Bridging Disciplines while Fueling Engineering and Management Skills: A Case Study in Transitioning from Undergraduate Research to Graduate Study

Ashley S. Carey[1], Dr. Alta Knizley[1], and Dr. Isaac L. Howard[2]

[1]Mechanical Engineering – Mississippi State University (MSU)/ [2]Civil and Environmental Engineering-MSU

Abstract

Undergraduate research experiences can be a key factor in recruiting and retaining quality graduate researchers, and the lead author's non-traditional experience in cross-discipline undergraduate research fueled her motivation for graduate study while developing engineering and management skills. This paper uses the lead author's experiences alongside the framework in place within the Bagley College of Engineering (BCoE) to describe the value of undergraduate research experiences. As a sophomore mechanical engineering student, Ashley worked as an undergraduate research assistant (URA) researching concrete. She relied on her fellow student researchers and faculty to replace her initial fears with confidence in a laboratory setting. These experiences and a love for thermal-based science led Ashley to working with an interdisciplinary research group for her graduate study. What has become evident through this transition is that the BCoE and faculty advisors intentionally put a framework in place where undergraduate students can succeed in research and that this framework allowed the aforementioned reservations to erode fairly quickly in favor of excitement and enthusiasm. The lead author now understands how she is part of that framework, and sees graduate research not only as an opportunity for engineering discovery, but also as a responsibility to do her part to invest in undergraduates and ignite a passion in them similar to what happened for her. The primary goals of this work are to describe the potential benefits of undergraduate research for enhancing graduate student experiences, to encourage faculty and colleges to incorporate undergraduate research experiences (especially across disciplines), and to share personal experience to enhance faculty and student perceptions of advantages of undergraduate research.

Keywords

Undergraduate Research, Interdisciplinary and Cross-Disciplinary Research

Introduction

Laboratory experiences in the undergraduate curriculum are critical in giving students an opportunity to apply theories they learn in the classroom to real, hands-on projects. It is important to produce engineers that know both theory and how to apply theory in a realistic situation[1]. Laboratories that are required in undergraduate curriculums can lead to a piqued interest in research for some undergraduates. Undergraduate research allows students to enhance their learning experience and to expand on research interests while assisting faculty on different research projects. MSU and the BCoE support undergraduate researchers through the Research Experience for Undergraduate (REU) program, the Shackouls Honor College Undergraduate Research Symposiums, educational working groups, and Student Research Travel Awards programs, to name a few. Also, MSU Engineering faculty are encouraged to support

undergraduate researchers in their funded research projects. Many faculty actively recruit URAs, having recognized the mutual benefits of hiring and training high-quality undergraduate researchers: enhanced learning for undergraduates, reduced workload on faculty and on graduate students, better prepared graduate students when URAs decide to transition into graduate study, etc. Many MSU Engineering faculty regularly employ several URAs at a time, with each URA easily gaining 150 work hours of experience in a single semester. Individual faculty members within the college have supplied dozens of undergraduates with tens of thousands of hours of research experience.

Students interested in laboratory research are able to gain hands on experience, workforce skills[2], and knowledge about what goes into a research project through undergraduate (UG) research experiences. While benefits of undergraduate research to students, like developing technical competency, enhancing professional skills, and improving personal development traits, are well known[3,4], the benefits UG researchers can provide for faculty should not be overlooked. When properly trained and managed, UG researchers can provide meaningful research support (at reasonable expense) beyond simple data collection, and they have the potential to transition deeper into their graduate study more quickly than their counterparts who are new to research. Since a strong benefit of UG research to faculty members includes developing mature graduate students who can engage in meaningful research near the onset of their graduate career, the likelihood of retaining quality UG students for graduate study should be considered. Several studies suggest that undergraduate research experiences heavily influence a person's decision on whether or not to obtain a graduate degree[5,6,7]. Zydney et al.[5] surveyed alumni of the University of Delaware to see effects that their undergraduate research program (URP) had on students' graduate school decisions. Surveys found that 53% of students involved in URP said their experiences played either a very important or extremely important role in their decision to attend graduate school. Additionally, 87% of students who went on to obtain a PhD were involved in undergraduate research. These numbers are consistent with a survey given to participants in research funded by the National Science Foundation (NSF)[6]. Eagen et al.[7] show that STEM students participating in UG research experiences are significantly more likely to pursue graduate degrees in STEM disciplines than non-participatory peers. The NSF survey[6] also asked participants how undergraduate research could be improved, and the overwhelming response was increased and more efficient faculty guidance. However, faculty are often simultaneously involved in multiple research projects, and graduate students are often asked to help undergraduate students complete their research. With appropriate training, graduate students can serve in an advisory role for undergraduates, while also assisting them in attaining an appropriate level of faculty guidance. Jacobs et al.[8] surveyed eight undergraduate students who worked closely with a graduate student during a summer research program about experiences. Three themes were found from compiling their answers: 1) academic programs and careers, 2) teaching and learning, 3) building relationships. Graduate students played key roles helping undergraduates understand the dynamics of the laboratory environment, teaching undergraduates how to design and conduct research, and giving support and guidance to undergraduates throughout the research process.

