migrations. For example, Henry and Clara Smith of Marshall, Texas wrote to Gov. St. John on behalf of the black residents of their town with inquiries about where to settle and the reception they could hope for in Kansas.[14] The white population of Lawrence also decided to assist the Exodus migrants when they voted to extend charity at a meeting held at Fraser Hall in 1879.[15] John M. F. Stinger, a Kentucky Radical Republican, also wrote letters to Gov. St. John requesting he convince others in the North of their moral duty in assisting the black refugees.[16]

In slightly more than ten years, the black population of Lawrence more than doubled.

The Great Migration caused the black population of Lawrence to grow, yet not as dramatically as the migrations of the 1870s had. Blacks did not leave the South in sizeable numbers because the black elite, those termed the "talented tenth" by W.E.B. DuBois, were unable to convince other blacks that a flight from the South was worth the risk because of the ambivalent attitudes of Northern employers.[17] Many blacks simply believed it was better to remain in familiar surroundings rather than brave new locations. The Great Migration, however, did cause a momentary growth in the black population of Lawrence. There were 1,764 black residents in Lawrence as of 1910, and this grew to 1,849 by 1915.[18] By 1920, the black population of Lawrence fell to 1,432, which historian William Tuttle Jr. attributes to the disgust many young African-Americans in Lawrence felt at the racial realities in Kansas and the belief that their dreams could not come true because they would be "stymied by white racism."[19] Rather than escape Jim Crow, migrants from the South

10. Nell Irvin Painter, Exodusters: Black Migrations to Kansas After Reconstruction (Alfred A. Knopf Inc.: New York, 1977), 147.
11. Painter, Exodusters, 147.
12. Kansas State Census, 1865: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-3; Federal Census for Kansas, 1880: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-9; see chart in Appendix I.
13. Colored Refugee Relief Board, "untitled pamphlet" (KSHS DaRT ID: 218449, St. Louis, MO, 1879), 1-4.
14. Henry and Clara Smith, letter to Gov. John P. St. John (KSHS: Governor's Records, St. John Correspondence Received, Box 14, Folder 1), May 7, 1879.
15. "Action of Other Cities on the 'Exodus' Question," Wyandotte Gazette (Wyandotte, KS), April 25, 1879.
16. John M.F. Stinger, letter to Gov. John P. St. John, (KSHS: Governor's Records, St. John, Correspondence Received, Box 14, Folder 1), May 18, 1879.
17. Sernett, Bound for the Promised Land, 26.
18. Federal Census for Kansas, 1910: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-8; Kansas State Census, 1915: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-75, K-76, K-77, K-78.
19. Tuttle Jr., "Separate but Not Equal," Embattled Lawrence, 139.

found the racial animus they had fled existed in Kansas as well.

JIM CROW IN KANSAS: SEGREGATION & RACIAL ANIMUS IN LAWRENCE

Although never codified by law, Lawrence experienced varying degrees of de facto segregation since the Civil War era. Upon their first arrival in Kansas, the first concern for blacks and whites was where to house the influx population. The vast majority of blacks that came to reside in Kansas during the Civil War era lived in segregated camps within white communities. The contraband camp in Lawrence was located on Massachusetts Street and drew the ire of the editor of the Kansas State Journal: "We already see more colored men than we ought about our street corners."[20] In the wake of the Civil War, Exoduster Migrations, and the Great Exodus, African-Americans in Lawrence experienced segregation in several social areas that included schools, theaters, restaurants, employment, and business transactions.

The educational sphere exemplifies the racial ambivalence of whites toward blacks in Lawrence. The segregation experienced by black schoolchildren resulted from the white inclination for a belief in "parallel development." The logic used to defend their view reflected white attitudes of racial superiority and paternalism, which assumed blacks and whites would pursue the same citizenship rights, but would do so separately as much as possible. Lincoln Elementary, located in North Lawrence, was the only school in Lawrence attended and staffed solely by African-Americans.[21] Other elementary schools offered all-black classes, occasionally taught by African-American teachers, yet only when there were enough students in a single age group.[22] When there were too few students to form a full class, black children would attend the same classes as white children; however, administrators and teachers used segregated seating charts to physically separate the students.[23] Racial segregation assumed several forms in education, often more subtle than segregated seating charts. Discrimination also presented itself in the handing out of assignments and the grading of homework.[24]

Segregation was experienced on sports teams and other after school activities in addition to classes. Blacks could not be teammates with whites, and Lawrence schools did not provide coaches for all-black athletic teams.[25] Volunteers from the African-American community coached all-black squads, which were typically basketball teams since there were never enough black students to form football teams.[26] George Bivens, the owner of a black billiards hall in Lawrence, devoted much of his free time to coaching an all-black basketball team.[27] Although blacks could not be teammates with whites, they sometimes played against each other. This further alienated blacks and whites, and reinforced prejudices that the two races had against each other. Another clear example of the second-class citizenship experienced by blacks in Lawrence was evident in school-sponsored dances, clubs, and other social functions that restricted participation to whites. For example, the senior banquet at Lawrence High school, paid for by the senior fees that were required of all seniors, only allowed whites to participate.[28] Such discrimination in schools reinforced perceptions of black inferiority held by many whites that had also been instilled in former slaves since birth.

Socially oriented businesses, such as theaters, pool halls, and restaurants, also experienced discriminatory practices as well. African-Americans experienced complete exclusion from all but two of the six theaters in Lawrence; the only two exceptions were the Bowersock Opera House and the Patee.[29] The Bowersock allowed black attendance, but required them to sit in the second balcony, commonly referred to as "Coon Hill."[30] The Patee was more progressive by far and had a liberal racial policy; blacks were permitted to sit anywhere in the theater, which also employed a black projectionist.[31] Nearly all white restaurants in Lawrence refused service to blacks, yet specific exemptions to this rule existed. In most establishments, it was permissible for African-Americans to enter through a back door and

20. Kansas State Journal (Lawrence, Kansas), January 9, 1862.
21. Zavelo, 12-13.
22. Ibid, 12-13.
23. Ibid, 13.
24. Ibid, 13.
25. Ibid, 13.
26. Ibid, 13.
27. Ibid, 14.
28. Ibid, 14.
29. Ibid, 14.
30. Ibid, 14-15.
31. Ibid, 15.

take meals served by black cooks in the kitchen.[32] Muzzy's, a white-owned café located in the 700 block of Massachusetts Street, was the only white-owned café in Lawrence that openly served African-Americans.[33] Muzzy's allowed blacks and whites to eat in the same dining room, though still segregated by a wooden partition that separated the lunch counter; whites ate on the side nearest the door while blacks ate on the side furthest from the door and out of sight for passers-by on the street.[34]

African-Americans had difficulty in acquiring insurance and loans as well. Banks showed little interest in extending loans and lines of credit to blacks; when African-Americans were able to get loans, they were at extremely high interest rates.[35] Insurance companies were also extremely hesitant to do business with blacks, although they weren't completely unwilling to do so. Insurance companies were hesitant to insure African-Americans because of the poor health and financial situations that prevailed in the black community.[36] Blacks were able to gain insurance from Metropolitan Life, but only at high premiums, which suggests that only the black middle-class was able to afford their premiums.[37] The largest local insurance company, the Charlton Agency, refused to do business with any African-Americans under any circumstances.[38] Poor living conditions resulted from the mal-distribution of wealth and prevailing racial attitudes in Lawrence that served to isolate blacks from whites.

Racial separatism evolved that created predominately-black neighborhoods, which reflected the economic situation of most African-Americans who lived in Lawrence from 1880 to 1920. Based on the City of Lawrence Directories, state censuses, and the sociological survey conducted by Frank W. Blackmar through the University of Kansas sociology department in 1917, it is possible to understand the physical boundaries of predominately-black neighborhoods, as well as the living conditions experienced by the residents of these areas.

Kansas state censuses show that by 1900, African-Americans in Lawrence numbered 2,032, which represented approximately 20 percent of the city population.[39] By 1910, the number of blacks in Lawrence fell to 1,764, and accounted for 14.2 percent of the total population.[40] This reduction was likely due to the outmigration of blacks for urban centers further north in search of more promising financial opportunities in industrialized Northern cities.[41] By 1915, there were 1,849 African-Americans in the city of Lawrence, which reflected 14.4 percent of the 12,884 residents.[42] Despite the lack of de jure segregation in Lawrence, the financial realities of African-Americans in Lawrence determined where blacks decided to live. The areas with the highest concentration of black settlement were in North Lawrence and an area known as the East Bottoms that was located adjacent to the Kaw River.

The main living arrangement for blacks was with the family or as a lodger. In Lawrence, 64 percent of blacks lived with family, compared to 71 percent of whites that resided with family.[43] The higher percentage of whites that lived with family is because black residents were more likely to take in lodgers to supplement family income. The Blackmar study found that 20 percent of blacks were individuals living with family members or as a lodger.[44] Cousins, nephews, and nieces were one form of lodger. Additionally, there were lodgers who were not related to the other members of the household. The study found an example of one such household on

32. Ibid, 15.
33. Ibid, 15.
34. Ibid, 15.
35. Ibid, 15.
36. Ibid, 16-17.
37. Ibid, 16-17.
38. Ibid, 16-17.
39. Kansas State Census, 1905: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-45, K-46, K-47.
40. Federal Census for Kansas, 1910: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-8.
41. Donald B. Zavelo, The Black Entrepreneur in Lawrence, Kansas Collection, RH MS D168, Kenneth Spencer Research Library, University of Kansas, 2; D.B. Zavelo was a graduate student at the University of Kansas in the History Department who investigated the formation of the African-American Entrepreneurial class in Lawrence, Kansas that formed during the Great Migration. Zavelo has conducted several interviews that serve as the basis for much of this case study of early community formation in Lawrence.
42. Kansas State Census, 1915: Douglas County Population Schedule. Topeka: Kansas State Historical Society: Microfilm, K-75, K-76, K-77, K-78.
43. Frank W. Blackmar, Lawrence Social Survey: Report of F.W. Blackmar, Director, and E.W. Burgess, Field Surveyor, University of Kansas, To the Lawrence Social Survey Committee, Lawrence, Kansas, Frank W. Blackmar Collection, University Archives, PP 53, Kenneth Spencer Research Library, University of Kansas Libraries, 12-14; Blackmar was a professor of sociology and anthropology at the University of Kansas, as well as the first Dean of the Graduate School from 1889 to 1929 and conducted this survey as "A Study of Social Conditions and Agencies in Lawrence as a Basis for a Constructive Program of Community Advance." The survey was conducted as a community enterprise for the betterment of Lawrence and was initiated through the enterprise of eight local committees.
44. Ibid, 12-14, a "lodger" was any person living with a family where they were not a member of the immediate nuclear family.

New Jersey Street, where twelve people "cooked, ate, lived, and slept in a single room."[45] These twelve people were members of three unrelated families that had to live together because of difficulty finding work due to the mal-distribution of wealth in the city of Lawrence at the time of the survey.

Blackmar's survey found that blacks in Lawrence tended to live in the poorest neighborhoods, which contributed to the high mortality rate experienced by African-Americans. These were not all-black ghettos: 21 percent of residents lived in these areas compared to the 39 percent of blacks in racially mixed neighborhoods.[46] In North Lawrence, there were 25 housing units surveyed. Of these homes, 11 received characterizations as "shacks," more than half of them had three rooms or less, and all but one residence relied on privies because of the primitive sewage system there.[47] African-Americans occupied 20 of these homes in 1915.[48] Living conditions in the East Bottoms were worse. In this area, 76 structures were surveyed which show the poor financial situation of blacks in the area. In this area, 28 of the housing units surveyed received characterization as "shacks": the study reported 12 of these homes as "beyond repair" and "in need of immediate destruction" for health reasons, and the study only rated 13 homes positively.[49] Few of the residents in this area actually owned the homes in which they lived: [54] of the residences rented at an average of $5.50 per month, with interest rates for late rent as high as 12.5 percent.[50] Over two-thirds of the homes in this area relied on privies and experienced inadequate garbage collection.[51]

Inadequate garbage collection caused many residents to discard their waste on lawns, which attracted rodents. This, coupled with the reliance on privies, was a contributing factor that resulted in a tuberculosis epidemic in 1913 which devastated the African-American community of Lawrence.[52] Dr. Frederick Harvey, an African-American physician and resident of Lawrence, stated that there were two to seven times more deaths from consumption among the blacks in Lawrence than any other race.[53] The mortality rate of blacks in North Lawrence and the East Bottoms was indeed higher than for whites at this time. The annual death rate for Kansans in 1913 was 10.6 per 1,000 people; in Lawrence, it was 14.36 per 1,000 people.[54] The death rate for blacks in Lawrence was even higher at 22.2 per 1,000 people, which reflects the sub-standard living conditions in predominately-black neighborhoods.[55] The death rate in the East Bottoms was 35.9 per 1,000 people, and tuberculosis claimed 26.9 per 1,000 lives in this area.[56] The close proximity of wells and privies that blacks in these areas were required to use because of the lack of adequate plumbing was a major cause of illness in the predominately black neighborhoods. The rodents attracted to the refuse left on lawns because of inadequate garbage removal, poor clothing, and dark rooms in windowless homes all acted as contributing factors to the high incidence of sickness and death in North Lawrence and the East Bottoms.

The black community responded to this problem in 1907 by devoting entire sessions of the Sunday Forum to tuberculosis awareness. The Forum was an educational and cultural program that met weekly at the Warren Street Baptist Church and was organized by the church's leadership.[57] Dr. Harvey and other physicians warned attendees against "…dressing too thinly and expectorating on the streets…" yet were powerless to improve the living conditions that would have allowed a decrease in the mortality rate of black neighborhoods in Lawrence.[58]

Lawrence in the early twentieth century was a poverty-stricken community.

Lawrence in the early twentieth century was a poverty-stricken community. Because of the discrimination they faced, African-Americans had difficulty in

45. Ibid, 56.
46. Ibid, 56.
47. Ibid, 56.
48. Ibid, 56.
49. Ibid, 56.
50. Ibid, 56.
51. Zavelo, 4.
52. Blackmar, 44-46.
53. 54 Zavelo, 5-6.
54. Ibid, 6.
55. Ibid, 6.
56. Blackmar, 44-46.
57. Topeka Plaindealer, February 28, 1907.
58. Ibid.

overcoming the conditions that made the tuberculosis epidemic possible in the first place. The Blackmar survey team estimated that $650 per year was necessary to feed, clothe, and shelter an urban family in Kansas, yet studies from 1913-1915 showed that 75 percent of Kansans, regardless of race, earned less than $625 per year.[59] The Blackmar survey also conducted an occupational survey of the 4,049 registered voters in Lawrence, Kansas that showed African-Americans generally resided to the most menial jobs in the city.[60] The relationship between city wards with large percentages of blacks corresponded to high numbers of persons employed in low-wage, unskilled work.[61] A similar correlation existed between wards with low percentages of blacks and high numbers of businessmen and professionals.[62] These findings further show that blacks typically found employment in unskilled labor roles at low pay and this reflected the de facto segregation that occurred in Lawrence along financial fault lines in addition to racial ones. The primary beneficiaries of this reality were the businessmen who employed workers, as they were able to use black labor as a bargaining counter against the demands of white laborers for higher pay. The African-American community was able to rely on their institutions to cope with the various forms of discrimination they experienced. Churches, clubs, and the celebration of anniversaries relevant to the black community helped blacks to resist the racism they experienced.

RELIGIOUS COMMUNITY, CHURCH ORGANIZATIONS, & WOMEN'S CLUBS

Church and spirituality were central features to the formation of the African-American community in Lawrence, Kansas and a means of coping with the discrimination blacks experienced in their daily lives. Historically, the black church in Lawrence and nationally has been one of the few institutions that blacks have participated in which allowed them a sense of independence and the ability to exercise control over their lives. As a cultural institution, the church has been a primary instrument through which blacks in Lawrence developed a collective identity and a sense of place in society. "The black churches in Lawrence became the forum for the sharing of language representing the experiences of blacks past and present."[63] Blacks in the North had several religious denominations to choose from, however, the black churches of Lawrence are of two distinct kinds, Holiness, and non-Holiness churches.[64]

E. Franklin Frazier, in The Negro Church in America, described Holiness church members by his assertion that, "They insist that Christians shall live free of sin and in a state of holiness. They refuse to compromise with the sinful ways of the world. By sin they mean the use of tobacco, the drinking of alcoholic beverages, cussing and swearing, dancing, playing cards, and adultery. All of such activities are regarded as 'carnal mindedness.'"[65] Holiness churches were typically more informal in their style of worship than non-Holiness churches. Leaders of Holiness churches were "traditionalists" who feared a loss of "the old time religion" that they brought with them from the South, and tended to focus on purely religious matters.[66] Conversely, non-Holiness church leaders were both religious and secular leaders of their congregations; these "traditionalists" were concerned with both religious fulfillment and social change. Milton C. Sernett observed that the ideological differences between the two churches are comparable to the debate between W.E.B. DuBois and Booker T. Washington.[67] Holiness and non-Holiness churches—much like DuBois and Washington—pursued different means to the same end and were often at odds concerning the proper way to worship. Black migrants from the deeper South tended to attend Holiness churches, while the established black community of Lawrence and the immigrants from further North or the Midwest tended to attend non-Holiness churches. Both styles of churches had a common goal, however, and created similar church institutions to service the needs of the community.

One institution that grew from within the church was the Sunday Forum, such as that at the Warren Street Church. The Sunday Forum was an educational and cultural program that acted as a means of disseminating information throughout the community.[68] Prominent speakers from Lawrence,

59. Blackmar, 37-39.
60. Ibid, 38.
61. Ibid, 38.
62. Ibid, 39.
63. Dorothy L. Pennington Collection, The Histories and Cultural Roles of Black Churches in Lawrence, Ks, Kansas Collection, RH MS P508, Kenneth Research Library, University of Kansas, 37.
64. Ibid, 35.
65. E. Franklin Frazier, The Negro Church in America (New York: Schocken Books, 1963), 56.
66. Milton C. Sernett, Bound for the Promised Land: African American Religion and the Great Migration (Durham: Duke University Press, 1997), 4.
67. Ibid.
68. Pennington, The Histories and Cultural Roles of Black Churches in Lawrence, Ks, 35.

Topeka, Atchison, Kansas City, and beyond often came to speak at these forums. Typical topics at these forums were spiritual, political, and health awareness. Spiritually, these Sunday Forums were indistinguishable from the Sunday Schools of churches today, and acted to provide spiritual refreshment to their congregations. Politically, they served as a means to educate African-Americans on issues relevant to the black community of Lawrence and the nation. Issues such as solutions to the "negro problem" and local elections were frequent topics. Health concerns were another topic of these forums because of the poor sanitation conditions in predominately-black neighborhoods. For example, in 1907 the Warren Street Church invited Dr. Frederick Harvey to speak to the congregation of Warren Street Church to educate members on the best means of resisting the tuberculosis outbreak that occurred in Lawrence that year. Good advice and visits to the sick members of the community proved to be the best the church could provide to combat health problems, as it was powerless to change the living conditions in black neighborhoods.[69] Children sometimes became the focus of these Sunday Forums. One such children's day held at St. James A.M.E. church featured an "instructive address" given to the children by T.M. Ward, after which the children exhibited recitations and dialogues interspersed with music.[70] These forums also held oratorical contests that showcased the advancements in education within the black community.[71]

Lawrence churches also regularly held basket meetings—often in tandem with the Sunday Forums—that focused on the children and less fortunate members of the black community. Basket meetings were akin to picnics and held to bring the community together or to celebrate dates special to African-Americans and church anniversaries. For example, the black community of Lawrence hosted a celebration at a local meeting place known as Bismarck Grove to celebrate the emancipation of slaves in the West Indies on August 1, 1839.[72] Planned by the Grand Council of the Independent Benevolent Society, this event attracted African-Americans from population centers throughout northeastern Kansas.[73] Entertainment was a central feature of these basket meetings. Basket meetings assisted members of the black community who were not members of the congregations that hosted them, and thus helped to bring the entire black community of Lawrence together to care for the less fortunate and to celebrate special dates and anniversaries.

The Sunday Forums and basket meetings held at churches also served as the basis for community-oriented organizations, such as women's clubs. As early as 1864, the African-American women of Lawrence had formed the Ladies' Refugee Aid Society to help former slaves acclimate to their freedom in Kansas through the charity. These women collected funds to help smooth the transition of migrants from Missouri and Arkansas to Lawrence financially. This organization also helped incoming migrants by providing Bibles to help educate former slaves.[74] At the turn of the century, because of their exclusion from white women's clubs, African-American women formed federations to coordinate their efforts.

In 1900, African-American women in Kansas formed the Kansas Federation of Colored Women's Clubs. Lawrence was the site of a convention of these women's clubs in 1913, where fifty-one clubs attended.[75] Blanche K. Bruce of Leavenworth explained, "The purpose of this Federation is to elevate our women to a higher standard in the art and musical world, and it is also a lesson that we must educate the hand as well as the brain."[76] These clubs sought ways to help the African-American race in the face of increasing discrimination and the rise of Jim Crow in Kansas. The Kansas women's clubs promoted an ideology of "self-help" influenced by Booker T. Washington that worked for mutual assistance within the community rather than forced integration into the mainstream white society.[77] Despite discriminatory exclusion from state and national club federations, African-American clubwomen provided several forms of "racial uplift" to black communities throughout the state while they attempted to promote interracial harmony.[78] Marilyn Dell Brady observed that, "For them, the national

[69] Topeka Plaindealer (Topeka, KS), February 28, 1907.
[70] W.I. Grant, ed., "Children's Day at A.M.E.," The Historic Times (Lawrence, KS), July 11, 1891.
[71] C.H.J. Taylor, "Declamatory Contest at 2nd Baptist," The Historic Times (Lawrence, KS), July 25, 1891.
[72] Ibid, "A Great Celebration," The Historic Times (Lawrence, KS), July 11, 1891; Sheridan, "From Slavery in Missouri to Freedom in Kansas," 47.
[73] Ibid.
[74] Sheridan, From Slavery in Missouri to Freedom in Kansas, 40; Annie Firor Scott, Natural Allies: Women's Associations in American History (Urbana: University of Illinois Press, 1992), 67.
[75] Brady, "Kansas Federation of Women's Clubs," 21.
[76] Topeka Plaindealer, June 14, July 12, 1901 in Marilyn Dell Brady, "Kansas Federation of Women's Clubs, 1900-1930," Kansas History 9 (Spring 1986), 22.
[77] Brady, "Kansas Federation of Women's Clubs, 1900-1930," 28-29.
[78] Ibid, 28.

motto, 'Lifting as We Climb,' did not simply mean educating 'peasant women'…but raising their daughters and those of their friends to be powerful, responsible women, proud of themselves and of their race."[79] Although their efforts were limited in scope because of discrimination and the exclusion of black men from positions of financial and political power that restricted their available resources, these women's clubs worked for the collective advancement of African-Americans. Through art and music contests, clubs were able to gather the finances they used to provide charity to the less fortunate and scholarship funds for black youth.[80] The African-American women's clubs of Kansas performed a role of "racial uplift" for the black community, which was in tandem with that of the church.

Dorothy Pennington capably enumerated the cultural roles of the church within the black community: "The black churches in Lawrence have played a major role in meeting the needs of blacks for status and recognition, exercising leadership, self-esteem, social and spiritual acceptance, and the need for having a sense of territory or 'space' that blacks could call their own."[81] Religion proved to be the central mechanism by which the black community coped with ingrained and pervasive discrimination experienced by African-Americans in Lawrence throughout the late nineteenth and early twentieth centuries. Black churches in Lawrence acted as an engine for "racial uplift" that served to educate African-Americans while it provided a social space where experiences common to congregations and the wider community could shape and address the needs of the black community of Lawrence. The church worked in combination with black newspapers and businesses to provide a connectedness between the black community of Lawrence and that of Kansas and the nation.

