Interdisciplinary Research Program to Inspire Underrepresented Undergraduate Students in Science, Technology, Engineering and Mathematics (STEM) Fields

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***Abstract* – This paper describes an interdisciplinary undergraduate research program in STEM fields intended to motivate female students to graduate with STEM degrees. The goal of the dual-role approach is to provide unique mentorship from distinguished technical leaders to female students while the students simultaneously pursue STEM research as a team. The students receive mentorship from distinguished female leaders in STEM fields through conducting an Oral History Project in collaboration with the IEEE History Center. Research results produced by the students are presented at national conferences and published in national conference proceedings, and oral history transcripts of the distinguished leaders are published on the IEEE Global History Network.**

Index Terms – Undergraduate research program, interdisciplinary research, oral history project, underrepresented students; science, technology, engineering, and mathematics (STEM)

INTRODUCTION

For the United States to maintain a globally competitive advantage in an increasingly advanced technology-based society with technically competent leaders, researchers, scientists, and engineers, undergraduate programs must produce sufficient graduates with baccalaureate degrees in science, technology, engineering, and mathematics (STEM) fields [1-3]. However, the U.S. Government Accountability Office reported in 2005 that "it is uncertain whether the number of STEM graduates will be sufficient to meet future academic and employment needs and help the country maintain its technological competitive advantage" [4]. In 2014 the American Association of the Advancement of Science reports that "fewer than 40% of the students who enter college with the intention of majoring in a STEM field complete a STEM degree" [4b].

A need exists for undergraduate students to become aware of STEM topics that are important for industry, defense, and security as well as commercial applications and technologies targeted specifically for DoD applications [1-7]. For example, the scientists and engineers who are working in government laboratories and other national organizations that are increasingly reliant on very competitive state-of-the-art off-shore manufacturing capabilities will need to understand and become technically competent regarding decisions on systems of interest to the DoD [1-4, 9-11].

Within the U.S. Air Force, "technical capabilities have always been critical to the missions and roles of the U.S. Air Force in military operations, and these capabilities are rooted in science, technology, engineering, and mathematics (STEM)" [12]. In 2010, "concerns have arisen over the future of both the military and civilian contingents of the Air Force's STEM workforce" [12]. By reaching out to students, the Air Force hopes to motivate them to continue the pursuit of their STEM degree and hopefully become a vital part of the DoD workforce [13-15].

This paper describes an interdisciplinary research program in STEM designed to motivate female undergraduate students to graduate with STEM degrees since women 'are more likely than men to 'leak' out of the pipeline in the sciences' [16]. While women earn 57% of bachelor's degrees [2009, 17], women earn 20.2% of physics degrees, 43.9% of mathematics degrees, 17.7% of computer science degrees, and 17.5% of engineering degrees [2008, 18, 19]. Thus, one goal of this project is to increase the retention of women professionals with STEM degrees and increase female participation in STEM fields.

PROGRAM STRUCTURE AND TIMELINE

The program is composed of two components throughout the academic year: a STEM Research Component led by an engineering student, and an Oral History Component led by a social sciences student. The goal of this approach is to provide unique mentorship while the students work together as a team to carry out state-of-the-art research in STEM fields through sponsorship of the National Science Foundation NSF ADVANCE under Award #0810989, Air Force Research Laboratory (AFRL) Sensors Directorate, Air Force Institute of Technology

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(AFIT), and Air Force Office of Scientific Research through the AFIT MOA program [13-15].

Each year, AFIT invites students to Wright-Patterson Air Force Base (WPAFB), Ohio, to participate in its Summer Undergraduate Research Program geared to motivate students to continue in STEM fields [13-15, 20]. The program in this paper began (Year 1: June-August) with the selection of two students in the AFIT Summer Research Program (See Figure 1). In Year 2 and Year 3, the program expanded to the entire academic year (September-June). Both students work continuously and remotely with AFIT from their home institutions in Year 2 and Year 3. The engineering major (first author) leads the STEM component, and the social science major (second author) leads the oral history component. Each student assists the other student on the component that she is not leading.