Another point of interest is that in summer research programs surveyed by Jacobs et al.[8], both the faculty and the student researchers involved were composed of several different departments working together on diabetes research. Departments represented in the program included Biomedical Engineering, Chemical Engineering, Mechanical Engineering, Biology, Chemistry,

Bioelectronics, and Industrial Engineering/Economics. Interdisciplinary research projects such as this can expand possible solutions by providing multiple backgrounds and areas of expertise. Interdisciplinary research can be defined as research that involves bringing together people and ideas from different disciplines to jointly frame a problem, agree on a methodological approach, and analyze data[9]. One criticism about a doctoral degree is that a student becomes an expert in a specific area versus being knowledgeable in a range of areas. However, many federally funded research centers conduct interdisciplinary work and hire researchers who know how to collaborate and problem solve across disciplines, which can be contrary to the narrow focus of some PhD projects. Engineering faculty can address this discrepancy by intentionally creating well-rounded doctoral candidates to fill these federal research positions. One method for fostering well-rounded graduate students is by recruiting them through positive undergraduate research experiences and proactively teaching them how to collaborate with other faculty and graduate students in their research. This collaboration can readily expose graduate students to interdisciplinary research. In this paper, a case study is presented to exemplify the benefits, to both students and faculty, of participating in undergraduate research programs. The intent of this case study is to encourage faculty and colleges to support and encourage undergraduate research and remain open to cross- and inter-disciplinary research even at the undergraduate level.

The following sections (Undergraduate Research Experience, Heat Transfer, and a portion of Transition…) are written from the perspective of the lead author. Since the lead author is recounting personal experience as qualitative feedback concerning undergraduate research experience, it is written from the first-person perspective.

Undergraduate Research Experience

In summer 2015, I was hired as an undergraduate research assistant (URA) for the Center for Advanced Vehicular Systems (CAVS) at Mississippi State University. While filling out my new employee paperwork, I was told what research project I would be working on going forward. I was fully expecting to be assigned research about characterizing properties of different metal alloys or finite element (FE) analysis of car accidents, like the projects that most of my mechanical engineering friends had been assigned; however, I was told that I would be conducting research on material properties of concrete. Initially I thought there had been a mistake in the research assignments; I was a mechanical engineering undergraduate, not a civil engineer after all. There was no mistake in the placement, and I was given my assignment in the Civil and Environmental Engineering (CEE) department, where I would be working that summer. When I left CAVS, I called my mom and told her that there was no way I could do concrete research because I knew absolutely nothing about it. She quickly told me I also did not know much more about characterizing metal alloys or programming FE analysis of car crashes, but they would teach me what I needed to know. I would still have a great research experience if I kept an open mind about the research topic and had a positive attitude during the research experience as a whole.

That summer I worked in the CEE materials laboratory making and testing concrete. Walking into a lab that I knew nothing about was extremely intimidating, but the other URAs and graduate students were extremely helpful in teaching me the layout and hierarchy of the lab. Although I felt alone and timid during the initial days of my URA position, in hindsight I can see that the graduate students were watching out for me and not going to let me fail. They would

take time out of their days to teach me how to run certain tests, such as ASTM C39 (compression of a concrete cylinder) and ASTM C469 (static modulus of a concrete cylinder) and answer any questions I may of had. As an URA, having a graduate student personally teach me how to run test equipment and answer questions was invaluable. Knowing the graduate students were there if I had problems increased my confidence tenfold. I also interacted with faculty on a regular basis who helped come up with a test plan and determine how it would best be executed. Although I did not interact with them as frequently as the graduate students in the lab, they still played an integral role in my acclimation to the lab and the project itself. As a current graduate student I can see now that less interaction with faculty did not correlate to disinterest on their part. They played a role in instructing graduate students to make sure URAs were adequately assisted. As a result, URAs are less intimidated about interacting with faculty, and graduate students learn how to properly manage and interact with URAs. As the summer progressed I could feel myself becoming more comfortable with the laboratory environment and confident in my ability to perform tasks I was being asked to complete.