POLITICAL ACTIVISM

The African-American community of Lawrence exhibited a long tradition of political activism that pushed for the advancement of equality within the state. As early as 1865, the interracial organization of the Kansas Emancipation League helped find work for blacks and lobbied the state legislature to strike the word "white" from the state constitution to expand the civil liberties and political inclusion of African-Americans in Kansas.[82]

The African-American community of Lawrence exhibited a long tradition of political activism.

Aided by the efforts of black entrepreneurial newspaper owner-editors C.H.J. Taylor, who founded the Historic Times, and John L. Waller, who founded the Western Recorder, African-Americans in Lawrence remained politically aware and engaged in political activism that was occasionally extremely effective. Each of these papers—founded in Lawrence before the turn of the century—shows a connectedness between the African-American community of Lawrence and black communities in other Northern towns as well as an awareness of issues, organizations, and political events relevant to the African-American community of the United States. For example, the Historic Times featured a section titled "Racial Hits" in each of its weekly publications that highlighted the activities of black publishers, preachers, organizations, and orators throughout Kansas and nationally.[83]

The legacy of African-American political activity in Kansas that began with the interracial Kansas Emancipation League continued through the 1920s and beyond. Blacks in Lawrence attained a degree of political relevance because of two important factors. First, the concentration of blacks in identifiable neighborhoods in Lawrence increased the power of their vote because Lawrence, modeled on the ward system, allowed blacks to mobilize their vote to achieve local political successes. Second, the rising dissatisfaction with the Republican and Democratic parties that resulted in the rise of the Populist Party in Kansas meant that three separate parties, all willing to make some concessions to remain in power, courted the black vote.

In April 1883, the hotly contested city elections for Lawrence concluded.

[79] Ibid.
[80] Ibid, 22, 30.
[81] Pennington, The Histories and Cultural Roles of Black Churches in Lawrence, Ks, 37-38.
[82] Sheridan, Charles Henry Langston and the African-American Struggle in Kansas, 274; White Cloud Kansas Chief (White Cloud, Kansas), September 14, 1865.
[83] C.H.J. Taylor, "Racial Hits," The Historic Times (Lawrence, Kansas), July 24, 1891.

These elections saw the elevation of John L. Waller—editor-owner of the Western Recorder—to a seat on the local Board of Education by "a good majority" by the electors of the sixth ward.[84] The same issue thanks the African-American women of Lawrence for their effort in securing the elections of black officials and whites friendly to African-Americans. Although not allowed to vote themselves, they hosted dinners for friendly candidates and assisted in ensuring their men voted on the day of the election. The Western Recorder printed, "These ladies deserve much praise for their fidelity to principle. They labored the live long day for the success of the Republican ticket, on behalf of the colored voters of this city."[85] Despite victories, J.D. Bowersock was re-elected mayor of Lawrence to the chagrin of the Western Recorder's editors—the paper's editors believed that Bowersock had accepted "hush money" and circumvented city statutes banning saloons in the city for his friends. "We do not believe that Mr. Bowersock polled to exceed fifty colored votes in this city."[86] J.D. Bowersock owned the Bowersock Opera House on Massachusetts Street mentioned earlier. Bowersock's ownership of a segregated opera house and allowance of saloons in town angered Waller. Waller wrote, "The colored people of this city will contend to the bitter end for the enforcement of the law, for we have seen it violated to our sorrow; it operates heaviest on us, therefore we cannot afford too [sic] violation of any law on the Statute's book."[87] Geographic concentration of blacks and the ward system frustrated the political ambition of Mr. Bowersock for a time.

CONCLUSION

The influx of thousands of African-Americans into Kansas as early as the Civil War created a tense, racially charged atmosphere in Kansas, a state then known for its seemingly egalitarian opposition to slavery. Racial tension was deepened by the migration of southern African-Americans from 1870-1880 and the First Great Migration that lasted roughly from 1910-1930. Racial tension caused fears of job competition and pervasive racial attitudes forced African-Americans who migrated to Lawrence into second-class citizenship. Unable to realize the full panoply of citizenship rights enjoyed by whites, the black community of Lawrence turned inward and relied upon itself for sources of support and identity.

Hundreds of Southern blacks came to Kansas for the perceived promise of racial egalitarianism and the possibility of economic advancement from social conditions tantamount to slavery. They arrived in Kansas destitute of many of the necessities of life during three migration periods, a deplorable situation that sometimes caused black migrants to become dependent on the charity of whites and the existing black community.

Because of racial and class isolation, African-Americans became targets of discrimination in employment, education, social enterprises, and extra-curricular activities. Blacks were the focus of racial discrimination in social businesses such as diners and theaters that either excluded them completely or segregated blacks from white patrons as much as possible—with few exceptions. The result of racial isolation was a black community that came to rely upon itself and looked inward for social acceptance and pride.

The church became a cornerstone of the African-American community. Whether attendees of Holiness or non-Holiness churches—and even non-members or irregular attendees—the church provided blacks in Lawrence with a sense of community based upon a shared past and present, and a common hope for the future of the African-American race. Through basket meetings and Sunday Forums, the black community was able to discuss issues relevant to them and address concerns that intimately affected African-Americans locally and nationally. The church provided an educational element that allowed blacks to stay informed of issues and the knowledge to protect themselves against problematic issues such as disease. This institution provided a coping mechanism for Lawrence blacks to cope with the constant racial discrimination they faced. Women's clubs also grew from the sewing circles and leadership positions within the church; these clubs celebrated the music and art of African-Americans, and strove for the educational advancement of the African-American community.

Black-owned newspapers became another way of disseminating information and philosophies

84. John L. Waller, The Western Recorder (Lawrence, KS), April 4, 1883.
85. Ibid.
86. Ibid.
87. Ibid.

throughout the African-American community. These newspapers kept blacks in Lawrence informed of what other African-Americans throughout the country were able to accomplish and the dangers faced by their brethren elsewhere. The Lawrence newspapers The Historic Times, The Western Recorder, and the Topeka based Plaindealer, also featured socialite columns that allowed the black community of Lawrence to keep themselves aware of the actions of their own "elite." Newspapers also promoted a sense of community pride and élan within the African-American community because it allowed blacks to see they were indeed capable of accomplishing all the things that racial animosity and exclusion had taught them were impossible. A combination of black-owned newspapers and churches also allowed blacks in Lawrence to remain aware of political and social trends that affected blacks in America, and thus allowed blacks in Lawrence and elsewhere in Kansas to organize into a political force that the white-dominated political sphere had to account for—Republicans, Democrats, and Populists alike. Blacks also kept aware of black-owned businesses they could patronize as an alternative to the exclusion experienced in the business world—economically dominated by a small segment of the white community.

Thus, in the face of discrimination and isolation from the dominant white community, the African-American community of Lawrence created for itself a viable social framework that promoted a sense of pride in individual members and their community as a whole. Based on a shared past, contemporary realities, and hopes for improved future, blacks in Lawrence remained politically relevant within a political establishment dominated by a white majority that sought to marginalize the African-American community. African-Americans became increasingly self-reliant and utilized strategies of "self-help" to advance the needs and concerns of the black community. Breaking ground in the land of Canaan was difficult, yet African-Americans who came to Lawrence into the 1920s found the ability to create a viable community despite the challenges faced.

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Q&A

How did you become involved in doing research?
I became interested in research through the McNair Scholars Program. As a McNair Scholar, I have had the opportunity to conduct and present research in communications systems and indoor air quality over the past two years. In fact, this research is a continuation of a literature review on living walls that I worked on this past summer with McNair.

How is the research process different from what you expected?
I have definitely learned to have patience throughout the research process. There were some times when I was working on my project where the experiments that I was running were producing odd results. While it was confusing trying to figure out why the experiment was producing odd results, that experience definitely helped me better understand how to conduct my research.

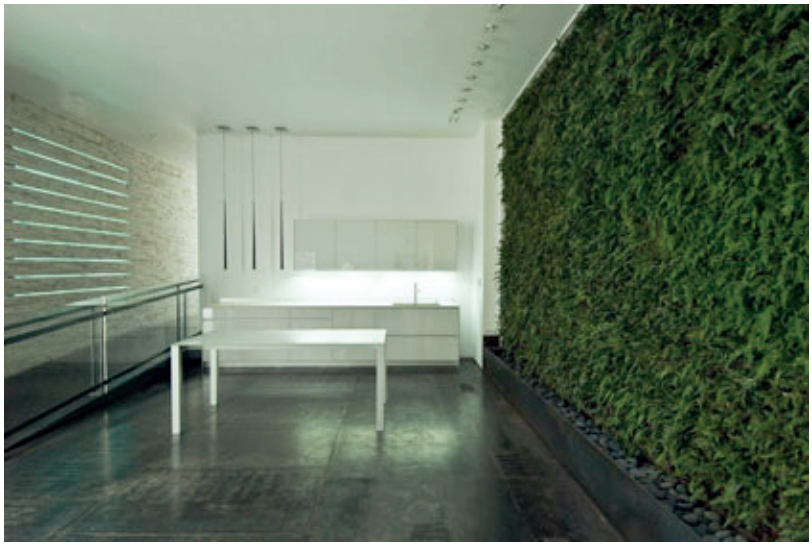
What is your favorite part of doing research?
I like being able to take a subject that you're interested in knowing more about and further exploring that topic. Most importantly, I like the feeling after completing a research project, regardless of the results, because that experience helps you become more knowledgeable in your subject of interest.

Quantifying CO_2 removal by living walls: a case study of the Center for Design Research

Eric Rivera

ABSTRACT

Indoor air quality (IAQ) is a good indicator of a healthy building environment, as it evaluates how indoor air affects the health and comfort of building occupants. This study investigated a living wall, designed for the Center for Design Research (CDR) as a means to improve IAQ, located at the University of Kansas. This study investigated the effectiveness of the living wall in reducing carbon dioxide (CO_2) concentration levels indoors, as well as the impact the mechanical system has in reducing CO_2 concentration levels. The research was designed in the computational fluid dynamics (CFD) program, FloVENT, which allowed for comparisons of the CDR under the following conditions: without the living wall, with the living wall with the air on and off and with the return air grilles placed behind the living wall. Data for the CO_2 concentration rates of the CDR was gathered from occupancy rates found in the CDR's construction documents, and the living wall's CO_2 absorption rates was gathered from previous studies, using the CO_2 absorption rates of the plant species Bird's Nest Fern. Data was then inputted to the four models of the CDR designed in FloVENT. Results showed that the living wall reduced CO_2 concentration rates by 56% and reduced the amount of CO_2 being returned to the recirculation system. Results of the study also hypothesize whether reduced airflow rates and the placement of supply and return grilles can further reduce CO_2 concentration levels. Further study will provide more information on whether these claims are true.



1. INTRODUCTION

An examination of indoor air quality (IAQ) looks at the cleanliness of the air inside a building and is a good indicator of the health and productivity of building occupants. Issues with IAQ started to develop in the United States during the energy crisis of the 1970s, when buildings began to be tightly sealed from the outdoors as a response to increasing heating and cooling costs (Heimlich, 2008). While doing so reduced both air leakage and heating and cooling costs, building occupants complained that they were feeling short-term discomfort from being inside the building. This discomfort, in which occupants experienced symptoms like dizziness, nausea, fatigue, and headaches, was known as Sick Building Syndrome (SBS). Other cases resulted in more chronic health effects that occurred after long-term exposure, such as respiratory and mental illnesses and cancer ("An Introduction to Indoor Air Quality," 2013). These were better known as Building Related Illnesses (BRI). IAQ is an especially concerning issue as North Americans spend more than 90% of their time indoors (US Environmental Protection Agency, 1989), and thus they are at risk if exposed to poor air.

Some sources of poor IAQ include improper ventilation of the building, infiltration and combustion from stoves and fireplaces. Additionally, building materials and certain household products can emit gases in the air that contain organic solvents known as Volatile Organic Compounds (VOCs) that can become trapped inside the building if the building is not being recirculated and being introduced with fresh air. One strategy to improve IAQ is to introduce vegetation indoors, which has been shown to improve indoor air quality by absorbing pollutants via photosynthesis and producing fresh air. Initial research on this topic was conducted by NASA in the 1980s (Wolverton et al., 1989), which showed that plants had the ability to remove the VOCs benzene, trichloroethylene, and formaldehyde. Results showed that up to 90% of benzene and up to 23% of trichloroethylene could be removed during a 24-hour exposure period. Further research has also shown that vegetation can also trans-locate other pollutants to the soil, where microorganisms break down the pollutants (Fujii et al., 2005). Additionally, plant leaves can trap particulate matter and heavy metals in the air (Ottele et al., 2010; Sternberg et al, 2010), as well as carbon dioxide (CO_2) (Fujii et al., 2005; J.-F. Li et al, 2010).

Vegetation can be introduced inside a building as an architectural feature known as a living wall. A living wall is any form of vegetation that can be fixed vertically to a wall or freestanding structure (Green Roofs for Healthy Cities, 2008). Living walls consist of a system that can be constructed from either pre-vegetated panes, vertical modules, or planted blankets that are fixed vertically to a structural wall or frame.

Living walls can be constructed with a variety of plant species that can provide optimal improvements to a building's IAQ. Since living walls encompass a large surface area (the area that is covered by the plants), they can also remove more pollutants from the air. Furthermore, living walls can improve health and increase productivity in the workplace (Dravigne et al, 2008). Living walls have the potential to improve IAQ in buildings. However, there has been little data that supports the ability of living walls in improving IAQ.

To determine the ability of vegetation to improve IAQ, several factors can be used. Factors such as light intensity and wind speed were investigated in J.-F. Li's study on green roofs (J.-F. Li et al., 2010). Results showed that during the day, a decrease of CO_2 concentration was reported when abundant sunlight was present. Meanwhile at night, an increase of CO_2 concentration in the air was reported due to lack of light. Additionally, a lower wind speed increased the absorption rate of CO_2 by the green roof. Since the pollutants were not being mixed as much in the air, the plants could trap pollutants more effectively.

One factor that has not been previously investigated is the role of supply airflow rates that are produced by mechanical ventilation systems. Girman et al. (2009) states

in his review that previous IAQ studies did not include mechanical ventilation rates of the building sites investigated. These values are important because mechanized ventilation plays a major role in diluting the indoor air with outdoor air and thus, can affect the pollutant concentration in the air. Understanding how these mechanical systems work together with vegetation, such as living walls, can provide a better understanding of the effectiveness of living walls in removing pollutants from the air.

This research looked at the ability of living walls to remove CO_2 from the environment and the role of ventilation in the CO_2 removal by living walls. The Center for Design Research (CDR) at the University of Kansas, as shown in Figure 1, provided for a unique laboratory for this study.

2. RESEARCH DESIGN

2.1. The Building

The Center for Design Research (CDR), located on West Campus at the University of Kansas, was constructed in 2011 and is a multi-use facility designed to promote interdisciplinary research among faculty and graduate students, as well as to provide a place to hold conferences, meetings, and classes. The CDR contains various environmentally-friendly and energy-efficient features, including a living wall located in the north side of the conference room (as shown in Figure 2) that measures 12 ft. tall by 33 ft. wide. This organic vertical plant wall was designed using several types of fern. The purpose of the living wall is to help purify the air in the building. The wall is sustained using an irrigation system that operates on collected rainwater.

Figure 1: Center for Design Research (CDR), University of Kansas

make physical changes to the site. Therefore, the following models were designed in FloVENT:

Model 1 - The CDR without the living wall (which acted as a base case for the study)

Model 2 - The CDR with the living wall and mechanical system on

Model 3 - The CDR with the living wall and mechanical system off

Model 4 - The CDR with the return grilles placed behind the living wall (which acted as the experimental case in this study)

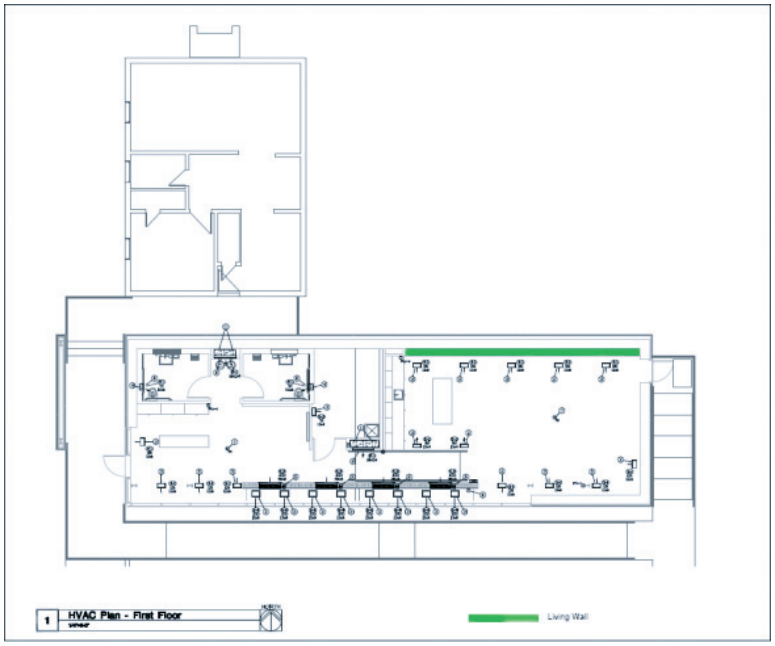


Figure 2: First floor plan of CDR illustrating location of living wall.

2.2. Data Collection

A computational fluid dynamics (CFD) program called FloVENT (FloVENT 9.3) was utilized to perform design simulations of the CDR. FloVENT models fluid and air flow and can also be used to measure the pollutant removal rate of an area over a period of time. FloVENT was used to measure the absorption rate of CO_2 by the living wall, as well as the CO_2 concentration levels throughout the CDR and near the return grilles.

2.3. Building Models

Another benefit of using FloVENT was that it allowed for the testing of the building under different building conditions without the need to

Three comparisons were done between these four models. First, Model 1 was compared to Model 2 to assess the role of living walls in removing CO_2 from the air. Model 2 was then compared with Model 3 to assess the role mechanical systems have on the living wall's ability in removing CO_2 from the air. Finally, Model 2 was compared to Model 4 to determine under which mechanical system configuration the living wall would provide the optimum reduction of CO_2 concentration levels in a building.

To model the CO_2 concentration rate in the building, people were

added to the building models. Each of the people added were modeled as a cuboid to simulate the body with a heat source to simulate the head, and the heat source was given a source value representing CO_2 exhalation rates. The CO_2 exhalation rate of 1.833 X 10-5 kg/s was used, which was gathered from Dougan's study and converted from L/min (Dougan et al., 2004). As indicated below in Table 1, (ASHRAE 62.1-2007), the maximum occupancy of the conference room was 32 people, so 32 people were added in the conference room to each model.

The living wall was modeled as an enclosure with a heat source and volume region. The heat source was given a negative source value to represent the absorption rate of the living wall. This value was determined using the absorption rate from Birds Nest Fern based on results from Su and Lin's study (Su, Y.-M., & Lin, C.-H., 2013). The absorption rate of -1.1111 X 10-7 kg/m3*s was used for the study and was added to all models except for Model 1.

The supply and return system for Models 1-3 were designed as oriented in the construction documents (as shown in Figure 2). In the case of Model 4, the return grilles were placed behind the living walls. The size of the supply diffusers are shown below on Table 2. The supply diffusers S-3 and S-4 were not modeled because those diffusers were for the Trombe wall ventilation, which was not modeled in FloVENT. Airflow rates for S-1 and S-2 varied from 125 cfm to 135 cfm1. The return grilles were 36 in by 24 in; one was located in the back of the entry room between the restrooms and the other was located facing opposite the Trombe wall, near the entrance of the conference room. In Model 4, the return grilles were designed to be the size of the living wall and were placed behind the living wall.

2.4. Variables

Variables looked at in this study were: CO_2 concentration, local mean age of air (LMA), and speed of airflow.

2.4.1. CO_2 Concentration Rate

FloVENT allowed for the storage of contaminant types for the model simulations. CO_2 concentration rates were investigated in all three comparisons. The values of CO_2 concentration are given in kg of the pollutant per kg of air. To activate the storage of CO_2, the "Concentrations" options was activated from "PM Model > Modeling." CO_2 concentration was selected from the material library. One plane was designed for this research, at human head level (Y-axis plane at Y= 5.25 ft). CO_2 concentration rates were also investigated by the living wall (Z-axis, 1.0 ft) and the return grilles at the entry door and the conference room were gathered from the geometry tables in FloVENT. Values from this study ranged from 0 to 0.20 kg/kg.

2.4.2. LMA (Local Mean Age of Air)

One of the most common complaints in buildings is the lack of fresh air, which leads to the perception that the air inside is old and stuffy. LMA

VENTILATION CALCULATIONS - ASHRAE 62.1 - 2007 & I.M.C. 2009									
MECHANICAL VENTILATION						REQD. VENT CFM	DESIGN VENT CFM	REQD. EXHST CFM	DESIGN EXHST. CFM
SYSTEM	AREA	SQ. FT	CFM/ SQ. FT.	PEOPLE	CFM/ PERSON				
HP-1	CONFERENCE	510	0.06	32	5	191	194	0	-
	ENTRY/CORRIDORS	461	0.06	3	5	43	43	0	-
	RESTROOMS	112			0	0	0	140	140
	CATERING	162	0.18	2	7.5	44	45	0	160
	STORAGE	101	0.12	1	5	17	17	0	-
TOTALS		1346				295	299	140	300

Table 1: Ventilation calculations of the rooms in the CDR.

GRILLE, REGISTER, & DIFFUSER SCHEDULE							
MARK	MANUFACTURER	MODEL	SERVICE	FACE SIZE	NECK SIZE	DAMPER	NOTES
S-1	TITUS		SUPPLY	14X8	12X6	NO	
S-2	TITUS		SUPPLY	14X6	12X4	NO	
S-3	TITUS		SUPPLY	38X8	36X6	NO	
S-4	TITUS		SUPPLY	14X10	12X8	NO	
R-1	TITUS		RETURN	38X26	36X24	NO	
E-1	TITUS		EXHAUST	12X8	10X6	NO	
E-2	TITUS		EXHAUST	14X6	12X4	NO	

Table 2: Schedule of the supply diffusers, return grilles, and exhaust registers in the CDR.

calculates the average time taken for fresh air to reach a certain point in the room and is a good measure of the effectiveness of the ventilation system. Values of LMA are normally expressed in minutes, with low values indicating regions that receive a good fresh air supply and high values indicating regions that receive a poor fresh air supply. LMA values were investigated for the first and third comparisons. One plane was created for this research, at human head level (Y-axis, 5.25 ft). Values from this study ranged from 0-60 minutes.

2.4.3. Speed

Speed was investigated to look at the effect of the supply air on the CO_2 removal properties by the living wall. Speed also allowed for further investigation of the role of air flow speed in mixing CO_2 with the air. Thus, speed was investigated in all three comparisons. One plane was recorded for this research, at human head height (Y = 5.25 ft). Speed values from this study ranged from 0-10 ft/s.

3. RESULTS AND DISCUSSION

3.1. First Comparison (Model 1 vs. Model 2)

In the first comparison, the CO_2 concentration levels were lower in Model 2 by 56% (as shown in Figure 3 and Table 3). This confirms the living wall's ability to reduce CO_2 concentration levels in the CDR. Additionally, the results showed that CO_2 concentration levels were present by the living wall, having an average CO_2 concentration rate of 0.0105 kg/kg, confirming the living wall's ability to absorb CO_2. The amount of CO_2 taken in by the return grilles is also listed below in Table 3 and illustrates the return grilles' role in removing CO_2 from the air. Results showed that Model 2 was exhausting 45% and 47% less CO_2 back to the mechanical system in the entry room and conference room return grilles, respectively. This means that in Model 2, less CO_2 is being brought back into the recirculation system.

Further analysis showed that the average LMA was slightly higher in Model 2 (as shown in Table 4), not providing much information about the living wall's ability to produce fresh air. However, it should be noted that LMA values were more consistent in Model 2, whereas the LMA in Model 1 was slightly higher in certain areas in the conference room. This indicates that Model 2 was able to distribute fresh air throughout the building, and thus, the living wall may have played a role in this. A comparison of the air speed between both models shows that Model 2 produces similar air speeds to those of Model 1 (Table 5), with Model 2 having slightly higher air speeds by 1%. In Figure 5, Model 2 also shows more consistent air speeds in the conference room, which indicates that Model 2 provides more comfortable air for building occupants.