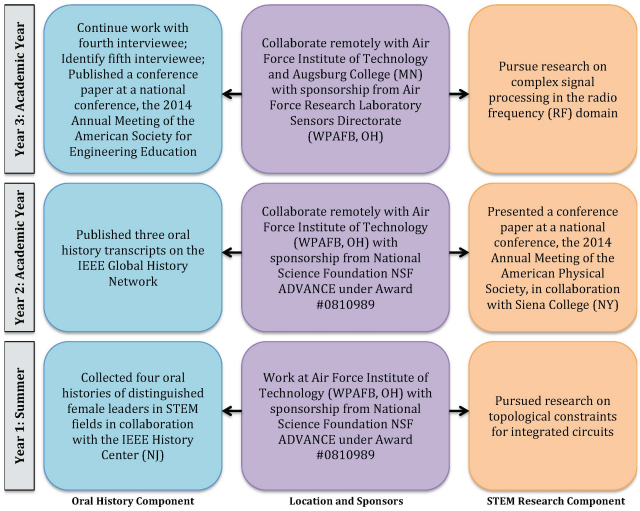

Figure 1. Dual-Role Program in Years 1, 2, and 3.

In Year 1 (summer), the students conducted four oral history interviews and pursued research as participants in AFIT's Summer Undergraduate Research Program. In Year 2 (academic year), the students coordinated the publication process of three oral history transcripts with the IEEE History Center [21-25] and were first authors on a technical conference paper at a national meeting [26]. In Year 3 (academic year), the students continue to work with the fourth interviewee, are identifying a fifth distinguished leader to conduct an oral history interview, and are pursuing STEM research. They are first authors on an Oral History Project paper at a national meeting [27].

This program supports multiple Air Force goals. First, it supports near-term technical goals through the completion of research tasks that support several ongoing academic research thrusts, as will be discussed in the next section. In the current fiscal environment, labor is scarce, and supplementing the time of faculty and senior lab researchers with undergraduate student time provides a very cost-effective way to complete necessary supporting tasks. Second, the Air Force has a vested interest in maintaining and even growing the pool of qualified STEM applicants entering the DoD workforce. By providing the students with skills through the STEM research component and motivation through the oral history component, qualified young researchers are produced and encouraged to join the ranks of DoD researchers. Third, by having enthusiastic young researchers reach out to senior professionals to conduct interviews, the Air Force gains visibility within the technical community, which can promote future technical interactions.

STEM Research Component

I. Topological constraints for integrated circuits (Years 1-2)

The two students conducted research on topological constraints for integrated circuits in Year 1. Results were presented in Year 2 at a national physics conference in collaboration with Siena College [26].

Since the results of this research are published previously, the purpose of this section is to summarize the motivation of AFRL on supporting this program. AFRL has a major interest in developing integrated circuits. The mission statement for the Integrated Circuits and Microsystems Branch is to conduct both in-house and contractual efforts focused on the development and validation of comprehensive design, integration, and control techniques for digital, RF, electro-optical (EO), and mixed signal integrated circuits including integrated circuit integrity and reliability, embedded power efficient processing, and reconfigurable computing. These complex technologies form the trusted building blocks critical to high performance signal processing as required to meet size, weight, power, and cost constraints for future high performance Air Force Intelligence, Surveillance, and Reconnaissance (ISR) Anti-Access/Area Denial applications. The AFRL mixed-signal design center is responsible for developing and designing integrated circuits. They have all the state-of-the-art design tools and capability to design the circuits that are fabricated at IBM using the latest technologies. The major driver is to reduce the cost, and having techniques, such as these two participating students developed on topological constraints, allow the integrated circuits to be modeled accurately without having to fabricate to get the results, which is a very powerful capability to have and significantly reduces the cost.

II. Complex signal processing in the radio frequency (RF) domain (Year 3)

The two students are conducting research on complex signal processing in the radio frequency (RF) domain in Year 3 [28-30]. Since the results of this research are published previously, the purpose of this section is to summarize the motivation of AFRL on supporting this program.