As the next year began, I still worked roughly 10 hours a week in the lab while also taking classes. During my materials classes I began to see relationships between concepts I was learning in class and undergraduate research I had completed. For example, in my materials class we began to go over concepts such as elastic modulus. Examples covered in class were mainly finding modulus on materials such as metals and composites, but conceptually it was the same as concrete. I soon began to realize that several of these concepts could be applied to different fields, whether it be biomedical engineers finding modulus of bone or forestry majors finding modulus of a wooden beam. Elastic modulus conceptually is simply slope of a linear section of stress-strain curve (or stress over strain), regardless of which material is tested.

Heat Transfer

During my undergraduate curriculum, I naturally gravitated toward thermal-based classes. When I took Heat Transfer, I realized that I had found a class about which I was extremely passionate. Everything about heat transfer clicked, and conceptually the material almost seemed second nature. For me, the concepts were easy to understand and interesting at the same time. I was able to take what I had learned in Heat Transfer and apply it throughout my senior level classes and laboratories, including Energy Systems Designs (ESD) and Thermal Fluids Laboratory (TFL). During ESD an in-depth study of heat exchangers was completed. As class progressed, I realized heat exchangers were just one of many applications of heat transfer. Different properties of heat exchangers can be found by applying different equations to find desired characteristics. Once I connected conceptual heat transfer material to applications in heat exchangers, ESD became an easier class to me thanks to the firm grasp I already had on heat transfer. TFL allows students to apply concepts learned from thermodynamics, heat transfer, and fluid dynamics to hands-on experiments including finding heat generated from heat pumps, efficiencies of heat exchangers, and flow measurements from orifice plates. Even though I was still conducting undergraduate research for concrete materials, I loved having the opportunity to conduct experiments based on heat transfer principles. Having the opportunity to combine heat transfer and a research setting piqued my interest in finding research where I could continue to use the concepts taught to me in heat transfer.

Transition from Undergraduate to Graduate Student

Student (Lead Author) Perspective: Graduate school had always been an option that I had considered heavily, but I was not certain that it was what I wanted to do. My undergraduate research experiences had an impact on my decision to consider graduate school as heavily as I did; however, I did not want to start a new research project. I had really taken an interest to material characterization of concrete, but I knew that, as a mechanical engineer, the likelihood of completing a project like that was slim. During my senior year, I was approached by an interdisciplinary group of faculty about attending graduate school and a possible research project requiring a strong familiarity with both mechanical and civil engineering topics. The project centered around thermal and structural modeling of concrete. I immediately agreed, as I knew this was an opportunity that would allow me to intertwine the two things I was passionate about. The following semester, as I was finishing my undergraduate degree, I was able to start a literature review for my project and familiarize myself with goals and objectives for our project. I could use my experiences from being a URA as well as the advice from other graduate students to guide me through some initial challenges in my graduate career. For example, setting up a data collection system took a relatively short amount of time since I was able to pull heavily from the data collection system I used as an undergraduate. When it came to writing a literature review, other graduate students were extremely helpful and gave tips on how to write a good literature review.

When our project began in summer 2017, our research group was given three URAs to help us complete the test plan we had prepared. Initially all of the URAs were hesitant to complete tasks unassisted. At the beginning of that summer, I spent a lot of time in the laboratory with them helping them mix concrete and answering their questions as they came up. As time progressed and they became more comfortable with the laboratory and the tasks set before them, they became more independent. Seeing their progression as researchers reminded me of my own experiences of transitioning from a new URA to graduate student. I remembered how influential a compliment for completing a test plan correctly was and how well thought out constructive criticism I received for missteps in the research process motivated me to complete tasks correctly. As a graduate student, I try to give my URAs these same types of compliments and constructive criticism that hopefully continue to motivate and affirm them throughout the project. I also see how these interactions are integral to the framework put in place by BCoE. Just as I was never alone in the early stages of my research experience, it is part of my responsibilities to make sure that URAs are not alone in their experiences and have every opportunity to succeed through hands-on help and advice.

Faculty Comments: As seen through the feedback presented, one primary novelty of Ashley's research experience is rooted in her research placement outside of her undergraduate discipline. Ashley studied as a mechanical engineer while performing purely civil engineering research at the undergraduate level. Not only did this require an open-minded approach and willingness to learn from Ashley, but it also required a faculty-led research team willing to invest in training a student who did not have a foundational understanding of some of the prominent components of their research project. However, that investment resulted in a mature graduate student with a background that bridges two distinct disciplines, in cross-departmental faculty collaborations, and in a substantial research project intertwining multiple facets of mechanical and civil engineering.