3.2. Second Comparison (Model 2 vs. Model 3)

Results from the second comparison showed that Model 3 had near-zero CO_2 concentration rates (as shown

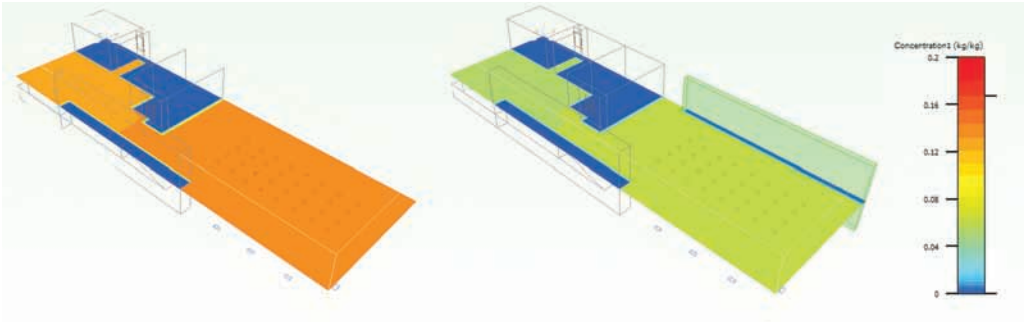


Figure 3: A comparison of CO_2 concentration between Model 1 (left) and Model 2 (right)

Average CO_2 Concentration Rates (kg/kg)			
	Model 1	Model 2	Difference
Y-Plane	0.114	0.0504	-55.8%
Living Wall	---	0.0105	---
Entry Room Return	0.10774	0.059045	-45.2%
Conference Room Return	0.10651	0.05688	-46.6%

Table 3: Quantitative comparison of CO_2 concentration between Model 1 (left) and Model 2 (right)

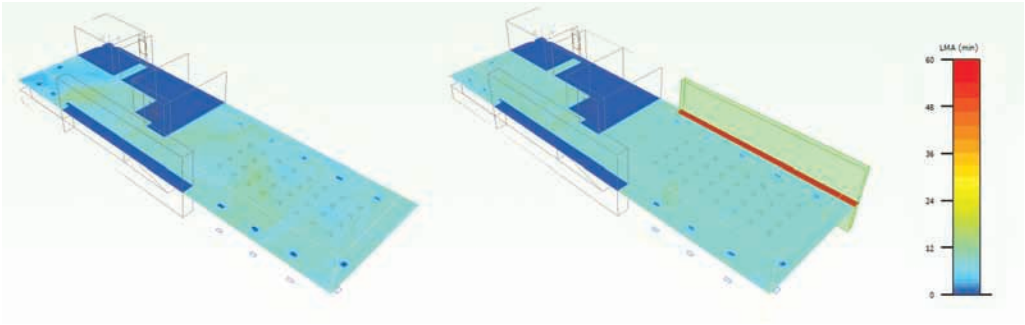


Figure 4: A comparison of LMA between Model 1 (left) and Model 2 (right)

Average LMA (min)		
Model 1	Model 2	Difference (%)
6.81	7.49	+2%

Table 4: Quantitative comparison of LMA between Model 1 (left) and Model 2 (right)

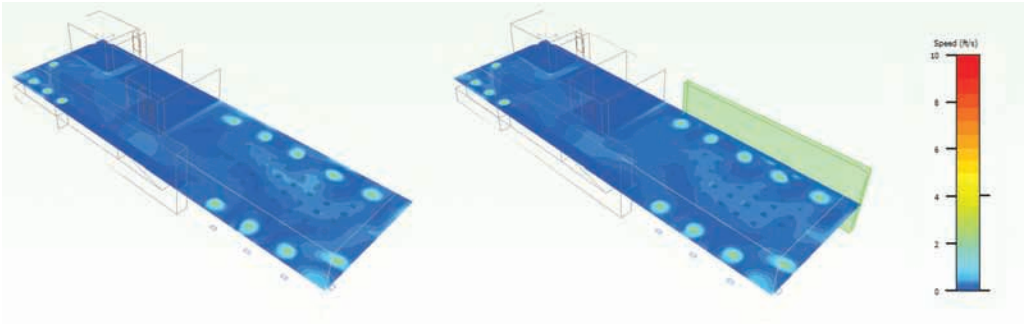


Figure 5: A comparison of wind speed between Model 1 (left) and Model 2 (right)

Average Wind Speed (ft/s)		
Model 1	Model 2	Difference (%)
0.162	0.163	+1%

Table 5: comparison of wind speed between Model 1 (left) and Model 2 (right)

in Figure 6 and Table 6). This may be because in Model 3, the mechanical system was not turned on, thus CO_2 was not being mixed with the air, which made it more effective for the living wall to absorb the CO_2 in the building. These results posed the question whether reduced airflow rates can increase the effectiveness of the living wall in reducing CO_2 concentration levels in the building. Since the speed in Model 3 was negligible (as shown in Table 8), these results could not prove whether this claim was true.

It should be noted that while the CO_2 concentration values around the return grilles were zero, this was because the supply air cfm was set to zero to simulate the mechanical system turned off; therefore, the return grilles were not returning air through the recirculation system.

In Model 2 the LMA is higher than the LMA in Model 3 (as shown in Figure 7). However, these results could not be compared side by side because LMA looks at the air being supplied into the building. Because Model 3 was not bringing in air, the LMA showed zero values (as shown in Table 7).

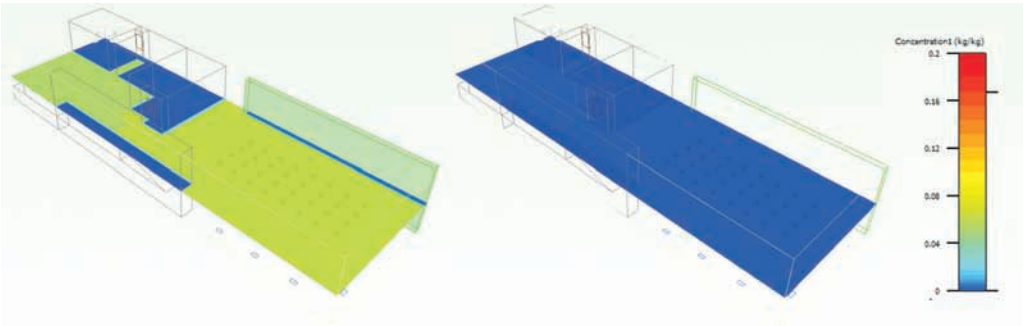


Figure 6: A comparison of CO_2 concentration between Model 2 (left) and Model 3 (right)

Average CO_2 Concentration Rates (kg/kg)			
	Model 2	Model 3	Difference
Y-Plane	0.0504	1 X 10-10	-~100%
Living Wall	0.0105	1 X 10-10	-~100%
Entry Room Return	0.05945	0	-100%
Conference Room Return	0.05688	0	-100%

Table 6: Quantitative comparison of CO_2 concentration between Model 2 (left) and Model 3 (right)

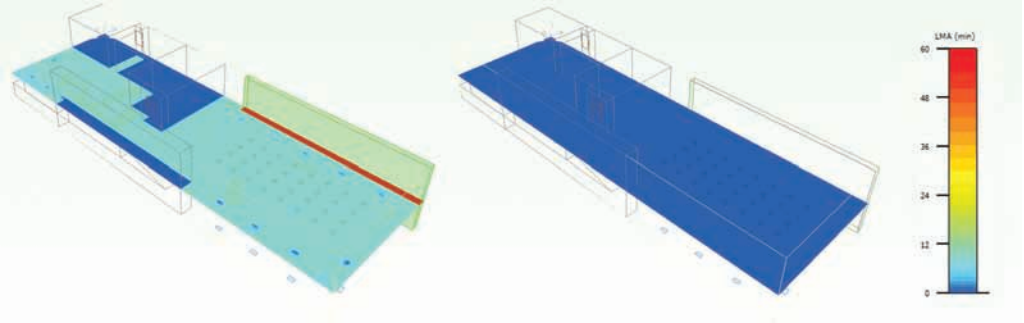


Figure 7: A comparison of LMA between Model 2(left) and Model 3 (right)

Average LMA (min)		
Model 2	Model 3	Difference
7.49	---	---

Table 7: Quantitative comparison of LMA between Model 2 (left) and Model 3 (right)

Average Wind Speed (ft/s)		
Model 2	Model 3	Difference (%)
0.163	---	---

Table 8: Quantitative comparison of wind speed between Model 2 (left) and Model 3 (right)

3.3. Third Comparison (Model 2 vs. Model 4)

In the final comparison, Model 4 produced results similar to Model 3 (as shown in Figure 8 and Table 9). The CO_2 values for Model 4 were lower than in Model 2 by 98%. This may be because of the proximity of the CO_2 source to the return grilles, which provide a deposit for CO_2 to leave the room. CO_2 concentration levels were also present in the living wall in Model 4, albeit having lower values than in Model 2. This may be because in Model 4, the air is quickly being returned to the return ducts from the supply diffuser. Also, the CO_2 concentration rates are listed below in Table 9. The reason for the low CO_2 concentration rates may be because of the size of the return grilles; since the return grilles were designed to be the size of the living wall; the CO_2 concentration rates would be lower. A test using different return grille sizes may further assess the role of the return grille size in removing CO_2 from the air.

LMA values were slightly lower in Model 4 than in Model 2, by 8%. It should also be noted that in Model 4, the LMA values near the living wall are zero, while areas further from the living wall are relatively higher. This may have been because the return grilles were very close to the supply

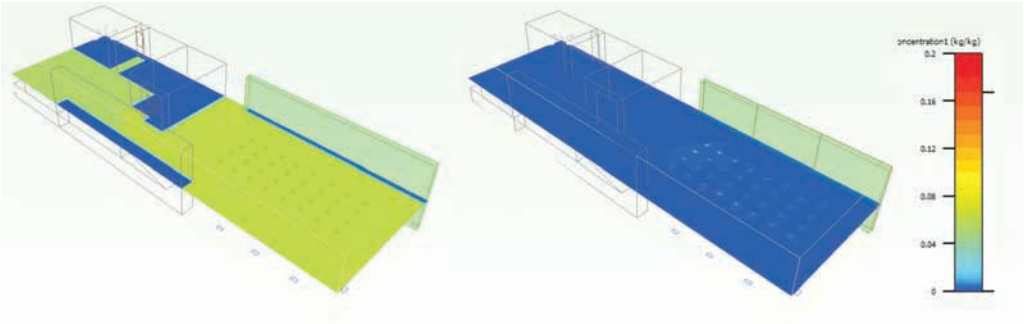


Figure 8: A comparison of CO_2 concentration between Model 2 (left) and Model 4 (right)

Average CO_2 Concentration Rates (kg/kg)			
	Model 2	Model 4	Difference
Y-Plane	0.0504	8.6 X 10-4	-98.3%
Living Wall	0.0105	4.65 X 10-4	-95.6%
Entry Room Return	0.059045	0	-100%
Conference Room Return	0.05688	0	-100%

Table 9: Quantitative comparison of CO_2 concentration between Model 2 (left) and Model 4 (right)

Average LMA (min)		
Model 2	Model 4	Difference
7.49	6.88	-8.1%

Table 10: Quantitative comparison of LMA between Model 2 (left) and Model 4 (right)

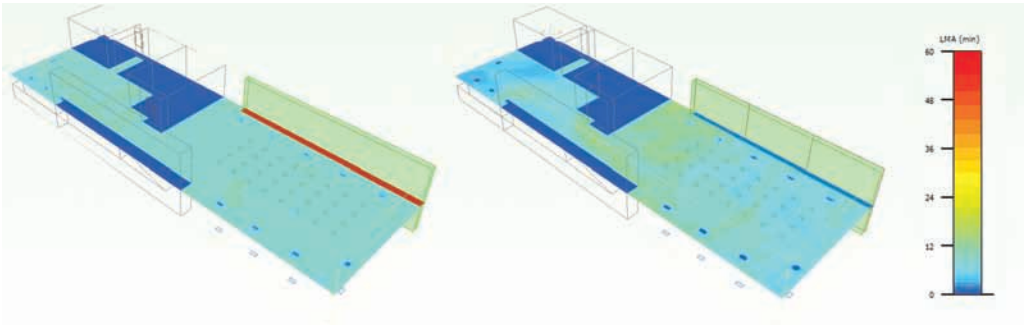


Figure 9: A comparison of LMA between Model 2 (left) and Model 4 (right)

diffusers, which meant fresh air was quickly being returned as soon as it was supplied to the room. This may also explain why certain areas in the conference room had a higher LMA.

An analysis of air speed between the two models shows that Model 2 provided a 4% higher air speed than Model 4 (as indicated in Table 11). Once again, the fact that the return grilles were placed behind the living wall may have been the reason for this.

This may indicate that a living wall system, in concert with a return grille system behind the living wall, may increase the productivity of the living wall, given the proper orientation of the supply diffusers and return grilles. Further analysis of the CDR under different return grille placements could provide a more accurate understanding of the role of return grille placement. Additionally, further study of the CDR under different supply grille placements can also provide a more accurate understanding of the role of supply diffuser placement.

4. CONCLUSION AND RECOMMENDATIONS

A case study of the CDR was done, using three building comparisons to assess the effectiveness of living walls in removing CO_2 from the indoor environment. The first comparison confirmed the living wall's ability to absorb CO_2. It also confirmed that the living wall helped reduce CO_2 concentration in the CDR by 56%, as well as providing more consistent fresh air throughout the building. Finally, it showed that less CO_2 was being returned into the recirculation system under the model of the CDR with the living wall. The second comparison poses the question that reduced airflow rates can increase the effectiveness of the living wall in reducing CO_2 concentration levels in the building. Further research using reduced airflow rates would have to be conducted to confirm the validity of this claim. The final comparison indicated that CO_2 concentration levels may be further reduced by living walls by installing return grilles behind the living wall. However, further research testing the placement of the supply diffusers and return grilles would have to be conducted to confirm this claim.

One of the limitations during the study was not having the proper equipment to conduct field measurements of the CO_2 concentration levels inside the building. Having this field data is valuable to the research as it would allow for the validation of the simulated models with actual measured data. Additionally, the case study would have been more valid with the determination of the exact absorption rate of the ferns in the living wall. This data can easily be gathered with a device such as a CO_2 sensor. Future study will be designed to resolve the aforementioned limitations.

5. ACKNOWLEDGEMENTS

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Average Wind Speed (ft/s)		
Model 2	Model 4	Difference
0.163	0.156	-4.3%

Table 11: Quantitative comparison of wind speed between Model 2 (left) and Model 4 (right)

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Q&A

How did you become involved in doing research?
I started by meeting with EECS faculty whose research I knew about. What does your lab do? What position or project do you think would be well-suited to an undergraduate? These were the kinds of questions I would ask. They were very helpful; professors enjoy talking about their work. But there was one question they often asked me that stuck with me: what is it you want to do? From this question I realized the most important part of research—do what you love. Anything can be research, provided somebody has an interest to investigate it. Because I had always been fascinated by building computer systems that interact naturally with people, I thought it would be fun to build a project around this idea.

How is the research process different from what you expected?
Honestly, I didn't really know what to expect. I thought working as a "research assistant" might be a lot like any other job. In a way that's true, but I now believe research is more like school. There are papers to write, tests to perform, formulae to solve... all the sorts of problems I might encounter in the classroom. However, there is one important difference, and that is that I was the one deciding the next steps. I didn't have a teacher telling me what to do and when to do it. Rather, I had a personal goal of what I wanted to show and had to meet with my mentors to work out the plan to get there.

What is your favorite part of doing research?
I love learning, and to me, research is like the opportunity to get paid to learn. Of course, there is a lot of work involved, but I feel that it is very rewarding. When a research project is complete, you've acquired a lot more skill in the field and, hopefully, accomplished what you set out to do.

An analysis of electromyography as an input method for resilient and affordable systems: human-computer interfacing using the body's electrical activity

Seth Polsley

ABSTRACT
As hardware continues to become smaller and faster, software becomes more powerful. The continual improvements in our technology promise to bring about significant changes in our lives and in how we interact with the world around us; new and popular devices with touchscreens and voice interfaces are evidence of this. Yet, even the most cutting-edge consumer devices have their limitations. For example, many individuals are still unable to use modern computers because of accessibility restrictions. Rehabilitation devices, such as robotic orthotics, and military projects, like exoskeletons, have not been fully realized using existing tools. Even in the massive computer-gaming industry, a device's interface can be as much a distraction to the player as an aid. An emerging field of interface technology may be able to help

solve some of these problems: natural interfaces that seamlessly interpret our bodies' biological signals. Electromyography (EMG), the recording and processing of muscular electrical activity, is one of these technologies. EMG shows a lot of promise, especially in rehabilitation and accessibility, but it has yet to become a mainstream technology. This work studies EMG through the construction of an EMG-based interface, considering its cost and reliance. The analysis seeks to determine the plausibility of implementing EMG systems in consumer devices, as well as examining some of its potential when applied to new problems.

Keywords—electromyography (EMG), neural network, Fourier transform, signal classification, human-computer interfaces

INTRODUCTION

In the past few decades, technology has significantly altered our lives. The digital revolution saw changes not only in electronics themselves, but also in the way we interact with them. Once mostly relegated to office workers and hobbyists, computers have become vital components of nearly every tool we use, and the integration of computers into so many electronics has paved the way for new human-computer interfaces as we seek to find better and more appropriate ways to control them. For example, the keyboard and mouse were long the standard in computer input technologies, but these devices were not very practical as a means of controlling telephones. For that reason, many modern cell phones now use touchscreens to interpret user commands. Touchscreens allow for very reliable and mobile device control, but they necessitate the use of hands. To allow hands-free control, voice interfaces have become increasingly popular in recent years. These interfaces have continued to advance, and as they improve, they have been able to understand humans more naturally.

However, even with our most advanced consumer-level technologies, like digital voice assistants and touchscreens, there are still those who cannot use these devices. Particularly, those suffering from physical disabilities or certain types of mental disorders may be restricted in their ability to interact with computers. The search for universally accessible technology is an open project in the scientific community. The continuing developments in hardware that allow for smaller and more powerful devices have led to growing interest in a new class of computer interfaces [1]. These types of interfaces would interact with users solely through their bodies' natural signals. The gold standard of this field of devices would be a true brain-computer interface (BCI). A BCI could, theoretically, interpret any user's action by monitoring his or her brain activity. Such an interface removes accessibility restrictions and has been used successfully in a large number of studies as evidenced in [2][3][4][5] and many more. A BCI would supersede all existing technologies since it would interpret commands directly from the source, our brains. BCI is a growing field that shows a great deal of promise; within the last decade alone, hundreds of new laboratories have been created to research BCI [6]. Unfortunately, most methods of monitoring brain activity, such as electroencephalography (EEG) or Functional Magnetic Resonance Imaging (fMRI), require expensive, specialized equipment in carefully controlled environments. These limitations are currently preventing BCI from spreading much beyond the world of research.

There are many other options than BCI that could make technology more accessible. Heart rate monitors in watches are an example of consumer devices that interact with the user based on his or her body's signals [7]. These rely on sensors that are inexpensive and reliable, in many kinds of environments [8]. The existence of such devices demonstrates that the hardware and software for more natural interfaces are available. One technology that may be viewed as an intermediary to BCI is electromyography (EMG), the subject of this analysis. EMG is the measurement of electrical activity across muscle groups. To understand why EMG is beneficial, recall that BCI often uses EEG. EEG measures the electrical activity of the brain. The popular, non-invasive techniques do this through an array of electrodes placed on the scalp. Unfortunately, these signals are difficult to acquire outside of controlled conditions, due to signal attenuation caused by the skull. Conversely, muscular electrical activity is much more pronounced, making it easier to detect. In fact, in many BCI applications, EMG is considered interference because it is so strong compared to EEG [9]. The relative strength of EMG enables EMG-based systems to use less

expensive hardware. The stronger signal acquired by EMG is also more noise-tolerant than EEG.

Not only can EMG be more affordable and reliable than EEG, it also offers some of the advantages of BCI. One prominent example is in the field of physical therapy and rehabilitation. EEG has been successfully applied to a number of rehabilitation applications. EMG is also applicable to this field [10] [11][12]. Furthermore, EMG could be paired with types of robotic orthotics to aid in rehabilitation for individuals suffering from more severe conditions, such as spinal cord injury [13]. The applications are not just limited to therapy. Specialized hardware like braces and exoskeletons could be driven by EMG, giving the operator a much more intuitive control than an interface using levers and buttons. Virtual reality systems, video games, and even general computer interfaces could employ EMG to give users an immersive and natural experience. It would be challenging to apply most modern interface technologies to many of these applications, yet BCI and EMG-based systems would be well-suited to them.

EMG is a very promising field for its combination of low-cost and reliability with a number of the advantages of more difficult interface methods such as EEG. This promise bears investigating and is the impetus behind this analysis. This paper outlines the construction of a very basic, end-to-end EMG system. In developing and building the final system, factors such as cost and noise-tolerance are considered. The resulting construct is also tested on a specific problem—distinguishing between two distinct movements of the arms. These tests are primarily intended to be demonstrative, not fully investigative of the developed system's capabilities; as discussed, there are of course many other possible applications.

METHODOLOGY

In order to analyze the effectiveness of EMG with regard to its cost and reliability, a complete EMG system was constructed. The developed system was composed of three primary components: the hardware, middleware, and software. Figure 1 shows an overview of the system. Briefly, the hardware is a small circuit that acquires the raw EMG signal. Middleware is being used in this case as a general term for all of the operations performed between the hardware and software; in this problem, the most important action is the analog-to-digital conversion (ADC) at a given sampling rate. The software is the portion of the system that does meaningful operations on the EMG data. In the tests performed, the software determines when muscle movement occurs and classifies the activity. A more detailed discussion of each section follows.

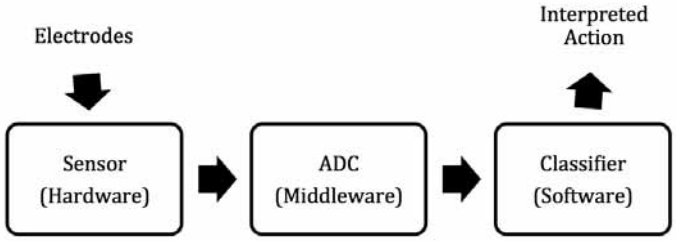

Fig. 1 Block-level view of the EMG movement classifier.

Hardware

The goal in the hardware phase of the project was to build an inexpensive yet functional EMG sensor. While there are some EMG schematics available online, such as the Advancer Technologies sensor seen in [14], many of these heavily pre-process the signal. The few sensors that are available for some consumer applications often only measure a single value, which is the amplitude of voltage across a muscle. Recording only the level of muscle activation removes a lot of potentially useful information from the signal; it certainly reduces the number of techniques that could be used with EMG that are found in current EEG systems, like spectral analysis. With the motivation of maintaining as much information from the original signal as possible, the final circuit was relatively simple. The circuit schematic is shown in Fig. 2.