When one considers a dense RF spectrum plus agile signals of interest that could be positioned in frequency space either close to a large interfering signal or close to the spectrum noise floor, signal isolation followed by excision becomes quite a challenge recognizing that waveform

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characteristics have to be encoded and decoded into a digital format for thorough signal analysis. However, inclusion of additive noise, phase distortions, gain control, and saturation effects due to aperture, receiver and transmitter components are additional limiting factors to system architecture sensitivity. The measurement of the signal of interest in the presence of strong interference, which is characterized as a function of frequency separation, is often referred to as instantaneous dynamic range or IDR. If one considers complex signal processing in a dense RF environment, the equation defining IDR needs to include time-dependent terms with respect to the signal amplitude coefficients R_1 and R_2 as the likelihood that they are agile in frequency is probable and thus dynamic in power. The modified IDR equation in (1) also accounts for frequency separation of the signals (Δf), and adds an additional dynamic to characterizing real signals,

$$F(t) = R_1(t)f_1 + R_2(t)f_2[R_2 + \cos(2\pi\Delta ft)/1 + R_2^2 + 2R_2\cos(2\pi\Delta ft)] \quad (1)$$

ORAL HISTORY COMPONENT

Oral History is a well-established historical technique to collect the stories and recollections of individuals and make those recollections part of the historical record for posterity. Oral Histories consist of recorded interviews between a well-prepared interviewer and an interviewee. Oral history is the oldest type of historical inquiry, predating the written word, and is also the most modern, initiated with tape recorders in the 1940's and now implemented with 21st century technologies such as digital recorders [31-33].

The Oral History Component draws on best practices from other oral history projects, such as those collected in 2001-2003 through the "Oral History of Women in Computing Project" of Dr. Janet Abbate [34-35]. The Oral History component is intended to

> "create a … one-on-one career-building and life-changing mentorship program for female undergraduate students in …STEM. This project provides the students with … one-on-one exposure to some of the world's leading female science and engineering pioneers….The students identify, select, contact, interview, and transcribe a new oral history for the entire career of female distinguished leaders, whose research and career align with the students' goals. Through this process, the students … [receive] one-on-one mentorship with distinguished female leaders, and preserving a critical part of the historic record (the oral histories) at IEEE." [22]

Both students collaborate with historians at the IEEE History Center [21-22]. The historians trained the students in the practice of oral history and assisted them in preparing their question and topic lists for each interview.

Table 1. Oral History Interviewees #1, #2, and #3 [21-25].

#	Name	Interview Date
1	M. Dresselhaus, Professor at MIT [23]	July 2013
2	D. Anderson, Daughter of J. Desch [24]	July 2013
3	J. Hwang, CEO of H-Technologies [25]	July 2013

In Year 1, the students identified distinguished leaders whose career paths aligned with the students' career goals. Three individuals are M. Dresselhaus (Professor, MIT), D. Anderson (Daughter of Joseph Desch), and J. Hwang (CEO, H-Technologies) as shown in Table 1. The reasons the students selected these individuals are described now in their own words (text in italics):

Interviewee #1 was selected because of her background and success in physics and electrical engineering, and especially due to her success in carbon sciences. We found her background information on the National Academy of Engineering website. Interviewee #2 was selected because of her connection to her father's work in decoding the German enigma in WWII at the National Cash Register in Dayton, Ohio. We found her information through a reference from a colleague at the Air Force Research Laboratory. Interviewee #3 was selected because of her materials engineering and international business experience, in addition to being the only woman from Ohio inducted into the International Hall of Fame – Women in Technology. We found her background information on the National Academy of Engineering website and her own personal webpage.

At the end of the process, IEEE History Center staff worked with the first three oral history subjects to prepare their transcripts for publication, and then supervised undergraduate student assistants at Stevens Institute of Technology, who posted the transcripts on the center's website, the IEEE Global History Network [21].

PROGRAM FLOWCHARTS OF MS. IRVIN (CO-AUTHOR)

The first student and co-author, Ms. Irvin, started in Year 1 as a rising sophomore at Washington University in St. Louis. Figure 2 shows her career pathway.

I. Career Pathway and Goals of Ms. Irvin

When beginning the Oral History Project during the summer of 2013, my five questions for the interviewees were the following: (1) How did you first get into your profession? (2) What were the key decisions or paths you took that affected your career? (3) Was there any additional pressure to balance your professional and personal/family life? If so, how did you handle it? (4) What do you feel were the most vital skills in your field? (5) How has your field changed since you entered it?