Due to her familiarity with faculty in each department, Ashley has facilitated collaboration between mechanical and civil faculty members, and she is now pursuing a mechanical engineering PhD through a funded project. The project involves thermodynamics, numerical modeling, and experimentation. Thus, this is a broad-scale project that requires significant and effective cross-disciplinary collaboration. Ashley has been able to make near immediate progress in the research by helping in the following areas: taking on responsibility in a lab with graduate and undergraduate workers; designing, organizing, and implementing the experimental component of the research project; performing a literature review encompassing all facets of the project; and laying the groundwork for an analytical model of the thermal component of the project. It is possible that Ashley will have helped author at least one journal article on this research submitted by the end of the spring 2018 semester, or, to add perspective, by the end of her first year as a graduate student. Thus, Ashley's maturity in and familiarity with her research can be readily quantified through these metrics. When compared to an inexperienced graduated student (did not complete UG research), the expectation for this field would typically be to begin preparation for journal submission at a later stage. This level of academic growth and development in Ashley has been intentionally fostered by the open and supportive environment toward UG research created within BCoE. Ashley's research interests and inter-departmental experience have fostered the working relationships between multiple civil and mechanical engineering faculty, at varying career stages, as they have embarked on collaborative efforts to ensure a successful academic trajectory to meet Ashley's research goals and capabilities. Ashley's undergraduate research benefitted not only her, but also the faculty who invested in her undergraduate education and research. Ashley has benefitted through enhanced understanding of multiple disciplines of engineering, through jump-starting her graduate career and streamlining completion of her MS and PhD degrees, through allowing her to weave her varied academic passions into a cohesive research plan, through gaining leadership and management skills from a laboratory setting, and through fostering relationships with faculty and funding collaborators participating in the project. MSU faculty members have benefitted from Ashley's UG research experience through gaining a mature graduate student able to organize laboratory testing – delegating responsibilities, setting timelines, designing appropriate experiments to collect meaningful data, training workers on experimental apparatus, etc., through investing in meaningful collaborations brought about in part through her research interests.

Conclusions

The lead author's transition from a timid undergraduate student to a current PhD student over the past three years has been an eye-opening experience into benefits of undergraduate research. Personal gains in student confidence, competence, and leadership capabilities are evident, and these gains can be attributed to a welcoming environment of this BCoE interdisciplinary REU program. Through this REU, Ashley moved from timidly observing laboratory operation and protocols to confidently managing URAs and actively developing an interdisciplinary research dissertation plan. Additionally, the positive research experiences and development of personal connections with faculty and other graduate students heavily influenced Ashley's decision to continue research in graduate study. However, even if Ashley had not decided to continue her studies as a graduate student, the management skills, independent learning requirements, laboratory exposure, and cross-disciplinary education (among other benefits) would readily translate into workplace advantages[2]. Conducting this interdisciplinary research led Ashley to be more open-minded and a better problem solver by introducing her to a broader knowledge of

topics that can be used to find solutions. Lastly, having experience as an URA was invaluable in her transition to graduate student. Ashley's experiences as an URA made relating to her URA's current experiences easier to understand, which allowed her to manage and mentor to them more effectively. Through sharing her experiences, Ashley hopes to convey to research faculty the significance of undergraduate research experiences for developing quality graduate researchers, as well as to inspire undergraduates and faculty members look for research opportunities and collaborations outside of their specific areas of expertise.

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Ashley S. Carey

Ashley Carey is currently a graduate research assistant at Mississippi State University. She completed her BS in mechanical engineering at MSU in May of 2017 and is currently pursuing her MS and PhD in mechanical engineering.

Dr. Alta Knizley

Alta Knizley has been part of mechanical engineering faculty at MSU since 2012. Her research areas of interest include energy sustainability and engineering education. Special interests include k-12 STEM outreach and minority and female leadership and recruitment in mechanical engineering. At MSU, Alta has organized and advises the Mechanical Engineering Ladies Organization. Currently, she works as an Assistant Clinical Professor and teaches courses within the thermal/fluids and analysis areas of the mechanical engineering curriculum at Mississippi State.

Dr. Isaac L. Howard

Isaac L. Howard joined the MSU faculty in 2006 and is currently the Materials and Construction Industries Endowed Chair in the department of Civil and Environmental Engineering. As an ASEE Member since 2006, educational areas of interest include hands on opportunities for undergraduate and graduate students, engagement of practitioners in the education process, and improving universal skills such as technical writing and presenting. He is a member of the Bagley College of Engineering's Academy of Distinguished Teachers.