The essential piece of the circuit is an instrumentation amplifier. Instrumentation amplifiers are ideal for this type of application because they measure the voltage

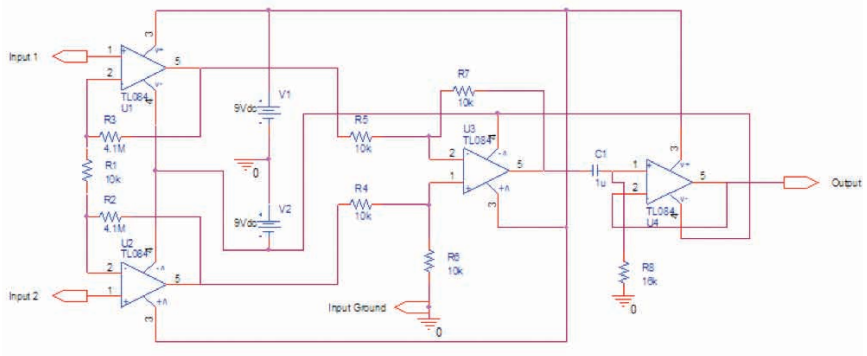

Fig. 2 Schematic of the instrumentation amplifier used as an EMG sensor.

between two points without heavily contaminating the signal. The amplifier's design is based on the discussion provided in [15]. TL084s were used as the op-amps because their JFET-based implementation helps to reduce current leakage on the input. Certain component values were selected based on recommendations provided in [16]. The resistors R2 and R3 were responsible for determining the gain, and their values were selected for a gain of 820, boosting the signal strength significantly. A large gain was preferred so that small muscle movements could be easily detected. Following the acquisition and amplification, some minor filtering is performed using a passive high pass filter with a cutoff frequency near 10 Hertz (Hz). This filter reduces the low-frequency components of the signal and is primarily intended to remove noise introduced by the sensor's batteries. More extensive filtering could be applied to examine specific bands, but in keeping with the goal of maintaining as much of the original signal as possible, no more filtering was done at this point.

There are three electrodes used as the input to the circuit: a global ground and two placed side-by-side across the muscle group of interest. The two electrodes on the muscle are used to find the voltage across the region of interest. This voltage is then referenced to the global ground. The signal goes through the amplification and filtering, and the final analog signal is sent on to the middleware.

Middleware

The middleware is the portion between the hardware and software. It abstracts all of the hardware away by providing digital measurements at a requested rate. A Bluetooth-enabled Arduino microcontroller, the BLUNO, was used for this part of the system. The BLUNO's ADC can sample analog signals between 0 and 5 Volts (V), converting them into a digital value with 10 bits of resolution; these parameters were quite sufficient for this problem. The BLUNO sends the digital value over a serial connection, either USB or Bluetooth. The USB interface was used in this project, even though the Bluetooth interface could be used for wireless applications. As an Arduino-based device, the BLUNO was programmed in the C language with a process that listened for new connections and would stream the EMG signal at the defined sampling rate.

Software

The software used the EMG data to assemble a feature vector and classify the user actions through a neural network.

1. Building the Feature Vector

A feature vector is a matrix of values, ideally those that are the most distinct across a number of different classes, used by a classification algorithm to learn and classify data. Since the task was to distinguish between movements, a feature vector had to be built to represent movements in a classifiable manner. Using thresholding, whenever a measurement above the threshold of 0.5 V is detected on the amplified signal, the next 120 milliseconds (ms) are assumed to be the beginning of an action. This time window was selected based on prior research suggesting there is up to an 80ms delay between when the electrical activity of a movement becomes recordable and when the movement actually begins to occur [17]. Of course, a 120ms window adds at least 40ms of delay over the body's natural one, with some extra latency due to sampling rate and processing time, but a 40ms delay is sufficient in most user applications. Indeed, delays of approximately this length are found in many consumer-level interfaces such as keyboards and touchscreens [18].

The collected samples in the 120ms window are then transformed using the Discrete Fourier Transform (DFT). The DFT, a form of spectral analysis, alters the signal so that levels of activation of certain frequencies may be examined. The DFT is also the reason a 120ms window was selected instead of an 80ms one, since the number of samples in the time window determines the resolution of the transformed signal, and the 120ms window contains more samples. To further increase the resolution of the DFT, the window is padded to twice its original size using zeros. The resulting resolution is the Nyquist frequency divided by twice the original number of samples (Nyquist_frequency/[2*time_window*sample_rate]). The Nyquist frequency is always half the original sampling rate because half the values returned by the DFT are complex. With a sample rate of 256 Hz, the resolution was approximately 2 Hz. Figure 3 demonstrates construction of a feature vector.

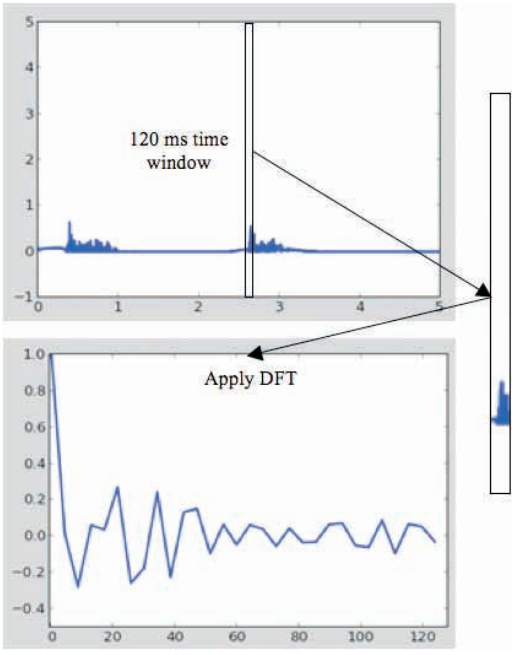

Fig. 3 A visual representation of building the feature vector

2. Classifying Movements

Classification is performed by a neural network with variable layer sizes. Neural networks are mathematical constructs that use layers of artificial "neurons" to learn how to classify some given data. For these tests, the input layer consisted of thirty neurons, the number of samples in the DFT, eight hidden neurons, and two output neurons. Only two outputs were necessary because the classifier was being used to discriminate between two movements; more movements could be added, but would require more output neurons.

Neural networks use supervised machine learning algorithms to classify signals, so before any meaningful results could be obtained, the network had to be trained. Training is implemented as an automated process wherein the user is instructed which action to perform and when. Training may be done in real-time or in batches because the software includes an additional feature of saving all the collected EMG data, along with the trained neural network's weights, at the end of each session. This information could be used for later batch training to improve classification accuracy. The trained network is loaded at the start of each new session, allowing the same network to be used repeatedly, whether training or classifying.

The final part of the software that merits discussion is the interface. Three plots are used to provide users with feedback and report the classification results. The first plot is a live graph of the acquired EMG data, which serves as a visual of muscle activity over time. The second plot is the DFT used for movement classification. The DFT demonstrates how much each frequency contributes to the muscle movement, dependent on the resolution of the transform. The final graph is used for classification reporting. The output from a neural network is the probability that a given input belongs to a specific class, and by taking the maximum output, the most likely class can be found. Thus, a plot of the output is not needed, since only the class must be reported. However, the plot provides the user with more information by indicating how certain the network is of a given input. Information like this can be helpful in determining how much more training is needed, especially when the training is performed live.

The resulting system is pictured in entirety in Fig. 4. As shown, the hardware phase was implemented on a breadboard, with clips for the leads to electrodes. The BLUNO's ADC is directly connected to the output of the sensor, and a USB connection links the software to the other components.

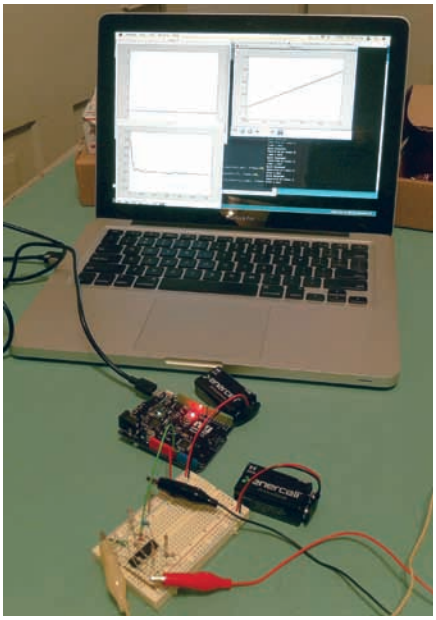

Fig. 4 The completed and assembled EMG system

RESULTS

By this point, the discussion has included the construction of an inexpensive EMG sensor built from a few circuit components and a microprocessor. The next phase of the analysis was to explore the capabilities of the sensor through testing. The test selected for this examination was the discrimination between two distinct movements of the bicep.

First, the electrodes were placed on the arm as shown in Fig. 5, with the ground electrode placed on the elbow. Areas over bones are ideal grounding points since there is little interference from the muscles in these regions [16]. Once attached to the EMG system, with the software launched, the training could begin. In these tests, all training was done over a set of live sessions, where the experimenter was connected directly to the system performing the indicated actions. As anticipated, the network was not able to classify correctly during the early part of the training, but after several hundred examples, classification accuracy increased noticeably. Following training, the resulting network could be tested on only its classification

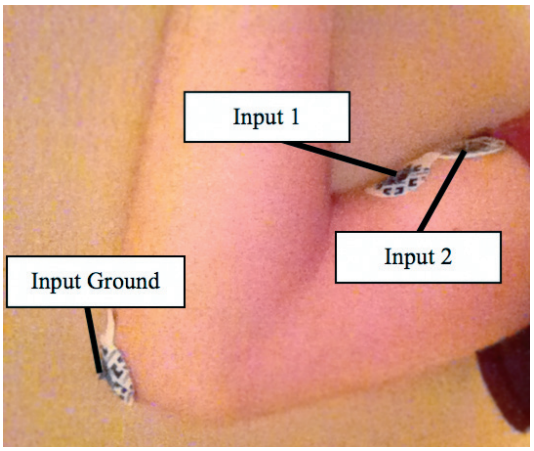

Fig. 5 Electrode placement for the experiments

accuracy. Six trials were run in all; Table 1 reports the individual trial accuracies. An average of all six trials indicated an accuracy of 74 ± 6 %.

Classification accuracy across multiple trials	
Trial Number	Accuracy
1	64.3%
2	77.1%
3	68.5%
4	71.4%
5	75.7%
6	84.3%
Average Accuracy	
74 ± 6 %	

Table 1

Figures 6a and 6b show the average-case DFT for both classified actions. The first action in Fig. 6a, which was sustained holding of an outstretched arm, demonstrates a roughly exponential drop in frequency activation, which is a typical phenomenon observed in EMG and EEG [19]. The second action seen in Fig. 6b, which was making a clenched fist, has a very different DFT. Notably, there is more activity in some of the higher frequencies, while frequencies around the 10 - 20 Hz range are more suppressed. These differences were sufficient for the neural network to distinguish between the two activities in most cases, and they demonstrate some of the potential of EMG to broader applications. If most movements have a relatively distinct DFT, a neural network or other classifier would be able to differentiate between such movements.

DISCUSSION

Based on the results from testing, the EMG sensor worked well. It was fairly inexpensive to construct, and the parts necessary to build the basic circuit are easy to find. Also, the amplifier's gain is tiny compared to what is required for EEG recording, further simplifying design, and the sensor did not need to be placed inside protective casing. Of course, any consumer product using this technology would need to enclose the sensor in a case, which should improve accuracy by shielding it from noise, but leaving it exposed in these tests demonstrated noise tolerance.

Tests were performed in several locations, but none of them were in a controlled environment. As seen in Fig. 4, the sensor was only implemented on a breadboard, and the exposed wires would have left it open to much more noise than a highly-sensitive system, like an EEG amplifier, could tolerate. These findings are encouraging, since they show that EMG-based interfaces would likely be very noise-tolerant, functioning under many kinds of non-ideal conditions. Because the hardware is also affordable, EMG seems like a promising technology that could precede BCI in consumer-grade applications.

It would be beneficial to explore a few possible improvements to the implemented system, as they could be used to build better EMG devices. Most importantly, the classification accuracy could be improved by building a better feature vector. In these tests, the DFT of a small time window is all that is used. However, in BCI, feature vectors are often constructed using a variety of techniques, and they combine scientific knowledge of human physiology to select the best features [20]. This is a case where EMG technology could benefit from the body of work available for EEG. Likewise, the classification algorithm itself could be improved. Many different ones are employed in BCI, including neural networks [21], and a number of them may also be well-suited to EMG.

The hardware could be improved without much additional cost. Extra filtering could be used for better

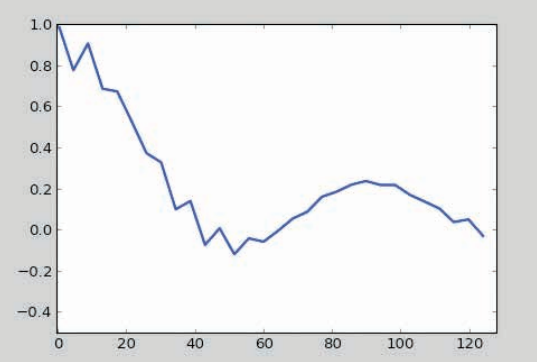

Fig. 6a The typical feature vector of the first classified movement, the continued holding of an outstretched arm

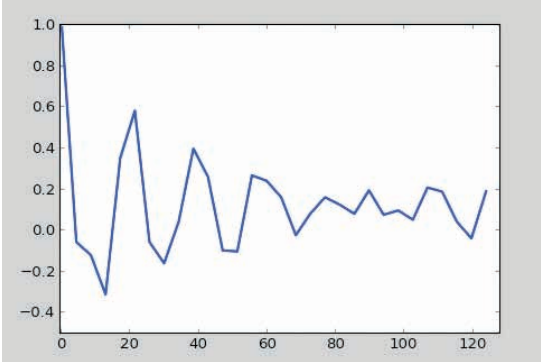

Fig. 6b The typical feature vector of the second classified movement, flexing of the arm

noise reduction. Certain frequencies could be removed if they were not beneficial in a given application. Alternatively, all frequencies could be removed except for a particular bandwidth of interest. As mentioned above, enclosing a soldered sensor in a shielded case would also significantly reduce noise.

It should be noted that the software for interpreting and acting on EMG signals is completely extensible. It was written in python and run on a laptop for this analysis, but it could be written in C for greater speed and run on a standalone processor. If the software were run on a microcontroller like the BLUNO, all of the signal classification could be done wirelessly, and any device paired over an interface like Bluetooth could use that information. For example, an exoskeleton could perform the same action the user is doing by using the interpreted signal from the EMG sensor. Even though this study focused on movement classification, EMG may also be used for movement tracking with the inclusion of some physiological models, as demonstrated in [22]. These improvements could make EMG very well-suited to exoskeletal control.

This analysis is not fully-conclusive. EMG is a broad field, and there is an extensive body of research in the area. There will likely continue to be developments in this subject for many years, along with continuing breakthroughs in EEG and BCI-related topics. However, the results from this cursory study of EMG show that the technology is very nearly ready to expand outside the world of academic research.

To reiterate some of the earlier findings, EMG sensors can be built that are both affordable and able to perform well in varying conditions. BCI is not yet to this point, providing EMG with the opportunity to reach a market that is relatively new and untouched. Even though EMG is not applicable to all of the possible uses of natural interfaces, as BCI would be, it would allow for a number of these applications to be explored with present technology. As evidence of this, note that one of the first EMG-equipped consumer products was very recently announced, the Myo armband [23]. This band allows users to connect to many types of devices wirelessly and control them using EMG. Based on the findings of this analysis, it is likely that more EMG devices will be entering consumer markets soon. This is an exciting technology, and not only will it change how a number of existing technologies function, but it is bound to bring about some new ones that were never before possible.

ACKNOWLEDGMENT

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RESEARCH MENTOR
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Q&A

How did you become involved in doing research?
Having been familiar with Fresco since childhood, I began researching his life as a personal interest. I then wrote a short biography summarizing my findings. I sent this to Fresco. I was then invited to pursue my research more directly and thoroughly by visiting him for an interview and review of his materials. From there my research grew into a film project, a biographical compilation project, and an archiving project.

How is the research process different from what you expected?
For me, research is a very comfortable process. Finding meaning and making connections is rather easy when there is a powerful drive to discover and when one knows what they are seeking at every turn. Perhaps the most surprising aspect of research is the need for proper planning and organization from the outset. Without a plan for how sources and information will be organized when it is discovered, a researcher can encounter much hassle and wasted time or effort. It is a matter of making the process efficient.

What is your favorite part of doing research?
Most of all, I like discovering something new about the subject, such as a new source or lead. Each new discovery is a brushstroke that helps complete the picture. In my case, I am researching a person's life. Therefore, the subject is a closed one. Ultimately, only so much significant information can be discovered about a person living in a limited number of places and limited range of time. Because of this, it is easier to know what parts of the picture are missing and that the picture is being completed when new information is found.

Man of Tomorrow: a film on Jacque Fresco

Nathanael Dinwiddie

ARTIST STATEMENT
Research for this project has involved investigating the life history of renowned futurist, Jacque Fresco, and gaining more insight into the multiplicity of factors that have produced him. This was done by uncovering various forms of documentation of his life, interviewing people who knew him, and researching historical and intellectual movements that influenced him. The project has evolved into a three-part project involving the production of a documentary film, compilation of biographical information, and the archival preservation of Fresco's materials. This project has come to be known as *Man of Tomorrow*.

Jacque Fresco is a 98 year-old man who has worked in many fields. This has earned him the title "multidisciplinarian." Throughout his life, his occupations have included commercial inventor, aircraft engineer, industrial designer, technical consultant, illustrator-draftsman, and behavioral therapist, but he has primarily been a socioeconomic theorist and futurist for the last 40 years. The result is a captivating and enigmatic thinker. He was born in an age of tremendous technological promise and ideological permutations. Though much time has come to pass, Fresco remains a valuable figure of a once great episode in human history. As much as he may be the beginning of something great, he is the end of something tremendous. Fresco, as a descendant of a lineage of similar thinkers, may very well be the punctuation of a dissipating

intellectual legacy. The virtue of Fresco's work is the synthesis of several disparate disciplines that converge to realize an attractive new paradigm for human life.

Today Fresco is often considered a futurist or futurologist, philosopher of science, or technological utopian philosopher. However, he may be better thought of as a global planner. Though he has gained prominence only in recent years for his vision of the future and has inspired a fairly substantial social movement, for most of his life he was quite obscure. This has resulted in poor and neglectful documentation of his life, efforts, and ideas. Though in recent years documentation of his efforts have surfaced, all have been concerned with the same area of his work, or fail to document him as anything more than a peculiar curiosity. In contrast, I am concerned with presenting Fresco in a more balanced manner, giving broader exposer and proportion to the subject's aspects. The standard manner of presentation has been deficient because too few have enjoyed unrestricted access to the vast and diverse collection of Fresco's creative work, as well as too little penetrative research into Fresco as a subject. Witnessing this deficiency of documentation, I have found myself, as archivist of his work and film/philosophy student, in the position to provide what has been missing. Perhaps no other medium better serves the function of reversing this deficiency than the art of film. Indeed, I find no other medium better suited for representing a subject with the credibility and realism than the documentary. Visual imagery, the subtleties of an interviewee's expression, informative commentary, and well-designed narration coalesce to provide an advanced form of communication, expression, and revelation.

Man of Tomorrow is an audiovisual inquiry into the efforts of Jacque Fresco, as a tribute to his life, and as an information source for anyone else interested in this provocative and fascinating figure. Of his life, I explore his early experiences during the Great Depression, his early efforts as a scientist, engineer, and inventor, his turn toward social engineering and urban planning, his current efforts as a philosopher of the future,

and ultimately the culmination of his work as embodied by the organization he has founded, known as the Venus Project. Of his ideas, I explore his views regarding the future, human values, government, economics, behavior, language, social change, the role of science and technology, as well as the individuals and intellectual movements that influenced these views. Such themes will be explored due to the emphasis they receive in his work. To compliment these themes, I also explore Fresco's innovative designs, elegant architectural illustrations, and bold visualizations of future cities.

Production of *Man of Tomorrow* has entailed travel to locations in Florida, primarily Miami and Venus, and entails further travel to Los Angeles and New York. Currently, more than 200 hours of footage have been recorded and fourteen interviews conducted.

In addition to new footage, interviews, and commentary, the film will contain much of the recently organized archival materials, consisting of more than 2,000 audio and video recordings, 2,500 photographic images, 3,500 design renderings, 300 physical models, and hundreds of documents. The film will use old television and radio shows, video and audio recordings, newspapers, magazines, photos, sketches, paintings, and other documents.

Funding and production of *Man of Tomorrow* has been made possible by the Center for Undergraduate Research, School of the Arts, and the Department of Film and Media Studies.

Work for *Man of Tomorrow* has been proceeding since fall 2012 and is expected to continue into 2015.

Patrick Niehaus

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ACADEMIC LEVEL
Senior

RESEARCH MENTOR
Mark Holder, *Associate Professor of Ecology & Evolutionary Biology*

Q&A

How did you become involved in doing research?
I applied for an REU (Research for Undergraduates) at KU last summer and worked with Dr. Mark Holder for ten weeks. It was an amazing experience!

How is the research process different from what you expected?
The amount of trial and error used in fixing everything. It's not as simple as going from point A to B. There's a lot of tear-downs in between.

What is your favorite part of doing research?
Running simulations on the supercomputer.

Performance study of supertree methods

Patrick Niehaus

INTRODUCTION

Phylogenetic trees depict the relationships among varying species [1]. A simple example of this is a family tree. When referring to Figure 1, the three most important components of a tree include: the Node(s) (denoted by squares), the Branches (denoted by lines), and the Tips (denoted by circles). The Nodes represent the hypothetical ancestors. The Branches represent the evolution of a lineage. Lastly, the Tips represent the species being studied.

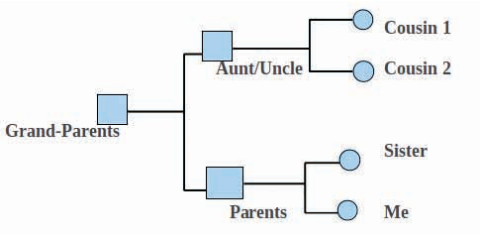


Figure 1. This figure is a visual example of a tree.

Most phylogenetic trees are estimated from DNA sequence data. A supertree is a phylogenetic tree estimate which is produced by merging smaller phylogenetic tree estimates together [2-4]. By combining several phylogenetic trees together, we can gain a better understanding of how species are related to one another. One example would be combining the human and primate phylogenetic trees.

MRP works by translating each branch of each individual tree into a matrix column; this process is repeated until a character matrix is formed [5,6]. All taxa that descend from the branch are represented in the matrix with a '1', other taxa that are found in the tree are represented with a '0', and taxa that aren't found in the tree are represented with the missing data symbol '?'. Each branch of each input tree is encoded as a series of columns. Once complete, the character matrix includes all of the phylogenetic relationships contained in the source trees. The supertree is estimated from this

matrix using the same parsimony approach that is used when estimating a tree from two-state character data. Refer to Figure 2 for additional reference.

TAG exploits the fact that trees are actually part of a graph. Phylogenetic trees are directed and require that each node has, at most, one parent. However, TAG relaxes these requirements, and allows multiple trees to be combined into one common graph [1]. Through this process, computational time and resources are believed to be greatly minimized. Refer to Figure 3 for additional reference.

MRP is one of the more accurate supertree methods for problems with smaller taxa sets. When faced with a larger taxa set, MRP loses accuracy. TAG, however, is designed to work best with larger taxa inputs and is hypothesized to be more accurate and efficient when working with a larger taxonomy input.

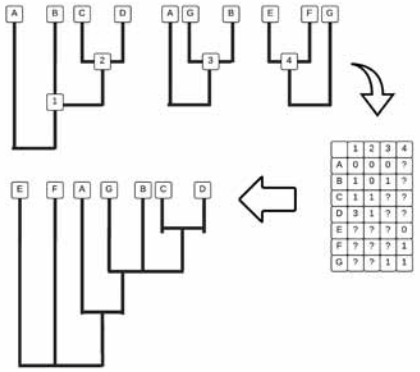


Figure 2. This figure is a visual example of the MRP process.

METHODS

This study first requires an input taxonomy. A true tree is generated from the taxonomy by randomly resolving areas of uncertainty and then altering the tree to mimic the effects of taxonomic errors. Several input trees are generated from the true tree to mimic a set of inputs which could be obtained by several overlapping phylogenetic studies. The input trees produced sub-sample the taxa in the taxonomy, and also differ from the true tree because the simulator introduces random changes to the topology. Each input tree is then run individually through MRP and TAG as an estimate and are then compared to the true tree. Whichever estimate is closest to the true tree (e.g. the least amount of false negatives and positives) and takes the least amount of time is believed to be the more accurate and efficient algorithm. Refer to Figure 4 for additional information.