From the answers provided by the interviewees of the Oral History Project, I find that according to these successful women in STEM fields, the most crucial skills in STEM fields are hard work, interpersonal skills, focus, leadership, confidence, drive, time efficiency, and prioritization. I also find that these women all felt additional pressure to balance family and professional life. Further, they all agree that while more women are present in STEM fields than previously, the overwhelming majority of professionals in STEM fields are male, and that this fact is not changing quickly. This was my interpretation of the interviews in the summer of 2013, and it is my interpretation now in the fall of 2014. As I now think about the questions I want to ask an additional interviewee, I want to ask the interviewee the same five questions.

II. Selection of Summer 2014 Opportunities (Year 2)

For the past year, I have worked as an undergraduate research assistant in the Cognition and Development Lab at Washington University in St. Louis, a psychology lab investigating how young children understand and learn from the world around them. During the year I began working on my own study looking into how children understand social exclusion. Because of my interest for developmental and social psychology and my previous positive experience in the lab, I decided that I

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wanted to continue this research over the summer. I applied for and received an Undergraduate Research Grant to work in the lab over the summer of 2014. With this grant, I completed the study along with a control condition. I chose to do this work over the summer to broaden my understanding of developmental and social psychology as a work towards applying to graduate programs in clinical psychology.

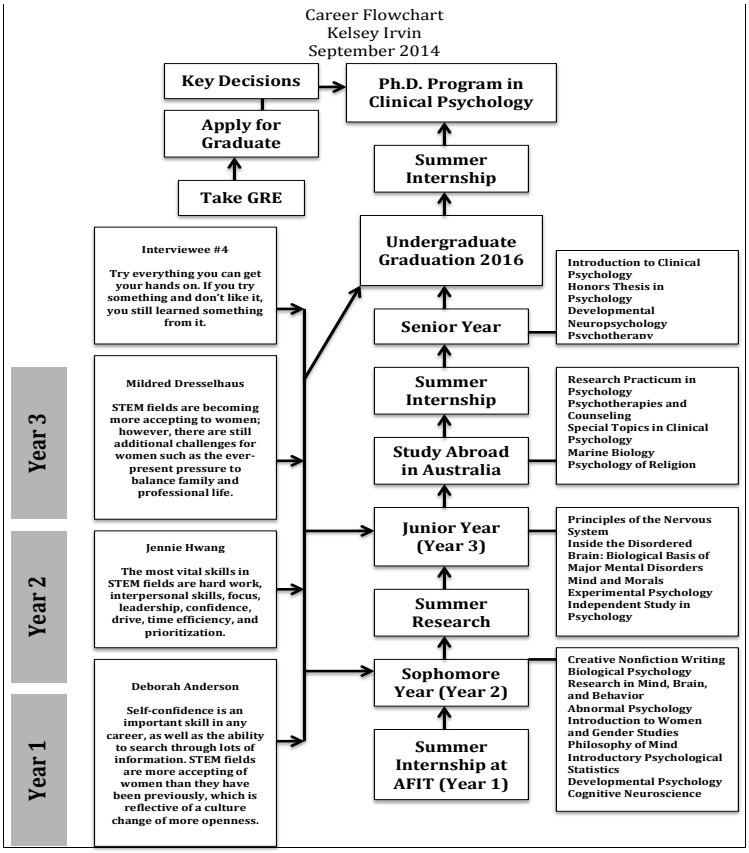

Figure 2. Career Pathway of Ms. Irvin (co-author).

III. Selection of Fall 2014/Spring 2015 Courses (Year 3)

This semester I chose to take Principles of the Nervous System, Mind and Morals, Experimental Psychology, Inside the Disordered Brain: The Biological Basis of the Major Mental Disorders, and an independent study in the Cognition and Development Lab to continue work on my study from the summer of 2014. The courses I am taking now build upon those that I have previously completed. Principles of the Nervous System builds upon the knowledge I gained in Biological Psychology, and Experimental Psychology builds upon the knowledge I gained in Psychological Statistics. Completion of these courses is in pursuit of my dual-major in Philosophy-Neuroscience-Psychology (Cognitive Neuroscience Track) and Psychology. All courses meet requirements for my majors.