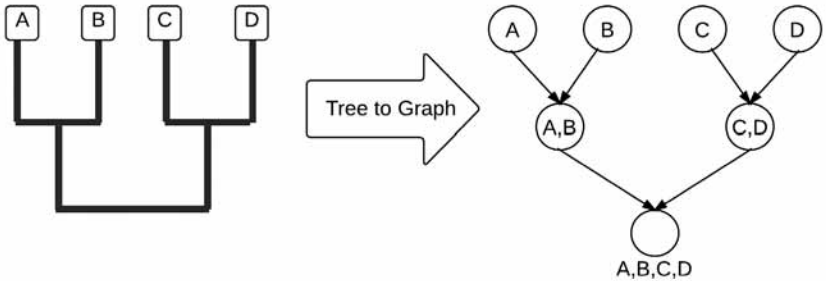


Figure 3. This figure is a visual example of the TAG process.

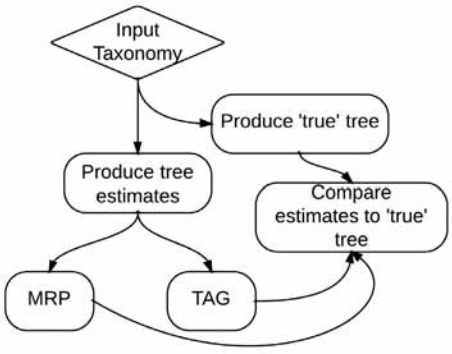


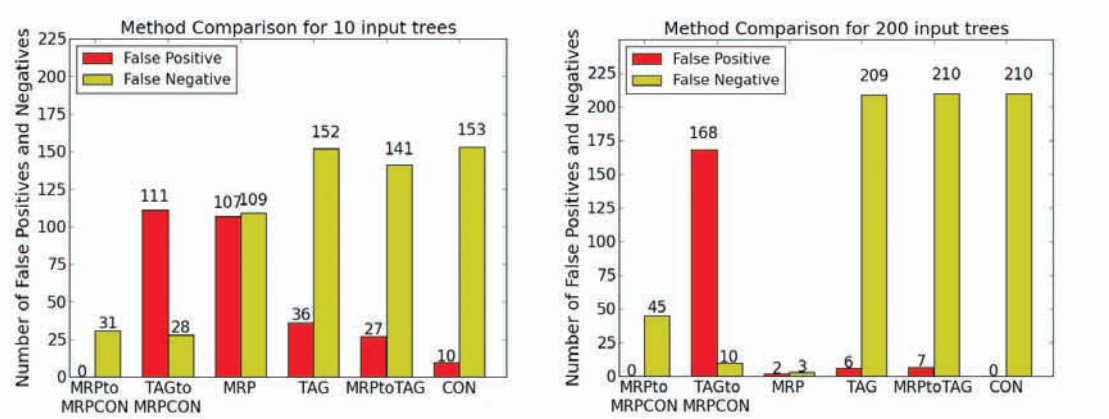
Figure 4. This figure is a visual representation of my model.

RESULTS

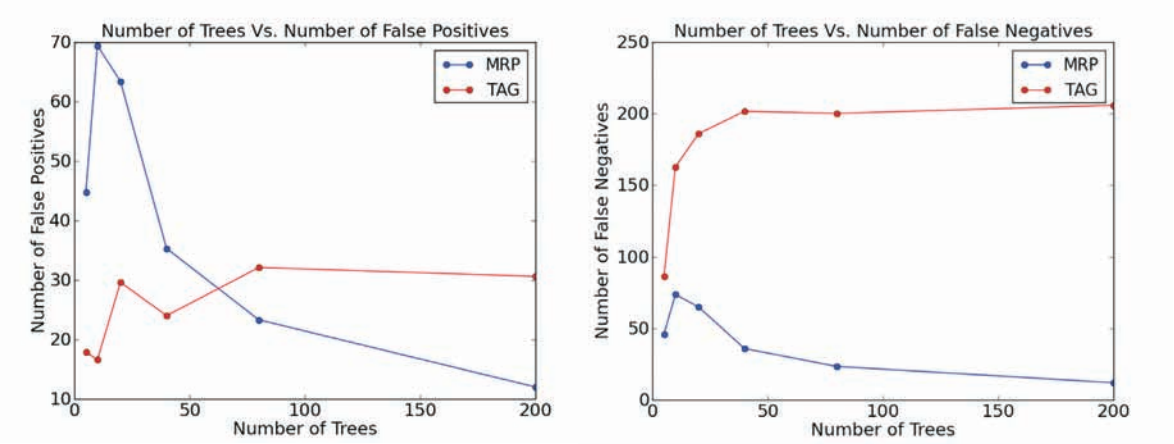
At this point of the study, MRP and TAG have only been compared with the primates' taxonomy, totaling around 1400 input lines. With the smaller taxonomy input, there are many differences in the outputs produced by MRP and TAG. The differences seem to be caused by false positives, false negatives, and differences between MRP and TAG to the consensus tree (CON). A false positive occurs when the input tree has a branch that isn't found in the true tree, and a false negative occurs when the true tree has a branch that isn't found in the input tree. A consensus tree is a tree that has all of the branches common to the input trees. This is particularly helpful in finding how similar the outputs of MRP and TAG are.

As of now, it appears that MRP far surpasses TAG for a smaller taxa input, such as the primates' taxonomy. However, Figures 5 and 6 show how the number of input trees affects the outputs of MRP and TAG in terms of false negatives and positives. MRP appears to become more effective in terms of false negatives and positives as the number of input trees increases. TAG, however, appears to become less effective as the number of trees increases, and even appears to have about the same number of false negatives/positives after around 60 input trees.

To explain why the outputs of MRP and TAG vary so greatly when the number of input trees was increased, detailed bar graphs were generated for 10 and 200 total input trees (Figures 7 and 8). When referring to Figure 7, it appears that TAG surpasses MRP in terms of false positives and false negatives. However, when looking at 'MRPtoTAG' we see that the two are returning very different outputs, and referring to 'TAGtoMRPCON' only confirms the varying outputs. Figure 8 shows that MRP far surpasses TAG in both false positives and false negatives, and in its comparison to the consensus tree. Therefore, it's easily apparent that MRP requires a



Figures 7 and 8. These two figures show a detailed method comparison for MRP and TAG. These two outputs were chosen at random. This was done to avoid any bias.



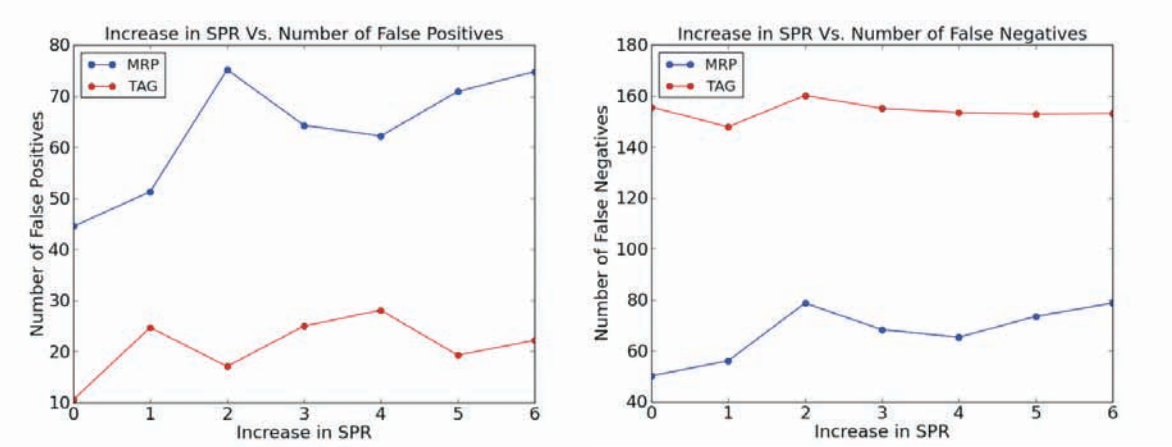
Figures 5 and 6. These two figures show how increasing the number of input trees affects the number of false positives and false negatives. Each dot represents an average of 10 different simulations for a given number (x) of input trees. This was done to avoid any large fluctuations in the outputs of MRP and TAG. The number of input trees (x-axis) goes in the order of 5, 10, 20, 40, 80, and 200.

larger number of input trees, but TAG, when finished, may be able to require less input trees.

Figures 9 and 10 show what happens when we increase the SPR value for a total of 80 input trees. "SPR" stands for Sub-tree Prune Re-graph. In essence, this cuts off a branch of the tree and reconnects it elsewhere. The larger the SPR value, the further along the tree the branch is placed. Interestingly enough, this caused MRP to return more false positives as SPR was increased, but TAG's false positives remained below 30. In terms of false negatives, TAG remains consistent, and MRP slowly rises. At this time, we're unsure as to why TAG returns so many false negatives despite the lower SPR value. This will be further investigated at a later stage in the study.

CONCLUSION

While MRP seems to be the more effective algorithm in this part of the study, it is important to remember that TAG was designed to work with inputs in the form of many large overlapping phylogenetic trees with a complementary taxonomic hierarchy. It is unclear how to best simulate a realistic taxonomic input in our study system, which may result in suboptimal performance by the algorithm. In future work, MRP and TAG will be compared with a larger taxonomy (e.g. the Tree of Life, which is around 2.7 million species).



Figures 9 and 10. These two figures show how changes in SPR affect the number of false positives and false negatives. Each dot represents an increase in SPR for a total of 80 input trees over an average of 10 simulations.

This study is being conducted with the principles of open source code. All non-proprietary software is publicly viewable through the links listed below.

- https://github.com/mtholder/supertree-study. This link holds the code which ran the entire model illustrated in Figure 4.
- https://github.com/OpenTreeOfLife/big-tree-collection-simulator. This link represents the algorithm that takes the input taxonomy and creates a 'true' tree and the input tree(s). Refer to Figure 4 for additional information.
- https://github.com/OpenTreeOfLife/treemachine. This link holds the code of the TAG algorithm.

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Q&A

How did you become involved in doing research?
I became involved in exploring this topic following a Study Abroad program to Matazano in 2013. I noted the environmental conditions prevalent that were directly influencing community health. It was during this trip that I recognized my desire to work with developing communities to find sustainable methods to live in cooperation with their environment while improving their collective health. I was introduced to the Community Health Club method by a fellow student and was intrigued by their success record in Africa. I felt it might be a good fit for the ongoing Engineers Without Borders project in Matazano.

How is the research process different from what you expected?
I expected the research process for this project to be mostly reading and disseminating information. However, translating the method and trying to understand how it would fit with the conditions experienced in Matazano raised more questions than I was initially prepared to answer. This meant that I had to spend more time researching the history of development projects and the region in particular. Overall, the research process raised more questions than concrete answers, and that surprised me.

What is your favorite part of doing research?
Visiting with the community and getting a first-hand experience of the conditions under which they must function as part of their daily lives was definitely my favorite part of the research. Corresponding with the author of the Community Health Club method was also great, as it allowed me to get a better feel for aspects of her work. The other aspect that was important was working closely with my mentor on the final paper and getting his feedback; this reinforced the direction that I've taken in my academic career.

Community health club and its application for health promotion and community building in Matazano, Guatemala

Karen S. Lewis

ABSTRACT
My project was to research the participatory education method known as "Community Health Club" (CHC) and assess its viability for use as part of a larger sustainable development project organized by Engineers Without Borders-Sunflower State Professionals (EWB-SSP) with the Matazano, Guatemala community to provide and improve existing water supply methods. Currently the water in existing lines, which are contaminated with Escherichia coli, is adversely impacting the overall health of this community. It was suggested that the CHC, which was first officially introduced in Zimbabwe in 1994, should be considered as part of this project to help ensure project sustainability past direct EWB-SSP involvement. The core goal of CHC is to share information with community members that will improve the overall understanding of health and hygiene behaviors, as well as help foster skills needed for self-initiated development of the community. My research showed that the CHC has had very strong successes in Africa and other countries,

is supported by the World Health Organization as a strategy to reduce poor health worldwide, and definitely should be considered for long-term community development projects in the future. However, it was my conclusion that it would be challenging for the EWB-SSP to implement such a comprehensive program in the Matazano community at this time given the current phase of their project. However, I do feel it should be examined as a cooperative effort between local organizations, separate from the water quality project, to indirectly meet the end goal of project sustainability.

Assistance programs aim to improve the quality of life of communities in less developed countries, often by focusing on individual health and economy. Many programs have fallen short of achieving these goals, however, because the targeted communities have failed to sustain project inputs beyond direct involvement of outside organizations. Several education models have been introduced since the 1980s to break these trends by promoting participatory approaches, through which communities "buy in" and actively work with projects at multiple levels in order to promote long-term sustainability. The Community Health Club (CHC) is one such participatory approach that has achieved increased success rates in Africa and other countries. In my research, I examined the Community Health Club method and assessed its applicability for use with an Engineers Without Borders Water Quality project in Matazano, Guatemala.

View of the church and central meeting area in Matazano, taken from the community's water holding tanks.

METHODS

My research largely involved reviewing primary source documents on the Community Health Club method introduced by Juliet Waterkeyn in 2005 (and presented in print in 2010) and the few secondary source documents of others who have reviewed this method for the World Health Organization. In addition, I utilized the University of Kansas Library and Research databases to locate and review additional electronic source material on the background of development work and get a better understanding of the multi-disciplinary nature of current-day development programs.

To gain knowledge on the history of the Cho'rti' community and their history, I reviewed secondary source documents found at the University of Kansas Libraries. I also visited the community in Matazano, Guatemala, first as a member of a KU Study Abroad program and secondly as part of the Engineers Without Borders team. My role in the Study Abroad program, and as part of the Engineers Without Borders team, was to visit homes in the community to take water samples and to use Geographic Information Systems to map community infrastructure. During these visits, I made first-hand observations of the community dynamics, environment and social relations, and made inquiries (through an interpreter) of community members. I visited with various local agency operatives for this research and as part of an Engineers Without Borders team to assess what support mechanisms currently exist for this community and get their observations of the community dynamics and organization.

It was my intention as part of my research to visit with community members more in depth about their history, current challenges and hopes for the future; however, time limitations in the country and language barriers challenged this more than anticipated. While many in the community speak Spanish, my comprehension of the language is low and, to complicate things further, some members speak only native Cho'rti', which involved complex translation and limited deep conversation. To compensate some for this I visited in length with my mentor, Brent Metz, University of Kansas Professor of Anthropology. Professor Metz has established and maintained a long-standing relationship with people of this region and Cho'rti' communities within them that began with his graduate work in the 1980s. This provided valuable insight into their historical and present day social dynamics.

I presented and discussed my findings with other members of the Engineers Without Borders-Sunflower State Professionals and discussed my thoughts on the feasibility of using this participatory method in this particular community given the history of the project to

date and community expectations. It is my intention to remain involved with this project as part of the EWB-SSP and future projects with this and other organizations. It is my goal to try to find creative ways to educate others about the complex relationship that exists between personal and environmental health so we may find more sustainable ways to live. This research has given me valuable insight to the challenges that I will be faced with as I continue moving forward on this path.

INTERNATIONAL DEVELOPMENT PROJECTS

While the main goal of my project was to dig deeper into the Community Health Club program and process, and summarize this method for a specific audience, I believe it is first important to have an understanding of the larger events that have brought us to this participatory phase in local development programing on a global scale.

Early government-organized programs, like the Marshall Plan, began following World War II and focused on large-scale humanitarian aid while attempting to influence political ideology and agendas in strategically important countries (Harrigan, 2011, 1281-1285). With the creation of organizations like the World Health Organization (WHO) by the United Nations in 1948, the agenda became less government-driven and began to focus on achieving the highest possible level of health for the world in general. It was thought that providing basic health care and services would contribute to reducing the social and economic disparity often found in these communities and might reduce the conflicts which often follow these conditions. Specifically, the purpose of the WHO is to influence and improve quality of life by providing program materials to organizations within member states so they can better assist countries that are struggling with poor health and economic issues.

Past methods by the WHO and some health organizations, however, have often been costly and too generalized to achieve long-term success (Waterkeyn, 2010, 1960). Some of this occurred because they failed to incorporate local cultural values within their programs and were viewed by local communities as simply another form of outside interference in their lives. Project breakdowns also were (and continue to be) impacted by corruption, bureaucratic failures, aid inappropriate to the need, and lack of coordination between the donor, host organization and recipient. The largest issue, however, is that most methods failed to address the social and psychological needs of the communities by ignoring their unique group dynamics (McMillan, 1986, 14). It was not until the 1980s that NGOs began to place more attention on addressing these group needs by examining the methods being used to convey health information.

Effective information dissemination has become the determining factor of the most recent efforts to improve national health in developing regions. As part of the Millennium Development Goals, the UN intends to reduce by half the 2.4 billion people without adequate sanitation by the year 2015 (Waterkeyn, 2010, 1). In order to achieve this, multiple strategies have been attempted to convey health information and best practices. Some of these approaches have included: forced change through government edict, promises of future assistance following change, and appealing to personal status and "common sense." Each of these has had variable success over the past several decades, but those with the most progress were more often directly related to the collaboration between the communities' inherent cultures with the education style introduced (Azurdy, 2007, 17).

Some of the most promising methods have focused on long-term initiatives that emphasize long-term sustainability through a bottom-up approach which recognizes how group dynamics impact change. These most recent methods address the capacity of the community to participate in the construction of its own change while promoting, rather than merely teaching, healthy habits. By using multi-disciplinary theories for community development and organization that recognizes group social, physical and psychological needs, the communities are more invested in their own project at its inception, which has indeed often translated to long-term sustainability.

This coincides with recent sociological research which concludes that unless a community is actively involved in their own project initiation, development and maintenance, the project's success rate is negligible (Gaventa, 2010, 16-17). Those behind these promotion methods recognize that unhealthy behavior is not necessarily contingent or caused by missing information, and that individuals can develop their own solutions given the proper encouragement (Azurdy, 2007, 4). Participatory approaches that actively involve community engagement and enable people to increase control over and improve their own health have been recognized by the WHO as a highly effective methodology for health promotion (Azurdy, 2007, 2). Community Health Clubs are one such participatory method that incorporates this collusion and involves the individual as part of a larger collective movement.

COMMUNITY HEATH CLUB MODEL

The Community Health Club (CHC) education model for hygiene was first officially introduced in Zimbabwe in 1994 as part of the Africa AHEAD (Applied Health Education and Development) program. It has had measured success in multiple African communities in achieving health goals, such as tuberculosis control and sanitation (Azurdy, 2007, 23). CHC's primary purpose is to encourage healthy behavior changes within a community by building a group consensus for these measures. Using structured, measurable and inclusive methods, AHEAD recognizes that community development is a long-term process. CHC provides a relatively low-cost method that is easy to monitor, adjustable to regional customs, and works well with traditional forms of community organization (Waterkeyn, 2005, 1960). Through reinforcement, the CHC uses participatory learning methods to share information in a manner consistent with most traditional community gatherings. In addition, its club meeting structure has also been shown to develop leadership skills that aid in overall community strength. This is significant, since it has been established that community engagement and cohesion is vital to overall community success (McMillan, 1986, 8-9).

The core goal of CHC is to share information with community members that will improve the overall understanding of health and hygiene behaviors, as well as help foster skills needed for self-initiated development of the community (Azurdy, 2007, 4). Through the building of a group consensus in support of these habits, the method operates to build common unity by challenging the community norms and starting a chain of jealousy (Waterkeyn, 2010, 7). While a chain of jealousy is often seen as a negative aspect of human nature that causes neighbors to be envious of each other, these emotions can also be used to provide a bridge to consensus within a group of individuals.

CHC promotes group consensus through providing active discussion by community members of concerns in open meetings, discussion and introduction of potential methods to address these concerns, and agreement as a group to adopt these new methods. As such, conformity is achieved through creating a group consensus that leaves no individual acting alone in their actions as they try to impact these issues (Waterkeyn, 2010, 7). In addition, meetings are consistently open to new members and the adopted techniques (and benefits) visible to neighbors. As such, there is ample opportunity for non-attending community members to join in and adopt these tactics on their own. Since everyone has this opportunity to enjoy the benefits presented, it increases the likelihood the new tactics will become a standard community practice.

Women have been found to be the most receptive to new ideas, especially when it is perceived these tactics will improve their family's quality of life. For this reason, health programs often focus their attention on this particular demographic in order to modify health behavior in the community (Waterkeyn, 2010, 149). However, this group of individuals also performs a tremendous number of tasks as part of their daily lives, so outside organizations must be creative in their methods of instruction. CHC recognizes this time commitment, but also notes that there are few educational opportunities available, especially for women. By encouraging group activity in this forum, the CHC fulfills not only the specific learning goals but appeals to the individual desires to be social and expand their knowledge.

It is important to note that although CHC focuses on women as household managers, no one is ever excluded from membership in this club based on gender. As shown in research done for CARE International, female involvement was sometimes only slightly higher than that of males, depending on the village dynamics (Azurdy, 2007). It has also been noted with several Africa AHEAD communities that the men notice the "useful employment" of their wives following involvement in this program. There have been comments on the increased household upkeep and improved family health due to wives who have participated. In addition, these men have shown a commitment to participate themselves in the program, as a show of support to their families (Waterkeyn, 2010, 300). This illustrates one way that the CHC program is able to become an accepted activity within the community structure.

CHC also tries to become part of the community norm by carefully choosing the most appropriate facilitator to guide these meetings and creating leadership opportunities within its members. The facilitator not only guides meetings, but is responsible for periodic household visits to assess if goals are being met or additional support is needed from other club members or the facilitator. There are potential concerns over using local or international NGOs to share information if the organization is not following through consistently and failing to establish strong relationships with community members, as these can create potential risks to future program activity, but it is believed this can be overcome through designating a facilitator specific to this task and community.

CHC recommends using locally trained public health experts initially and training individuals from the community to act as future facilitators when community organization is stronger. This aspect

of the method has been shown to translate to long-term sustainability of the program, the ability to address a large number of health-related issues, and cost effectiveness. By utilizing local health organizations to train local individuals from the start as facilitators, trust issues within the community are often alleviated (Azurdy, 2007, 20). In addition, training from within the community provides opportunities for individuals to have leadership roles which will be important for future project initiation and community development.

The CHC creates new channels of communication and learning opportunities for its members in an informal social structure rather than formal education. It believes that in doing so this method helps the community to generate the knowledge and ultimately power to manage its own social, educational and health development. By encouraging its members to discuss objectives and the barriers to meeting these objectives, collective discussion tactics are used in these meetings to break down these barriers and develop community organizational skills (Azurdy, 2007, 20). One example of the leadership building aspect is the formation of committees within the club program.

It is the role of these committees to provide and organize support for members during the process, and then organize and lead later initiatives. Because CHC seeks to create a health "culture," it continues past the initial health promotion phase to community health management, income generation, and other social development initiatives like literacy and stigmatism (Waterkeyn, 2003). This concept of basic committee organization will be useful in future projects and initiatives, as it has illustrated the capacity of individuals to take active roles in their own community development.

Individual capacity is first measured and created in the club through the use of an activity membership card. This card acts as a tangible example of their involvement in a group project and a measurement of their commitment toward the main objective of creating a healthy environment for their families and community. The CHC card illustrates not only the weekly objective topic, but methods that will help them achieve this goal (Waterkeyn, 2005, 1961). Following each week's topic, the member is given a task to complete at home that coincides with the discussion at the meeting (Waterkeyn, 2005, 1961). As an example, the first topic might be "Safe Water Chain," and homework would include ensuring that water is always covered, dispensers are always clean of dirt, etc.