I hope to gain an in depth understanding of the biological underpinnings of psychological concepts and disorders. Principles of the Nervous System gives me a neurological basis to build upon in my Inside the Disordered Brain course, which connects to psychological concepts that I learn in my independent study. Experimental Psychology gives me the tools to understand how to design and analyze psychological experiments.

Next semester, I plan to study abroad in Australia. I chose this program because it is specific to psychology, and I hope to gain an understanding of the topics I am learning now as they are viewed in different parts of the world. I believe this will broaden my understanding of psychology. Because the Australian semester continues until the end of June 2015, I plan to take a GRE course and study for the GRE during the short summer before my senior year.

IV. Long-Term Goals (Beyond Year 3)

I also believe that the majors I have chosen will help me to achieve my goal of admission into a Ph.D. Clinical Psychology program. Criteria for a Clinical Psychology Ph.D. program varies, but often requirements include a minimum GPA of 3.0, completion of Experimental Psychology and Psychological Statistics, completion of the GRE, and a strong undergraduate education in general.

PROGRAM FLOWCHARTS OF MS. HITESHUE (CO-AUTHOR)

The second student and co-author, Ms. Hiteshue, started as a rising junior in systems engineering at the University of Pennsylvania. Figure 3 shows her career pathway.

I. Career Pathway and Goals of Ms. Hiteshue

My flow chart is designed in a bottom-up manner (increasing in time further up) and includes four main components: 1) education, 2) summer work, 3) research, and 4) future career plans. The first component, education, colored in blue, incorporates my high school education in Ohio through my current work towards earning my Bachelor's degree in Systems Engineering at the University of Pennsylvania. Secondly, my summer work is shown in orange and represents the research and internships I have completed during my three college summers. Jutting off the box for research conducted at AFIT and remotely are the boxes in red, representing the results from the Oral History project. The main conclusions from each interview are noted in each box. The red research boxes serve as inputs into the last component, my future career plans, represented in purple. This connection illustrates the impact and mentorship that the research and advice from influential women in STEM fields has had on my future career and life goals.

II. Selection of Summer 2014 Opportunities (Year 2)

Returning to Penn after my Summer 2013 research internship at AFIT, I realized I needed to gain experience in business, hopefully while still applying my technical interests. This was a common theme that I encountered during the Oral History project, in that these influential women were working with technology in STEM fields, but attributes of business were very prevalent and necessary to succeed. Thus, I decided to look into consulting internships for Summer 2014. After looking through the different types of consulting, I focused on and later obtained an internship that combined both my technical skills and client-facing consulting.

In this role as a summer consultant, I was staffed at a large energy delivery company where the team was in the later stages of a complex SAP Utilities (IS-U) implementation. I was initially challenged to quickly learn the details of a utilities company's

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daily operations and outdated information system, and understand how each of the components would be impacted with the project's future implementation of a SAP Utilities system. The complex dependencies, integration and organization of these tasks continuously fostered strong problem solving and critical thinking skills during my time on the project.

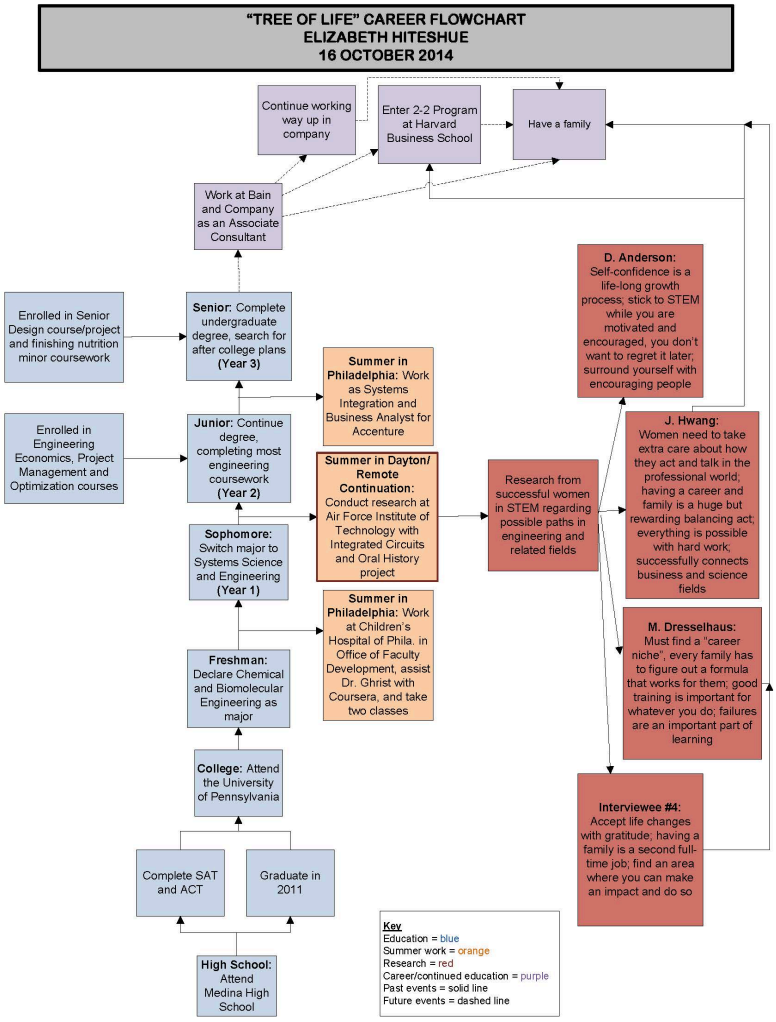

Figure 3. Career Pathway of Ms. Hiteshue (co-author).

III. Selection of Fall 2014/Spring 2015 Courses (Year 3)

My personal course selection is pretty limited for Fall 2014 and Spring 2015, seeing as the majority is required for either my major or nutrition minor. For instance, one course required to earn my degree in Systems Engineering is a senior design course, which includes initiating and completing a capstone project over the course of my senior year. For my elective course, I plan to take a course on negotiating. My reasoning for taking this course over a general course in debating is that this negotiating class has an additional emphasis on conflict resolution. This course has gotten great feedback as being applicable post-college, and I definitely feel like negotiating skills can be an asset in the business world and beyond.

IV. Long-Term Goals (Beyond Year 3)

My main long-term goals include: working my way up in a company, attending business school, and having a family. After graduation, I will work in management consulting. Here, I hope to be exposed to a number of different industries and gain various business skills. From there, I would ideally like to attend business school and then later return to industry to work my way up at one company, meaning that I would like to progress from a lower position to possibly partner, CIO or CTO of that company. Sometime during this entire process, I hope to have a family and use the advice from a few of the interviewees regarding raising a family while still being successful at work.

CONCLUSIONS

This project is intended to inspire students to continue in STEM fields. Figure 4 shows a word cloud generated from the transcripts of all three interviews combined. Words that occurred more often in the transcripts are given larger emphasis in the cloud, hence the cloud highlights trends that occurred during the interviews.

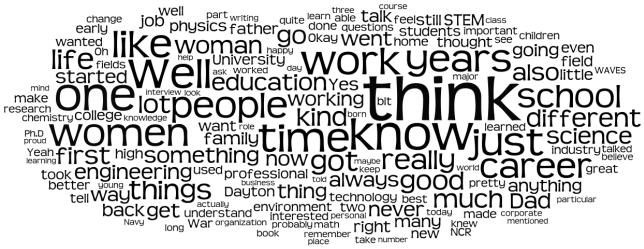

Figure 4. Word cloud of three published Oral History Interviews listed in Table I.

The project is underway with undergraduate students at Augsburg College. The ultimate goal is not just graduating female students with STEM degrees but also to ensure that these students are globally competitive. The effectiveness of the program will be assessed by comparing the performance of the female students with the performance of other students (both female and male) who pursue STEM research only. Factors will be identified to compare the student groups and may include student performance in STEM courses and student research productivity.

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