At the next meeting and subsequent meetings, the members discuss how they have implemented the process, barriers they may have encountered, and then problem-solve these issues as a group. Their card is signed by the facilitators as completed and the next topic is introduced (Waterkeyn, 2010, 155). The CHC method is open-ended and designed so that members can begin at any time during a session.

Professor Brent Metz taking a short cut through a typical hillside corn field found near Matazano.

Concurrent sessions will begin as the set program ends so that everyone has an opportunity to get involved in the process, catch up on missed initiatives and be recognized publicly for their achievement. Scheduling the program in this way encourages maximum community involvement, regardless of seasonal work schedules, and encourages generational buy-in as objectives become part of the individual and community culture.

COMMUNITY HEALTH CLUB APPROACH

The Community Health Club is designed to be utilized as a comprehensive program for building community health, culminating with the eventual phase-out of outside organization direct involvement. The method is meant to be conducted in a four-stage process over the course of four years through meetings that occur weekly for two hours, at a regular time and convenient location for the community members. Each of these yearlong stages involves specific initiatives to be accomplished that promote opportunities designed to improve the community's overall well-being.

To encourage community management of the method, a

committee is formed from within the Health Club group members to keep records of attendance, organize communication and assist the facilitator and community individuals. These are nominated and voted on by the attending members. While this first stage is initially time intensive for the facilitator and committee members, it is important to create recognition within the community that something important is being accomplished. This process becomes less intensive for the lead facilitator and any assisting organization as the community adopts the program and skills are put into practice at the community level. The program itself also becomes easier as individuals begin to participate in club management and recognize their capacity to take on initiatives which benefit the community.

The first stage of this method involves a health promotion campaign with activities that invite conversation and disease education. This is by far the most important stage of the method, as it sets the groundwork for good health and future community development. Using the Participatory Sanitation and Hygiene Transfer (PHAST) methodology developed for use by the WHO in the 1990s, a standardized tool kit has been developed and tested for the particular region that provides the trained facilitator with illustrated cards for each topic (Waterkeyn, 2005, 1959).

During the session, the group is divided into three subgroups, given a set of activity cards with which they work for about 30 minutes, and then discussion commences as each group presents their activity to the others. The facilitator acts only to direct discussion as needed so that groups can actively debate the issues. The group then discusses the "homework" to be accomplished to affect these issues. Homework involves changes made to household hygiene habits that are low/no cost and are easy to implement. Revision sessions occur until all members have the opportunity to catch up with adopted measures.

The second stage involves implementation of programs to supply water and contain waste. Ideally, this occurs following the health promotion phase to ensure the community has developed the organization needed to actively participate in this stage's planning. For example, if a communal facility is being used to supply water to the community, Health Club graduates can become responsible for oversight of specific water points in the community. As certified graduates of health promotion, they have shown their commitment to taking action needed to promote good health at the individual level and working as part of the larger community. They are given opportunities to receive further training on Community Based Management (CBM) and receive basic certification toward future and current project maintenance. These members are responsible for appointing the pump technician(s), record keeper, and treasurer as well as providing reinforcement and oversight of the system. This helps create a solid base membership for future community projects.

Another component of stage two is sanitation and construction of sustainable latrines or waste control measures. This is done both at the individual family level, and as part of a community effort to provide communal locations and facilities for families who may not be able to complete construction on their own. Because Health Club members understand good sanitation, they can take an active role in pit or composting construction for themselves. Through use of the Club Committee structure, committee members can help individual households initiate the documentation needed to secure funds for the construction of sanitation facilities needed in a given location. Because at this point they have more belief in their skills needed to organize these activities, the Club facilitator acts only as needed to offer advice and support the committee as they work with partnering NGOs to help fund these activities and ensure that all members of the community are being included.

Stage three examines the ability of its members to achieve a sustainable livelihood that will break the poverty cycle prevalent in so many developing communities. Having completed training to incorporate healthy habits into their lives and address sanitation concerns, it is appropriate to expand on the ability of members to care for their families beyond their current capacity. Through the use of the existing Health Club, additional skills training can be introduced for the generation of income using local resources. To do this, the Health Club first participates in a Participatory Rural Appraisal workshop where members identify what their priorities are and discuss what training they need.

This stage also includes financial management training and the appointment of a local coordinator who (after training) becomes a financial advisor for other members. The Club is then divided into smaller groups, with each being instructed on a particular skill, and the committee ensuring access to necessary low-maintenance equipment. At this point, the original facilitator acts only as requested to offer advice and mediate as needed with other organizations. Opportunities to generate additional income through low-intensity projects like gardens, soap making, and insect repellent lotion from natural products, allow for members to raise their living standards and improve overall community health, especially those

who are the most vulnerable due to age or impairment.

The fourth stage is designed to become a catch-all directed at social development within the community. Because the Health Club at this point has become part of the community structure, it can be utilized to address social issues such as abuse, physical and mental disability, human rights, and literacy. It would be appropriate at this time for the club facilitator to find members taking an active role in identifying and locating the resources needed to achieve these goals, as there should be a large number of the community active in the club. In this phase, there must be at least one individual trained as an Adult Literacy Tutor to work with club members on this issue. The facilitator should have initiated this process prior to the end of the third phase by identifying and training candidates.

The club will also now need a Home Based Care Trainer in the community who will take the lead to ensure families know how best to care for the terminally ill and displaced family members, as well as dealing with any illnesses that might carry a stigma, like AIDS/HIV. It is recommended that a small percentage of income from group projects is placed in a fund to aid in caring for these individuals and their children's education, as well as projects for these families to contribute to themselves. In this way, all members of the community are developing the capacity to contribute to community health and organization.

At this point in the program, staggered initiation of approaches is complete and the theoretical, practical, economic and social goals needed to promote a healthy community have been accomplished (Waterkeyn, 2010). The original supporting agency should be able to pull out of the community with reasonable assurance that a healthy community culture will be maintained by the group on its own recognizance. Because the populace has developed a more holistic idea of health, it will be able to initiate any additional development needed in the future with only minimal assistance from local organizations. In addition, because a successful program rollout has promoted broad representation and organization within the community, it has served to help empower its members in the face of any marginalization they might have encountered in the past (Azurdy, 2007, 17).

Adaptability is one of the key aspects that make this method attractive for use as part of health promotion by the WHO. As part of Africa AHEAD, this methodology has been successfully implemented in multiple Zimbabwe communities since 1994. It has been used extensively since then in additional wards throughout Africa and has been modified for use by Jason Rosenfeld, employee of Africa AHEAD 2007-2010, for use in communities found in the Dominican Republic and Haiti (Africa, 2013). Research performed on this method was assessed positively for implementation as part of a CARE International child survival project in Sierra Leone (Azurdy, 2007, 47) and additional development organizations are using this method in Vietnam and Bangladesh.

The initial purpose of this research was to examine the Community Health Club approach and determine if it could viably be used to convey health information as part of a larger water quality project in Matazano, Guatemala. Research indicates it has good success with conveying health information in an economical manner. This, in addition to its cultural adaptability, is positive enough to consider its use in this particular project. I also believe that its capacity to help create cohesion and increase community strength and self-reliance would be extremely beneficial to this community. However, before discussing this further I will provide some information on the Matazano community itself and the Engineers Without Borders project to date.

Some of the women of Matazano following a community meeting with the Engineers Without Borders-Sunflower State Professionals.

MATAZANO COMMUNITY BACKGROUND

In order to assess the feasibility of using this approach for this particular project, it was important to understand more about the community in question. In the following sections I will give a little of the background of the aldea of Matazano, Guatemala, part of the Municipality of Jocotán, introduce the Engineers Without Borders Water Quality Project in question, and discuss any obstacles that could impact implementation.

Matazano is an indigenous Ch'orti' Mayan community consisting of approximately 500 households that contain upwards of 3000 people. This aldea is located on limited amounts of land in the steep hills of southeastern Guatemala near the city of Jocotán, Chiquimula, only an hour or so from the borders of El Salvador and Honduras. Historically, the Ch'orti' people have been subsistence farmers using communal property for their crops and a population consensus method for decision making at the community level. Members of this community are at a stage in their development, due largely to overpopulation of available land and lack of local market opportunities, where individuals have been unable to effectively use their traditional subsistence lifestyles to sustain their families throughout the year. This is causing more individuals, especially men, to work outside the community. While traditionally there has been a distinct division of labor between men and women, this shift has meant long absences from their families for these individuals (Metz, 2006, 153). This shift is making it necessary for women to take on more decision-making roles outside of the home and has begun to alter some of the historical social structures of the community.

The community at large has also been impacted by discrimination and marginalization stemming from centuries of maltreatment, first during Spanish colonialism from 1524-1821 and later by the military during Guatemala's civil war that lasted from 1960-1996. Discriminatory class distinctions between indigenous and Ladino populations continue to be reinforced today through political maneuvering at the local and national level (Metz, 2006, 188-225). Governmental policies limit the educational and employment opportunities of the Ch'orti' and impact their access to adequate levels of healthcare and arable land. Political maneuvering has also influenced the success of past development projects in this community, as anticipated monies for projects have failed to materialize and land has been appropriated for non-community uses. This has caused individuals within the community to be cautious of people they do not know well and to regard unfamiliar ideas with caution; it has also influenced their personal sense of worth, resulting in a low level of self-respect.

Although members of this community are indigenous Ch'orti' Mayas, the use of the language is no longer common, with most individuals fluent in Spanish (Metz, 2006, 219). Few have had formal education past the primary level, with a number of individuals still relying on verbal rather than written communication to conduct daily and community business. The nearest town, Jocotán, is accessible to this community by footpaths that cut through fields, or using the common form of public transportation which consists of numerous people stuffed in the bed of a truck. These vehicles provide this service at a nominal fee that some cannot afford, although vehicles are typically full each trip. Many families have chiseled out house plots in the hills and most homes are a combination of mud brick, corrugated metal and palm leaf construction. Home construction has reduced the already limited arable land available for crops, and there are few options for this growing community to spread out further.

While many homes have water standpipes and some have electricity, the supply of these resources is inconsistent, creating obstacles for accessible potable water and basic sanitation. Typical home construction layout tends to trap smoke from wood cook-stoves, which has led to respiratory and other health issues. A 2006 report indicates 93% of rural Guatemalans live in extreme poverty (Warren, 2006, 9), although a more recent 2012 WHO report shows only 56% of families in rural areas live well below the poverty line, with a 24.8% mortality rate, largely in children under the age of 5 (WHO, 2012).

Efforts to impact these mortality statistics have driven some to work for long periods of time at large sugar and coffee plantations far from the community. When they return, they continue to use traditional methods for farming their poor agricultural lands on steep hillsides and store most of this product (mainly corn) for use as far into the year as it will last. Other individuals have begun entrance into the market economy using traditional skills such as weaving to produce mats, baskets, pottery and other products for sale at the local town. This income is limited, however, and has been impacted by increased transference to the use of less expensive factory-made products sold by local townspeople.

In addition, young adults have begun to emigrate from the community and country for work in an attempt to supplement their family's livelihood. Households that benefit from this remittance income are typically more noticeable in the community because they can afford more expensive upgrades to their lifestyle, such as cement walls for their homes and cell phones. Despite this remittance income, these families continue to struggle with the same poor water quality and sanitation

as their neighbors. These absences have also begun to impact the familial relationships that had defined their past culture. The cumulative changes to their social and physical climate over the years threaten to cause damage to the psychological sense of community found in Matazano, which are directly related to the individual need for membership, influence and shared emotional connection.

MATAZANO WATER PROJECT BACKGROUND

Multiple households in Matazano do not have sufficient access to water on a daily basis, and the water that is available is highly contaminated by microorganisms. Members of the community who do not have running water travel by foot over uneven terrain to the nearest source, representing an enormous amount of human labor each day. This lack of water access not only takes time from other household duties, but has detrimental impacts on their healthcare, as clean water is necessary for good hygiene and sanitary food preparation. Water sampling done in 2012 and 2013 reveal widespread contamination of existing water sources in the form of microorganisms like Escherichia coli (Sunflower, 2013). Unsafe water for consumption and hygiene is adversely impacting the overall health of this community.

The WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation reports that 93% of the households in Guatemala have sustainable access to safe drinking water and basic sanitation; however, this measures potential, not actual, availability. In the community of Matazano, accessibility to safe drinking water is well below 5%, with water standpipes present but not functioning consistently near many homes in the aldea and water contamination present in 100% of 2013 samples (Sunflower, 2013). Basic sanitation efforts in Matazano have not been recently measured, but would be closely linked with the lack of accessible clean water.

Currently the Engineers without Borders-Sunflower State Professionals (EWB-SSP) have been developing a project to address the accessibility and quality of water in an effort to improve local health conditions for the community of Matazano, Guatemala. To date, the EWB-SSP have made numerous site visits and determined that the current water collection and distribution system is inadequate to meet the daily consumption and sanitation needs of the community. In addition, sampling of household water pipes performed in 2013 has revealed widespread E coli contamination that must also be addressed. 2013 GIS mapping of existing waterlines and wells revealed current water lines were inadequate for water flow and demand, breakages and blockages were diminishing flow and allowing entrance of contaminants, and additional pipes were needed in response to community growth (Sunflower, 2013). A phased approach to address these issues has been proposed by the EWB-SSP which relies on the coordination and cooperation of a community-run water board, as well as involvement of local NGOs, over the next several years and health promotion to address additional community issues.

The success of this project relies on the entire community contributing to improve these services through the formation of a functioning water board and collection of fees for system upkeep. This proposed framework change is not a new concept to the community leaders; however, it has not been functioning consistently since the early 2000s (Sunflower, 2013). The reason for this previous breakdown has been reported to coincide with the failing water infrastructure and mishandling of maintenance equipment. Additionally, I would suggest that external stressors, such as absent household members and local government issues, are affecting how this community works as a collective and is impacting current collaboration efforts. As mentioned previously in this report, breakdowns are not uncommon in development projects; however, without community and individual buy-in to new ideas and methods, the effectiveness and likelihood that this project will still be sustainable past EWB-SSP involvement is suspect.

APPLICATION OF COMMUNITY HEALTH CLUB IN MATAZANO

"Important links exist between health promotion and community development," as development can help create an environment where community members can more easily identify needs and work together to solve problems (Azurdy, 2007, 11). In an effort to build support for future health and improve cohesion, participatory health promotion programs like the Community Health Club program should be considered as a helpful mechanism for long term EWB project plans in Matazano. Through this participatory learning method, which incorporates many traditional group decision making processes, phasing the introduction of information has been shown to help foster skills needed for self-initiated development of the community and promote long term success (Azurduy, 2007, 4). Based on the proven success record of this particular method in Africa and the Caribbean, it is my premise that this method can be adjusted for use in Matazano to create a solid base from which to carry out the current water project and promote activities that will build a sustainable healthy community for generations.

As previously stated, the primary goal of CHC is to promote good health through dissemination of health knowledge in a manner that encourages participation and acceptance. Many individuals in the community of Matazano have received health instructions in the past, but have not utilized them fully. Recent EWB research was performed with the cooperation of community women where they were given a camera and asked to take pictures of community issues. Upon follow-up explanation of photos taken by the participants, it was recognized that there is an acute awareness of the physical health issues in their community. While some ladies recognized related causes of these, it was interesting to note how few identified basic hygiene as one of them. What was also interesting about this event was how animated and how active discussion was during the presentation of the photos to community members.

While the community members EWB-SSP has interacted with recognize the correlation between health and sanitation, the CHC process would reinforce of this relationship between hygiene and health. As part of its first stage, the members in Matazano would use the knowledge they already have to assess these problems and gain additional information to address them. Information relayed with each other during discussion and activities will help them build self-reliance and confidence in their ability to impact their family's health and capacity to carry out the necessary tasks. As families and individuals share their success stories with others in the community and how it is achieved, more people will recognize their innate abilities to impact changes that will benefit their family's health and build on their self-esteem as personal goals are attained.

Community members walking on the road toward Matazano from a neighboring aldea.

Part of a sustainable healthy community is its relationship with community properties and adjacent lands. It is important to recognize how the space communities reside in encompasses more than merely a geographic location. It has been suggested that a particular place develops significance and meaning for its population over time. As places within the community, such as a home, a community park, or a soccer field, become part of community members' identity through social and cultural relationships, they are responded to differently (Tuan, 1977, 15). However, this community has been pushed to limited lands that are not well suited to their traditional agricultural practices, and climate variations are impacting productivity of these areas.

Although they have resided in this particular place for many generations now and do have significant places within it, I believe this may have impacted some of their current land use habits. Additionally, it is important to note the variance with which different generations are viewing shared common spaces like community paths and meeting areas. On recent visits, EWB members have been told and witnessed the youngest generations, those who are more used to "disposable" products, dropping these packages on the ground. This practice, compounded by the lack of accessible toilets, creates an unsanitary environment throughout the community, especially in the rainy season on the shared pathways. The land stewardship practices that result from this can potentially be strengthened through the use of the CHC method. While promoting overall community health and impacting refuse control, the CHC method touches on the interconnection that exists between environmental and personal health.

The steep rocky land where they reside was once heavily forested and held the limited amounts of topsoil in place. However, over the years population within this limited space has increased. People have needed the land to create homes and to grow food, resulting in a reduction of land cover and arable land for crops. In addition, traditional agricultural methods have been altered, with less crop rotation and mixed crops than were grown traditionally, which has depleted nutrients like nitrogen from the soil and decreased overall yields. In response, more residents are using chemical methods to add nutrients back and fight pests that attack the crops. At issue is how prone this area is to intense rainy periods, which creates erosion throughout the aldea as soil is washed away in torrents with the rain. Without sufficient ground cover to help stem this flow, it also spreads chemicals and fecal matter across all surfaces of the aldea and makes its way into exposed and underground water sources.

Although the Ch'orti' are aware of many of these issues, they lack the organization to tackle them effectively. As such, environmental health can be a CHC topic to promote discussion of how to improve land quality and as such promote individual and community

health. Utilization of the CHC committee can help organize measures such as fecal containment, trash disposal and nutrient replenishment, as well as strategic planting of indigenous plants and trees to reduce runoff around fields and homes, provide sufficient shade for gardens, and craft materials. Additionally, there are small measures that can be discussed, like keeping water hoses off the ground, and designated hand-washing stations away from food prep, which will aid in creating barriers to disease transmission.

Use of the CHC method creates opportunities not only to promote better environmental and personal health, but also strengthen rapport between the community members, the EWB project group and local project facilitators. As has been mentioned, inherent in many development projects is a level of animosity between the local community and visiting project members. Without sufficient personal history, the level of trust needed to foster collaboration has not been established and can impact project implementation. This bond has been initiated between the EWB-SSP and the community through the presence of an interpreter well known by the community and frequent visits since project initiation. Utilization of a local facilitator, who will be a consistent presence in cooperation with the EWB group, will continue this history building as well and strengthen the existing relationship.

There are a number of local NGOs and government agencies, such as Nuevo Día, Mancomunidad Copanch'orti', and the local hospital in nearby Jocotán, that could also be tapped to assist with continued rapport building. These have been approached as EWB project development has continued and have declared intentions to aid with implementation through training programs and their continued presence; while one has clearly expressed a limited investment, the others are willing, but face obstacles. One major factor that inhibits this collaboration is that these organizations are already working on other projects and have limited time available for this community. In addition, communication between countries is inconsistent, which has impacted the collaboration between not only the EWB and these organizations, but with the community as well. Due to this, there have been concerns about forward project movement in EWB physical absence.

An option to overcome this is approaching the number of educated Ch'orti' living in the community and nearby town who have history with the community to act as facilitator for the CHC program to help bridge any remaining gap; however, this could cause feelings of jealousy that would be detrimental to the program's success. Other options to consider could be staggering EWB member presence as facilitators throughout the year or seeking out another local Non-Government Organization to provide more consistent communication, community presence and aid in forward motion of the project goals.

The community is anxious to see that the project is coming to fruition through tangible examples; however, they don't completely comprehend the time it takes to implement a project of this scale and how important their own community participation is in this process. Although community meetings on the subject have had relatively good attendance, comprehension and buy-in of project issues like fee payment for future upkeep is low. The EWB has already been working to bring the community further into the discussion and planning phases of the project by introducing them to GPS technology and map reading. By having community liaisons accompany map makers as they walked existing lines, teaching them how to plot points using GPS and helping them understand the land variations represented on the map, they have been given available tools with which to build on. In addition, the EWB-SPP is attempting to build stronger community consensus and involvement through the creation a new water board in place of the non-functioning current water board. This board will function to provide future oversight for the projected construction and future upkeep of the new lines.

FEASIBILITY FOR CHC METHOD USE IN MATAZANO

Upon reviewing all the data at my disposal, I feel that the CHC method has a proven track record in other communities and should definitely be considered for long-term development projects with EWB groups that have long-term community development projects in mind. However, it would be challenging for the EWB-SSP to implement such a comprehensive program in the Matazano community at this time given the current phase of their Water Quality Project.

The EWB-SSP group is currently approaching the construction phase of this project. Given CHC program expectations, actual large-scale development would not occur until after stage two is completed, so this would constitute taking definitive steps backward in the current project timeline. In addition, given the history of past development project interactions in this community and animosity to outside interference, it is possible that trying to introduce the original form of this method at this point in the current project would be detrimental to forward movement. It could be considered community interference and damage the positive relationships that have been built to-date between the community and EWB-SSP.

Secondly, the community of Matazano requested only water system improvements, not a health and community overhaul from the EWB-SSP team. Their expectations of this project, due to past experience with other NGOs who have expected so little from them, will be difficult to alter given the current time frame. While health related assistance is definitely something that is needed and requested by members within this community, they have access and established ties with the health center and professionals in Jocotán. However, the EWB-SSP could look at expanding its cooperation with that organization in order to help place a health trained individual in the community. This would be optimal given the distance to Jocotán and definitely benefit both entities; it would be reliant on money and, given community history, would need to offer more than paper certificates to incite community buy-in. This individual could perhaps use some of their time introducing the CHC first stage method to the community.

In addition, by bringing in a resident health care professional/ facilitator to work on the education aspect within the community, they would be able to build good relationships with members. This would also help provide a much needed communication link between the EWB organizations in the state. In addition, this link has potential to help build a bridge for long-term involvement with local municipal and national organizations that could benefit future EWB projects. Part of this individual's duties could be to initiate the weekly meetings that the CHC method promotes so that the community can address health issues like toilets for all households, environmental measures related to the promotion of good health, and reinforce the committee structure and community organization. As health related issues are addressed using early CHC phases, the EWB-SSP Water Quality Project representatives will be able to step out with relative assurance that the community can sustain its health issues.

Photos courtesy of: Karen S. Lewis

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Q&A

How did you become involved in doing research?
I transferred to KU from a community college that did not emphasize research experience at all, so I was surprised and excited by the emphasis on research at KU. I contacted Dr. Lamb through email, expressing interest in the work she was doing, and was invited into her lab for a trial period. I fell in love with the research, and was excited to work on my own project.

How is the research process different from what you expected?
In order to scratch the surface of the research I was doing, I had to do a lot of research in the literature. I was definitely surprised by how much reading (and rereading!) it took for me to really get a better understanding of my research topic.

What is your favorite part of doing research?
Research is an inquiry driven field—I enjoy the process of asking a question and actively seeking an answer. I am so impressed by the ingenuity of the whole research process.

Isolation and crystallization of PvdJp2, a non-ribosomal peptide synthetase domain in *Pseudomonas aeruginosa*

Betsy Ramirez

ABSTRACT

During times of iron deprivation, many bacteria produce low molecular weight compounds called siderophores, which have the ability to scavenge iron from the host environment. Pyoverdin is a siderophore produced by *Pseudomonas aeruginosa* during extreme iron starvation. The biosynthesis of pyoverdin involves several multi-modular non-ribosomal Peptide Synthetases (NRPSs). The NRPS PvdJ incorporates two amino acids into the growing pyoverdin. PvdJp2 is a structural domain within the second module of PvdJ that acts as a scaffold and tether for the incorporation of formyl-hydroxyornithine. Present work is focusing on the expression, purification, and crystallization of PvdJp2. PvdJp2 was determined to express best after induction at 30°C for 22 hours, and is purified using standard chromatography techniques, exploiting the His-tag. Current methods of crystallization have not yet yielded diffraction quality crystals. Future work will focus on alternative methods of crystallization, such as increasing the protein concentration and changing the incubation temperature.

INTRODUCTION

Bacterial pathogens pose a major risk to the human population due to the increasing prevalence of multi-drug resistant bacterial strains. The opportunistic pathogen *Pseudomonas aeruginosa* is a Gram negative rod that attacks hosts with weakened immune systems. *P. aeruginosa* causes 10-15% of hospital-acquired infections worldwide due to the breakdown of physical barriers and high numbers of immunocompromised or elderly patients in hospitals (Strateva and Yordanov, 2009). Examples of typical *Pseudomonas* patients are burn victims, cystic fibrosis patients, and AIDS patients. *Pseudomonas* infections have been found in 80% of cystic fibrosis patients over 18 and are considered to be a major factor in their mortality (Conova, 2003). In addition, *P. aeruginosa* bacteremia carries a 31% mortality rate (Tacconelli et al., 2002)

As a significant hospital-acquired pathogen, *Pseudomonas* possesses many antibiotic resistance strategies—both innate and adapted from the environment (Strateva and Yordanov, 2009). *P. aeruginosa* intrinsically contains efflux pumps to pump out antibiotics almost as quickly as they are imported in. In addition, *P. aeruginosa* contains AmpC Beta-lactamase, which targets Penicillin-derived antibiotics by breaking apart a signature bond in their unique structure. *Pseudomonas* also has the ability to acquire resistance from the environment through horizontal gene transfer—which is the uptake of genetic material from the environment. It has been reported by Pechere and Kohler (1999) that *P. aeruginosa* is considered a "phenomenon" for having demonstrated almost all known enzymatic and mutational mechanisms for resistance. Multi-Drug resistance has emerged in 27-72% of patients infected with initially susceptible *Pseudomonas* isolates (Obritsch, Fish, MacLaren, and Jung, 2005).

One of the virulence factors that *Pseudomonas* possesses is the ability to produce siderophores, low molecular weight compounds released by the bacterium into the environment to scavenge iron for metabolic purposes. Iron, while abundant in the human body, is typically bound to hemoglobin, myoglobin, or cytochrome (Jurado, 1997). Additional iron is held by iron-sequestering proteins such as transferrin, lactoferrin, and ferritin. Therefore, the amount of free iron within the host is much less than what the bacteria requires to carry out its functions. In response to this, many bacteria have developed strategies to scavenge iron from the hosts' environment for essential metabolic processes (Jurado, 1997).

P. aeruginosa produces two types of siderophores: pyoverdin and pyochelin (Dumas, Ross-Gillespie, Kummerli, 2013). Pyoverdin production is energetically expensive, but highly efficient. Pyochelin is energetically inexpensive, but not as efficient. Pyoverdin is produced, therefore, during extreme iron deprivation, while pyochelin is produced during less extreme iron limitation. It has been found that alternating between these two siderophores allows the bacteria to survive in a wide range of conditions (Dumas et al., 2013). In this paper, the focus will be on pyoverdin biosynthesis.

Many siderophore biosynthesis pathways utilize non-ribosomal Peptide Synthetases (NRPSs), which are currently a hot topic in research. As indicated by their name, these enzymes do not use ribosomes to create proteins. Ribosomes are almost exclusively used to create proteins in nature, and work by binding to a specific template and translating the message from one biological "language" to another. This translation results in a protein product. Because they use a template, ribosomes must adhere to very specific rules regarding the types of molecules they will interact with. Alternatively, NRPSs are composed differently and therefore have more freedom to work with diverse molecules. Therefore, bioactive peptides generated by NRPS enzymes are incredibly diverse structurally due to their ability to incorporate unusual amino acids into their product. These amino acids can then be further modified by other biological processes (Mootz et al., 2002).

Non-ribosomal Peptide Synthetases are independent of nucleic acid templates and instead work by coordinating catalytic centers and using assembly-line production (Marahiel and Essen, 2009). Each module is responsible for a specific addition to the final peptide

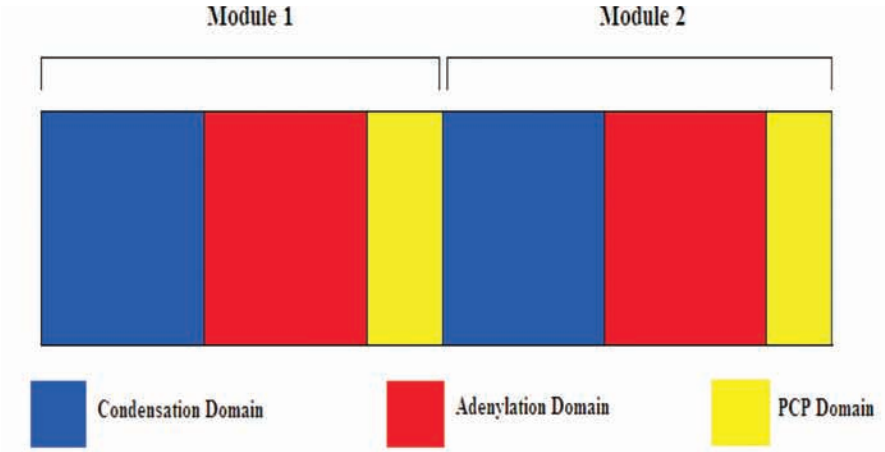


Fig. 1. Sequence of PvdJ non-ribosomal Peptide Synthetase domains. Module 1 incorporates Lysine, and Module 2 incorporates formyl-hydroxyornithine into the growing pyoverdine (Ravel and Cornelis 2003).

product. Each module contains three principle domains: the Adenylation (A) domain, which recognizes and activates the amino acid, the Peptidyl Carrier (PCP) domain, which acts as a scaffold and tether to the activated amino acid, and the Condensation (C) domain, which catalyzes peptide bond formation to join neighboring amino acids (Marahiel and Essen, 2009). The terminal module also may contain an additional domain, the Thioesterase domain, which releases the finished peptide from the enzyme (Ravel and Cornelis, 2003).

The protein domain studied in this paper is PvdJp2, a domain of a linear NRPS involved in pyoverdin biosynthesis in *Pseudomonas aeruginosa*. PvdJp2 is a PCP domain of an NRPS that catalyzes the addition of the traditional amino acid lysine and non-traditional amino acid formyl-hydroxyornithine into the growing pyoverdin chain. Linear NRPSs have the three aforementioned core domains arranged as C – A – PCP in an "elongation module" (Mootz et al., 2002) (Fig. 1). The peptides produced by linear NRPSs are entirely dependent on the order and the number of modules involved in the pathway, and therefore carry the possibility for creating novel products by the process of "module swapping" (Mootz et al., 2002).

The overall goal of this project was to characterize the structure of the protein domain PvdJp2. Understanding the structure of proteins allows for researchers to seek further information about how they interact with other molecules and substrates. In order to determine the structure, several steps must be taken. The protein must first be grown in very specific conditions that will allow optimum expression. These conditions vary depending on the protein, and therefore must be determined by methodical testing. Once over-expression patterns are determined for the protein, it must be purified from other proteins. The purified protein is then subjected to crystallization procedures, which can potentially induce the precipitation of the protein out of solution in a crystalline pattern. The protein crystal can then be collected and analyzed with X-Ray crystallography in order to create a 3-dimensional structure using computer analysis.

METHODS

See online appendix at http://ugresearch.ku.edu/Ramirez

RESULTS

The N-PvdJp2 protein overexpression plasmid was obtained from Dr. Kathleen Meneely. All further work on the overexpression and purification of N-PvdJp2 was completed by the author.

In order to determine the optimum conditions for N-PvdJp2 overexpression, an induction test was performed (Fig. 1). Results from the induction test indicated that two conditions led to optimal expression of N-PvdJp2:

1. Overnight growth at 15°C after being induced.
2. Overnight growth at 30°C after being induced.

Based on the relative darkness of the bands on the gel, it appeared as though growth at 30°C yielded slightly more protein at the appropriate molecular weight. All further tests with N-PvdJp2 were grown under these conditions.

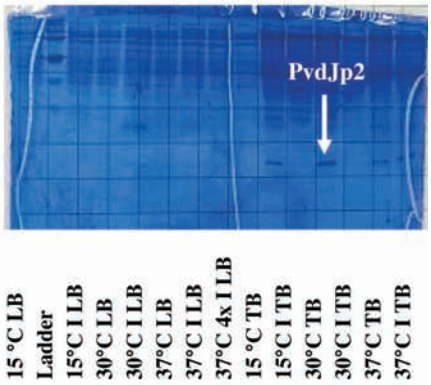
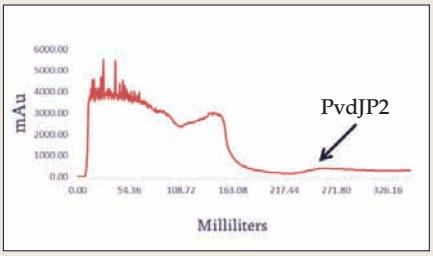


Fig. 2. Coomassie stained SDS-PAGE

The purification process was carried out using standard chromatography techniques, exploiting the His-tag. Chromatography is a collective term used to describe the different processes used to separate mixtures. The Nickel column binds the His-tag (a string of 6

Histidine amino acids that have a high affinity for nickel) selectively in order to allow for non-specific proteins to flow through (Bornhorst and Falke, 2000). Elution of N-PvdJp2 occurs when high imidazole is applied to the column, outcompeting N-PvdJp2 for binding sites and allowing the tagged protein to wash off the column in a single peak (Bornhorst and Falke, 2000). The fractions from this peak can then be combined and applied to a gel filtration column. Figure 3 illustrates the collection of N-PvdJp2 from fractions 47-65. The gel filtration column contains porous beads, which allow small molecules to diffuse slowly through the pores (Gel Filtration, n.d.). Larger molecules are not able to diffuse through the pores, and consequently move much quicker through the column. Gel filtration does not contain any denaturants, and therefore discriminates on the basis of molecular weight and 3-dimensional folding. Therefore, if dimers or tetramers of a protein of interest form, they will come out before the monomer, unlike during SDS-PAGE analysis (Gel Filtration, n.d.). Figure 4 shows that the last peak, sample 16, represents a monomer form of N-PvdJp2. Samples 15-17 were collected for concentration.

Buffer optimization screens were run on N-PvdJp2 to determine the optimum solubility for N-PvdJp2



On the Y-axis is Absorbance measured in mAU, and on the X-axis is volume measured in milliliters. My protein is indicated with the arrow and began eluting at 62 minutes.

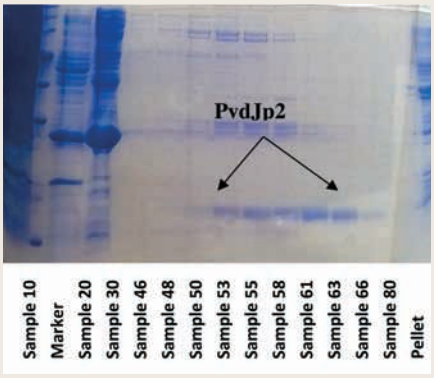
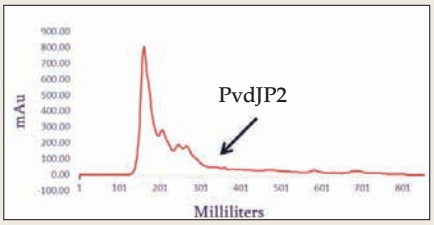


Fig. 3. Chromatogram and gel from Nickel Column



On the Y-axis is Absorbance measured in mAU and on the X-axis is volume measured in milliliters. My protein is indicated with an arrow and began eluting at 152 minutes.

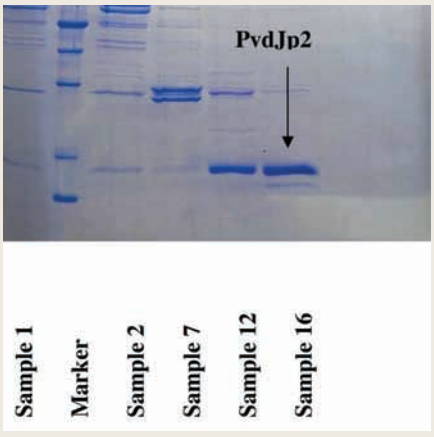


Fig. 4. Chromatogram and gel from Size Exclusion Column

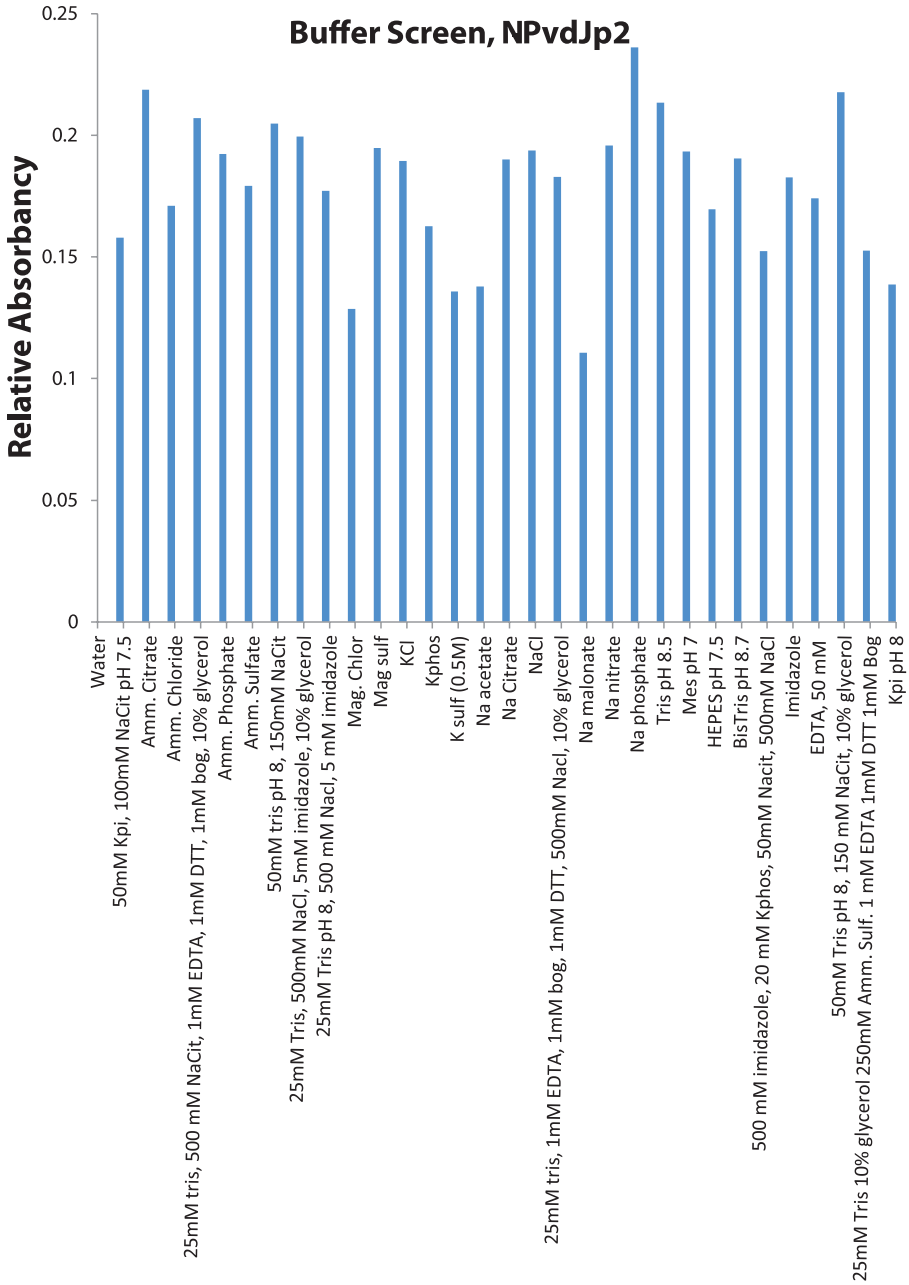


Table 3. Buffer optimization screen with N-PvdJp2. The addition of glycerol to Buffer A resulted in an increase in absorbance, and Buffer B was shown to be optimal for solubility.

in solution. When running a buffer screen, researchers are looking for high absorbency readings, indicating that the protein is soluble in solution and will therefore be present at higher concentrations when running crystal screen analysis. Results (pictured in Table 3) showed that in 25mM Tris pH 8, 5mM imidazole, 500mM NaCl, and 10% glycerol (Buffer A) solution N-PvdJp2 showed an absorbency of 0.199, comparable to the Buffer B solution of 50mM Tris pH 8, 150mM Sodium Citrate, and 10% glycerol at 0.218. N-PvdJp2 elutes at a concentration of 160mM Imidazole from the nickel chelating column. The resulting solution led to protein aggregates, most likely due to the high salt. Therefore, after being collected from the nickel chelating column, the protein was combined with equivalent amounts of Buffer B and concentrated with a stir cell. The addition of buffer before concentrating increased the protein collection significantly. After a complete preparation of Nickel and Gel filtration, 4mg of protein is prepared per liter of culture. The protein is determined to be 85% pure as estimated by coomassie gel. Protein was concentrated to 25mg/mL and stored at -80ºC until used in crystal screens.

Crystal trials were run with PvdJp2 in different conditions and concentrations. Trials included MCSG (Microlytic), Wizard (Emerald Biosciences) and Peg (Hampton Research). Crystal trials have thus far yielded no crystals suitable for X-ray analysis.

DISCUSSION

Great progress has been made in the characterization of PvdJp2. Optimum expression conditions and buffer screen analysis has led to a greater understanding of the purification process. In addition, crystal screens that do not yield diffraction-quality crystals have been ruled out from further study.

Once PvdJp2 has been characterized through X-Ray crystallography, it will provide further information about Peptidyl-Carrier Domains in NRPSs. As previously mentioned, NRPSs are presenting new options for antibiotic synthesis due to their ability to incorporate novel amino acids as well as the practical application of shifting the domains within a module to change the order of substrate incorporation (Doekel and Marahiel, 2000).

Determining the 3-dimensional structure of PvdJp2 is a small portion of the larger objective that the lab is trying to accomplish. PvdJ, as aforementioned, is a large, multi-enzyme complex composed of two full modules. Each of these modules incorporates a specific amino acid in a unidirectional fashion. The Lamb lab is currently working on several domains within PvdJ, including the full first module (PvdJm1), and the first PCP domain (PvdJp1). Once the 3-dimensional structures of each of these components have been determined, the lab can begin further work on analyzing where exactly the specificity for amino acid recognition comes from. Present research literature proposes mixed theories on whether it is the A domain or the C domain that confers specificity, as discussed below.

The Adenylation domain has been reported in many research studies as being responsible for recognition. In the article "Design and application of multi-modular synthetases," the authors report that the A domain is responsible for substrate recognition and adenylation driven by ATP consumption (Mootz and Marahiel, 1999). In another publication, the Adenylation domains are referred to as the "specificity conferring code" of NRPS systems (Stachelhaus et al., 1999). Ackerly and Lamont further this opinion, with the statement that A domains "provide active sites for the recognition and adenylation activation of a substrate amino acid" (2004).

A contrasting opinion is presented in the article "Construction of hybrid peptide synthetases," in which the authors state that while the C domain was not influential in selecting for specific amino acids, it is influential in "selectivity at the acceptor position of the C-domain of NRPSs for the correct stereoisomer" (Mootz et al., 2000). This selectivity shows a lower selectivity at the Donor site but a greater selectivity at the Acceptor site (Belshaw et al., 1999). This discovery indicates that the C domain is more selective towards the amino acids in the same module compared to amino acids in upstream modules (Lautru and Challis, 2004). In addition, low selectivity due to side chain size has also been observed (Ehmann et al., 2000).

A further goal for the overall PvdJ project would be to study the effect on swapping domains. Research has shown that domains can be swapped by fusion of linker regions and yield different products. Module fusions have been demonstrated to be increasingly effective, especially when the addition is within the linker region, where mutations, additions, deletions, and substitutions have no effect on the integrity of the NRPS (Doekel et al., 2008). Studies with Daptomycin have revealed efficiency of module exchanges exploiting the linker region to be as high as 50% (Nguyen et al., 2010).

Investigation of activity, specificity, and module or domain swapping will depend on the isolation and purification of each of the PvdJ domains. 3-dimensional modeling will provide additional insight into the functionality of these domains by providing a greater understanding of binding regions, conserved regions, and catalytic centers. In order to determine the structure of PvdJp2, further work must be done on crystal screen optimizations. Once determined, the structure can play a role in a greater understanding of NRPS systems and analysis.

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Julia Nehring

HOMETOWN
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MAJORS
Environmental Studies, Spanish

ACADEMIC LEVEL
Senior

RESEARCH MENTOR
Mary Anne Jordan, *Professor of Textiles*

Q&A

How did you become involved in doing research?
I became interested in a plant fiber that has hardly been researched, so I created a hands-on project where I could test it out myself.

How is the research process different from what you expected?
I thought I would have to complete a full manuscript by the end of my research, but the project is what you make of it. While it wasn't my original plan, my research became more of a creative project than a scientific one. Changes like that are part of the process.

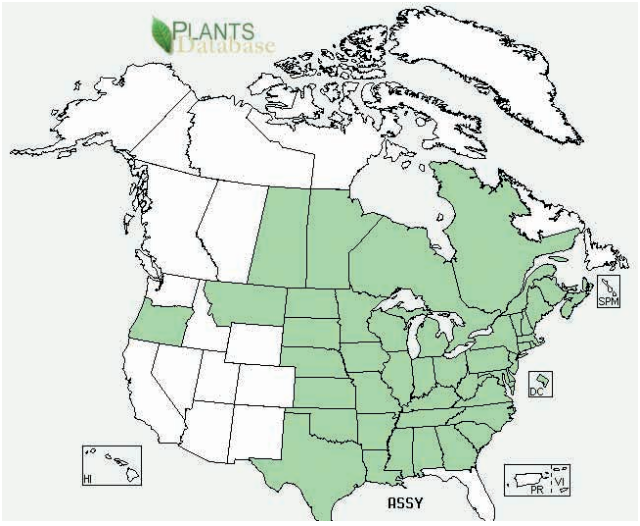
What is your favorite part of doing research?
Realizing how many students are doing independent research, and the great breadth of the different kinds of research.

The potential of milkweed floss as a natural fiber in the textile industry

Julia Nehring

INTRODUCTION

I work at an on-campus lab called Monarch Watch and became interested in milkweed because it grows all over the country, extending into Canada, and it is the only food source for monarch larvae. Map 1 shows the states and providences in which common milkweed grows; there are other species of milkweed that grow in Florida and all the Western states ("Aslcepias syriaca"). So not only are we surrounded by this plant, but it also provides essential habitat to one of America's favorite insects.



MAP 1

Unfortunately, as the name suggests, it does have the negative reputation for being a weed. Milkweed's numbers are declining as people use herbicides to get rid of them, even though they are not particularly unsightly plants. Another source of peril to milkweed is the conversion of land to make room for monoculture crop production. This means replacing milkweed and other native perennials with row after row of one crop and using herbicides to kill off any native plant that might pop back up. No matter what the cause, its numbers are declining, thus putting the monarch migration in danger.

Monarch Watch is fighting against the destruction of monarch habitat. Several years ago, the organization began a campaign to restore milkweed populations all over the country. Volunteers from all corners of the United States send seeds to the lab, the lab sends the seeds to its partner nursery, the nursery grows the seeds into plugs, and then sells the plugs back to the public to plant locally.

My role in this supply chain involves processing the seeds when volunteers send them to us. The seeds are attached to fluff, which both grow together in a seedpod. People sent us pounds of these seedpods in the fall of 2013, and, as I handled them every day, I became more and more curious about the fluff. I learned the fluff is actually individual fibers that are durable, hollow, buoyant, wax-coated, water-resistant and hypoallergenic. Above all, they are still very soft and have a cotton-like appearance. This fiber sounded incredible to me and I wondered why I had never heard of it being used before.

MILKWEED FLUFF USE

My initial research led me to find that the fluff has actually served several little-known purposes. During World War II, the Japanese cut off the United States' supply to a fiber called kapok; without kapok, they did not have any stuffing for lifejackets. Subsequently, the government launched a program that enlisted the help of children: if they could fill up a large onion bag of milkweed fluff, they would receive fifteen cents. This incentive proved very popular, and the U.S. was able to stuff over 1.2 million life vests with milkweed fluff (Woodward).

The only current commercial role is its use in pillows and comforters. There are just a couple of companies that supplement down feathers with milkweed fluff. Table 1 shows the cost of milkweed fluff relative to the cost of down, making it easy to see why it is a sound economic choice. It is worth repeating that milkweed fluff is incredibly soft and hypoallergenic, which are essential qualities in bed linen production.

Because it is so soft and looks like cotton, I was eager to find some use in textile production. The only examples I found in this category were demonstrated by a handful of eccentric women who took to the blogging world to showcase their spinning experiments involving all kinds of plant fibers, animal fur, and even their own hair. I could not find any commercial use of milkweed fluff in textiles.

PURPOSE

After realizing how little experimentation with milkweed fluff there has been in the textile industry, I chose to spin it into yarn to show its potential as a textile. The blogging women and my faculty mentor, Dr. Mary Anne Jordan in the Department of Visual Art, both agreed that milkweed fluff would be too brittle to spin on its own. This meant I had to choose a fiber to spin with it. Wool was selected because it is the easiest fiber to learn how to spin with, making it the obvious choice for a person, like me, who had no experience with spinning.

Since a 100% milkweed blend was not possible, the purpose of my project became finding the maximum amount of milkweed fiber that could be combined with wool.

TABLE 1

Market	Floss value ($/kg)
Down	15-30
Nonwovens	1-20
Cotton/milkweed	1-5
Pulp and paper	0.5-1.5

Source: Knudsen

METHOD

This section will use the help of visual aids to show the process that led up to the eventual spinning of the fibers.

Step 1: Collect seedpods

As aforementioned, I handle the seedpods that people send to Monarch Watch from all over the country. Because seedpods are only ripe during summer and into fall, there is a narrow window of time in which people collected and sent their seeds.

Step 2: Separate seeds from fluff

The seeds are attached to the fluff so that they can blow away in the wind. Unfortunately, this meant a very time-consuming process to separate the two. This step involves dumping them both into the makeshift seed separator contraption (made from a garbage can) and giving it a few spins using the PVC pipe lever. The seeds fall to the bottom while the fluff floats around the top. Opening the lid afterward sent fluff flying everywhere, but this method was still faster than separating by hand.

Step 3: Weigh fibers

I selected several different ratios of wool to milkweed fluff that I wanted to attempt to spin. This step meant weighing the fibers based on these ratios, which are discussed in the next section.

Step 4: Card fibers

Once the correct ratios were measured, they needed to be carded, or blended together. This was the most time-consuming process, as I had to brush the two fibers over and over again until they all evenly lined up in the same direction.

Step 5: Roll into rollag

When the fibers were all aligned, they were rolled into what is called a rollag—basically just a concentrated form of the blended fibers that one spins with.

Step 6: Spin

Using the wheel, I handspun all the different samples. My spinning lessons began late into my research process, meaning the samples I made were never perfect, but they serve the purpose for this project.

Step 7: Ply

After spinning two separate rollags on two separate bobbins, I made yarn by plying them together, which basically means winding one around the other.

RATIOS TESTED

This section contains the image results of the different ratios I selected to test. The ratios were measured by weight; in doing this, I would end up with a huge pile of milkweed fluff and just a small amount of wool because the wool is so much heavier. This made it very difficult to card the fibers together—because the milkweed fibers are raw, they face all directions and tend to fly away. The wool is used to help hold the fibers together, but having such a small amount made it difficult to blend.

I was pleasantly surprised that I was able to spin 75% milkweed; just a small sample took several hours, but it was doable in the end. The more milkweed I used, the fluffier and less uniform the yarn became.

100% wool, 0% milkweed

75% wool, 25% milkweed

50% wool, 50% milkweed

25% wool, 75% milkweed

RESULTS

Overall, using smaller amounts of milkweed fluff was much easier and took less time to process. If 75% milkweed was doable for me, though, then it would certainly be possible to have a more experienced spinner or a machine do the work.

When I presented my research at the Undergraduate Research Symposium, I asked people which yarn sample they liked best. I was very pleased to hear that people preferred the 25% milkweed blend to the 0% blend. This indicates to me that people like the texture and softness that milkweed fluff adds to the yarn, meaning that this sustainable fiber could have great potential in textiles.

FUTURE

In the future, I would like to try dying the milkweed-wool yarn to see how it holds color. Seeing how it holds up after several washings would also be essential if it were to be used in mainstream textiles.

Perhaps most important, though, is seeing how durable it is. To do this, I would like to weave samples of the different ratios. There are different professional ways to test the durability, but I will do a simple weight test. This involves starting with a small amount of weight on the sample, then adding more and more weight until, essentially, it falls apart.

Blending milkweed fluff with cotton could also help show the potential of the fiber in textiles. Milkweed fluff and cotton are very similar in size, so it may actually be easier to spin those two together.

Future researchers and/or artists should test the durability of textiles made with milkweed fluff to determine whether or not it could be suitable for large scale production. If it proves to be durable (throughout extended use and multiple wash cycles), then it could be grown in

mass. This means an increase in milkweed plants, which would result in more monarch butterflies and other pollinating species. It could also mean less dependence on less sustainable fibers, such as cotton.

ACKNOWLEDGEMENTS

Thank you to the Department of Visual Art for the supplies and use of the facilities. A special thanks is due to my faculty mentor in the department, Mary Anne Jordan, and the person who taught me how to spin, Danielle Yakle.

I am also very grateful to have received the Ruben Zadigan Award through the Environmental Studies program, which helped me fund this project. A huge thanks to the faculty in the program who inspire me to challenge the status quo and seek alternatives in every aspect of life.

Lastly, I would like to thank the Center for Undergraduate Research, which also provided me with funding and ample opportunities to better my research.

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Haider Tarar

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Senior

RESEARCH MENTOR
Kyle Camarda, *Associate Professor of Chemical Engineering*

Q&A

How did you become involved in doing research?
Dr. Camarda was my academic adviser. I asked him about the research he was involved in and what he did sounded interesting, so I decided to start working with him.

How is the research process different from what you expected?
It involves a lot more initiative from your end. There are no set directions or standards for what you are doing and you have to find your way forward.

What is your favorite part of doing research?
It is satisfying when experimental results match your hypothesis. Also, you get to see the application of a lot of theory.

Optimum protein-excipient interactions using molecular docking simulations

Haider Sulaiman Tarar

THE PROBLEM

Protein drugs have a tendency to aggregate, which adversely affects their shelf life and delivery as a stable drug formulation. Of the top 100 drugs by U.S. sales in the fourth quarter of 2012, 28 were protein drugs or other biologics (source: IMS Health, http://www.imshealth.com). More than 100 genuine, and similar numbers of modified, therapeutic proteins are approved for clinical use in the European Union and the USA, with 2010 sales of 108 billion (US$) (Dimitrov, 2012). Thus, there is a high demand for protein drugs, but any positive consequences of protein drugs are inaccessible if these drugs cannot be stored and delivered in a stable form. Therapeutic effects of the protein drugs are dependent on the specific primary structure of the proteins. During Aggregation, the protein irreversibly loses its unique shape, and thus its function. The aggregation process can occur due to physical interactions between protein surfaces or can result from chemical interactions of the amino acids, forming covalent bonds between proteins (Wang, 2005).

Lyophilization is the primary method used in the industry to improve the stability of protein drug formulations. Lyophilization removes water from the formulation by sublimation via a freezing step and then by evaporation through primary and secondary drying steps (Cleland, Langer et al. 1994; Costantino and Pikal 2004). The idea is to improve stability of the protein

by removing water to decrease its mobility and make it less vulnerable to water-based reactions. Even after this process, proteins may lose their native structure due to aggregation, leaving lyophilization alone as a dubious solution.

PROPOSED SOLUTION

The aim of this project is to find an effective, cheap and efficient method to develop stable formulations for protein drugs which are not vulnerable to aggregation and in turn have stable shelf life and effective delivery. A method using a combination of computer-aided molecular design and molecular docking simulations is proposed to find a specific optimum formulation for a specific protein, minimizing aggregation probability.

The choice of excipient in the protein drug formulation can lower the probability of protein aggregation through interactions between the excipient and hot spots on the protein. Excipients are inactive ingredients in the drug product that help hold a dose of the active pharmaceutical ingredient (API) together and keep it stable for a long shelf life (Ritter, 2008). Hot spots are aggregation-prone regions on a protein. In this project, a pool of candidate sugar and surfactant excipients is chosen based on specific physical and chemical properties. For each candidate excipient, molecular docking simulation is conducted with the protein. The interactions of the excipients with the hot spots on the protein are fed into Computer Aided Molecular Design (CAMD) which determines the optimum excipient formulation for that specific protein.

METHOD

The pool of excipient candidates are chosen based on their physical and chemical properties. An excipient having a high glass transition temperature is preferred. In the case of sugar excipients, glass transition temperature refers to phase change. Higher glass transition temperature means less mobility and more stability. Another aspect looked at is the water content in a lyophilized excipient-protein solid. Lower water content is preferred because removal of water slows down water-based reactions and also reduces protein mobility. Furthermore, the lower the protein loss after lyophilization, the better the excipient-protein combination will function. Loss of monomeric protein may indicate protein aggregation.

The next step is to model the interactions of this pool of excipient candidates with the protein. Molecular docking simulations of each protein-excipient combination are done in Autodock. The excipients looked at in this work are designed to provide stabilizing interactions for the protein myoglobin. In order to apply molecular docking, two commonly used excipients, the sugars sucrose and mannitol, have been investigated so far. Some of the surfactants which will be looked at as excipients in the future include Octyl glucoside, Tween 40 and Tween 80. Molecular docking simulations performed using Autodock predicted which residues were most likely to interact with the excipient in question. AutoDock employs a grid-based approach along with a semi-empirical free energy force field to identify interaction sites with minimal free energy.

Each simulation in Autodock provided ten docking conformations, which represent a local minimum free energy state. Ten docking simulations were performed for each excipient with myoglobin, providing a hundred docking conformations total for each excipient. Each conformation was evaluated to determine residues which were repeatedly involved in strong interactions (Van der Waal or hydrogen bonding) with the excipients.

The computational results from the above procedure were compared to experimental hydrogen-deuterium exchange (HDX) mass spectrometry experiments using lyophilized formulations of myoglobin with either sucrose or mannitol (Sophocleous, et al., 2012). The regions on the protein which exhibit free exchange between hydrogen and deuterium are uncovered and not protected by the protein-excipient interactions. Therefore, protein regions which show low deuterium uptake are protected by the excipient interactions covering those regions. These regions of low deuterium uptake are then correlated with protein-excipient interactions predicted by molecular docking simulations, to validate the simulation results.

Figure 1 below shows the concept by illustrating a 'perfect match':

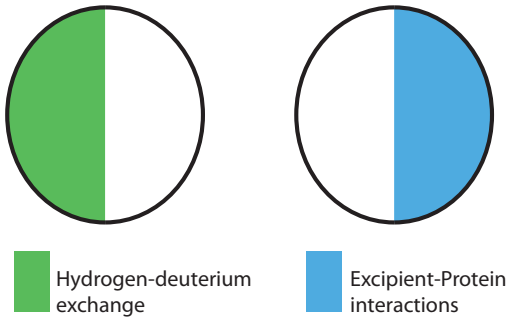

Fig. 1

RESULTS

Results were obtained from the execution of molecular docking simulations, providing 100 conformations for both myoglobin-mannitol and myoglobin-sucrose. The results were analyzed and compared with the results of HDX exchange experiments for the same

two pairs in the lyophilized state. Figure 2 shows the results for the HDX exchange experiments for those two excipient-protein pairs. Figure 2 is a histogram which presents the strength of molecular interactions at various residue locations, for both the simulation results and the HDX experimental results. Overall, the docking results compared favorably with the HDX results. Regions of high interaction in the docking simulations corresponded to regions that were protected from hydrogen-deuterium exchange. The regions which were protected by the excipients in the lyophilized state showed low deuterium uptake. These regions correspond to residue-excipient pairs, with sucrose and mannitol showing high frequency of interactions. Thus, the simulation predictions demonstrate utility as a formulation selection tool. The HDX experimental results show that the sucrose-myoglobin system always shows a lower deuterium uptake then the mannitol-myoglobin combination. For the simulations, the excipient (sucrose or mannitol) with higher interaction with a specific amino acid can be selected. An approximation made by the Autodock simulation algorithm is that the protein molecule remains rigid. While this simplification certainly suggests that the results of simulations alone should not guide formulation design, the use of Autodock in combination with the other software tools for screening of excipient candidates is not hampered.

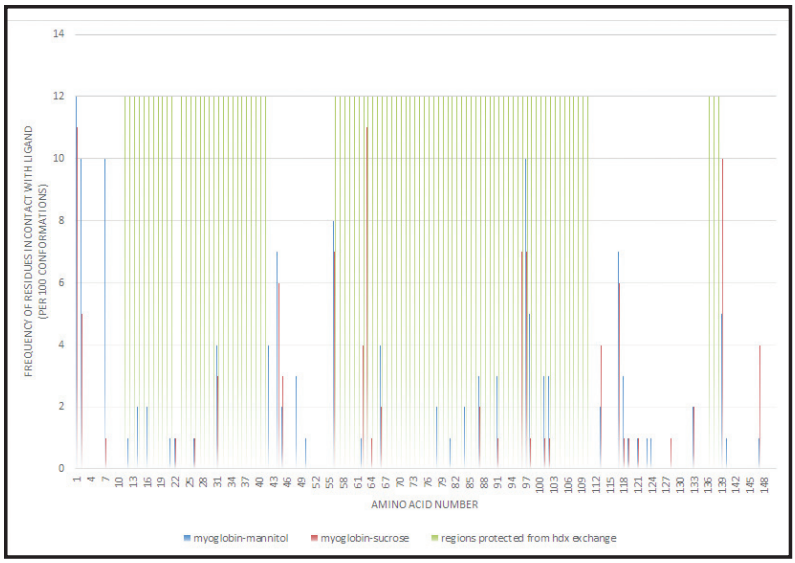

Fig. 2: Frequency of amino acid residues of Myoglobin in contact with sucrose and mannitol. Results are given for 100 docking conformations. The completely shaded regions in green indicate the amino acids that were protected by the excipient in the lyophilized state, as determined by HDX experiments.

Data provided by the docking simulations is used to optimally select excipients that have the highest number of interactions with aggregation-prone"hot spots."The hot spots were predicted using Aggrescan (Conchillo-Sole et al., 2007). For each hot spot, a sugar and a surfactant molecule are chosen to maximize protein-excipient interactions. For selection purposes, whichever excipient has the most interactions with a particular residue is chosen as the best candidate. It is assumed that the molecule with the most interactions with a residue would have the dominant effect and thus contribute the most to the protection of the residue of interest. The method may also be used to compare classes of excipients. For example, at each residue in the hot spot, the best sugar candidate and the best surfactant candidate can be compared. Whichever excipient had the most interactions is then selected and the process is repeated for the entire hot spot sequence. The sugar-surfactant pair providing the maximum number of interactions is selected as the optimal drug formulation. This part of the method aims to utilize Computer Aided Molecular Design (CAMD). Figure 3 summarizes the whole methodology:

A pool of excipient candidates, including surfactants and sugars, is selected based on certain physical and chemical properties.

Molecular docking simulations

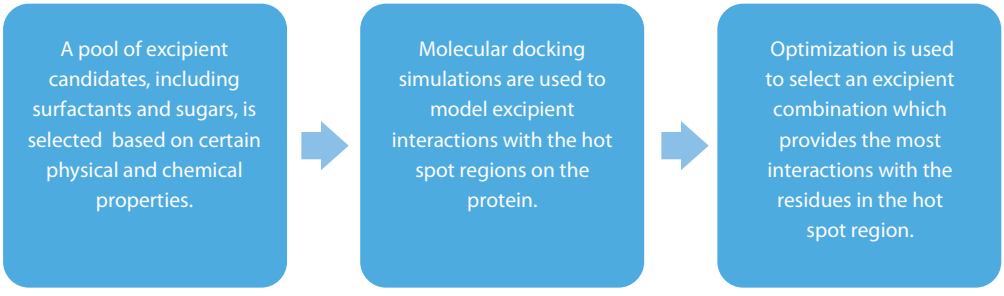

Fig. 3

are used to model excipient interactions with the hot spot regions on the protein.

Optimization is used to select an excipient combination which provides the most interactions with the residues in the hot spot region.

CONCLUSIONS AND FUTURE WORK

The hydrogen-deuterium exchange experiments were performed specifically to establish the utility of molecular docking simulations for the determination of the best excipients for a protein. For example, 25 excipient candidates may be generated for a particular protein using computer aided molecular design, based upon three properties of interest: high glass transition temperatures, low water content in the lyophilized state and minimum protein mass loss on lyophilization. The molecular docking simulation method can then be used to quickly screen this group into a short, ranked list of excipients for that protein. Formulations of different excipients which give optimal interactions with the hotspot regions of the proteins can also be determined. This procedure significantly decreases the time and resources expended in the search for novel excipients. Thus, this work aids in the ability to predict the optimal excipient for any provided protein, allowing the pharmaceutical industry to better develop safe, effective and financially viable protein drugs.

An approximation made by the Autodock simulation algorithm is that the protein molecule remains rigid. Molecular docking simulations will be run in AutoDock Vina to see if that minimizes this approximation. Furthermore, additional proteins and excipients will be added in the dataset to obtain a more detailed and flexible tool for protein formulation design.

ACKNOWLEDGMENTS

Professor Kyle V. Camarda, Chemical and Petroleum Engineering, University of Kansas

Brock C. Roughton, Phd Chemical Engineering, University of Kansas, 2013.

Molecular Graphics and Modeling Lab, Molecular Structures Group, University of Kansas.

APPENDIX

The structure of the protein was obtained in the PDB file format from the Protein Data Bank (http://www.rcsb.org/pdb/home/home.do). Structural information about the excipients was accessed via files in 3D-SDF format obtained from PubChem online (http://pubchem.ncbi.nlm.nih.gov/). Because Autodock cannot read sdf files, excipient files were converted to 3D-mol format using the CACTUS online toolkit (http://cactus.nci.nih.gov/translate/).

Docking Using ADT (Pokphanh, 2011).

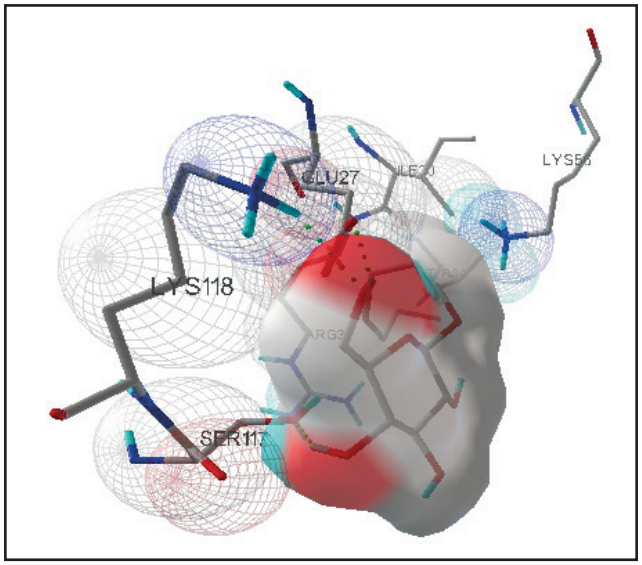

Fig. 4: A docking conformation of Octyl Glucoside with Myoglobin in Autodock.

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Paul Fowler was curious about the history of African-Americans in his hometown of Lawrence, Kansas. He connected with a faculty mentor, got funding for his research, and hit the archives.
See p. 9 to see what he learned.

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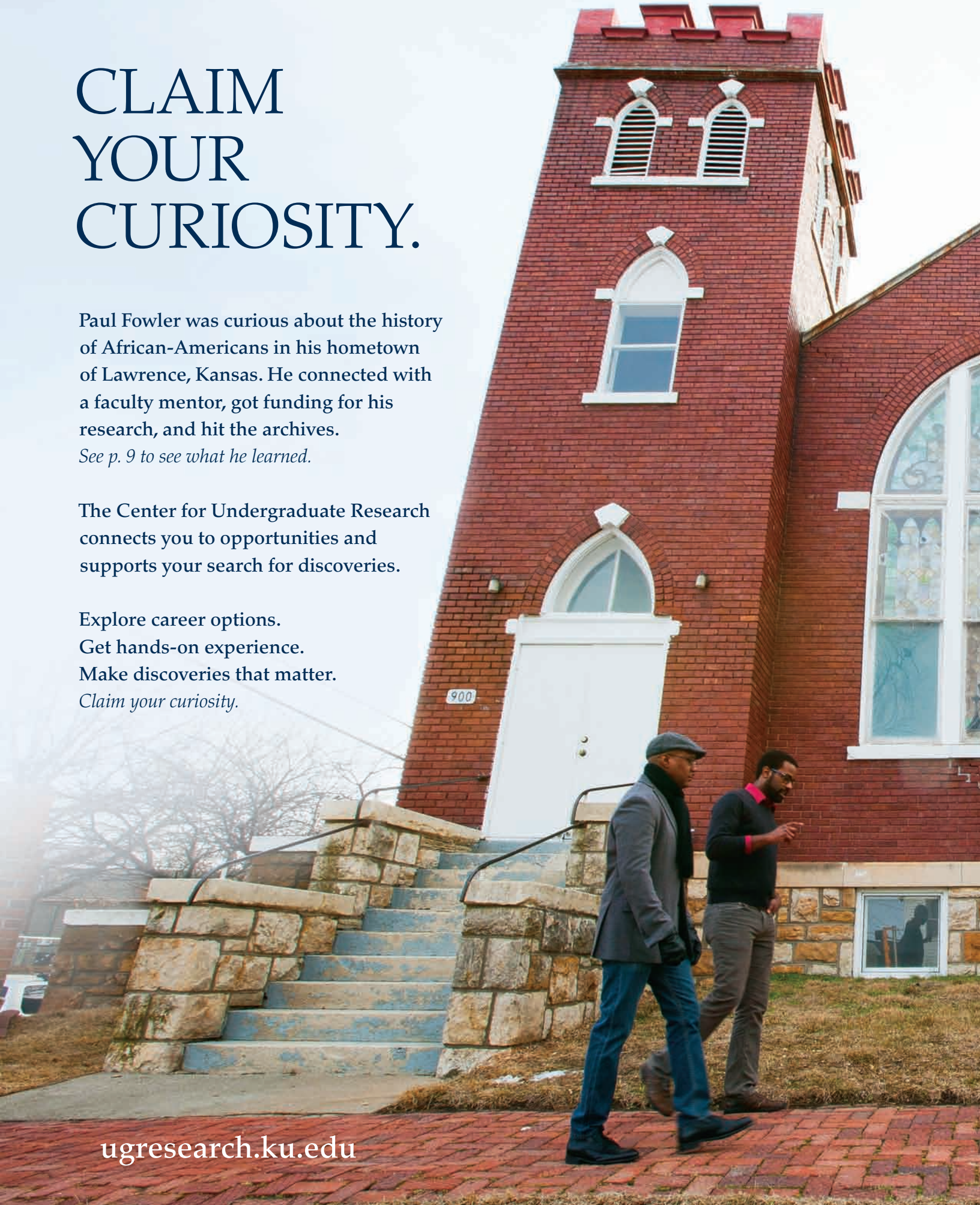

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