Benefits and Challenges of Undergraduate Research

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Abstract

Undergraduate engineering research provides an avenue for students to gain in-depth experience learning and conducting experiments with a topic related to their specific field of study. The students are exposed to how and why experiments are developed and are able to help solve problems that currently do not have answers. Typically, undergraduate students are not exposed to conducting research until their senior year when they are participating in a capstone project. Working with a research advisor provides the student direct mentoring at a one-on-one level whereas with a capstone project, the students are part of a group, with multiple groups in a section, resulting in the guidance they receive from the capstone course's instructor being more indirect. Undergraduate research also provides an opportunity for research advisors to guide the students on their path to becoming engineers and help them explore career opportunities that may not otherwise be available. This article describes the benefits of undergraduate research and specifically how the experience has applied to four students. The students of focus for this study are from two 4-year institutions where two students began research as freshmen and two began as sophomores.

Keywords

Undergraduate research

Introduction

Figuring out what one wants to do in life or finding a focus area within a chosen field can be a difficult process. How do you know what you like, or how do you know what is a good fit for your particular skill set? It can be hard to say without doing work in that field. Additionally, when it comes time to start a career in a discipline, if a company requires a certain amount of experience, how can that be gained without already working in the field? For undergraduate students, answering these questions can take many forms; it can be through participating in internships, co-ops, additional certificate programs, etc. Each of these are excellent options for finding out what the work and workload will be in the field. Another option for students to take is through undergraduate research at their school. Through undergraduate research, students work with research advisors, who are typically faculty members at the school, and their graduate research assistants, if the advisor has any. Additionally, it is believed that students conducting undergraduate research are more likely to enter into careers or complete advanced degrees in science, technology, engineering, and mathematics.[1]

Evans[2] found that undergraduates typically lack maturity when it comes to being disciplined in their approach to experimental work. Undergraduate research provides an avenue to develop skills such as utilizing good research methodology, interpreting data, discipline, translating their experiments into presentations to effectively communicate the work they have completed. Faculty members are uniquely qualified to develop the necessary skills for the students to improve, but that time-consuming responsibility requires balancing mentoring time with time needed for faculty to conduct scholarship themselves and manage their teaching loads.

Wenderholm[3] investigated analyzing the successes and challenges of undergraduate research, the author offered some keys to success for undergraduate research gleaned from a four-year undergraduate research project. They found that though it is difficult to find success with undergraduate research, it represents an opportunity to have a positive impact on a student's academic experience. The first challenge they faced was finding the right student for undergraduate research, which comes with a balance between motivation and level of training. More work can be completed by a first or second-year student, but that comes with a tradeoff of base-level knowledge and with the difficulty of identifying who would be successful. This was overcome through having contact with as many sophomore students as possible to gage who would be a good fit with the research. Another challenge involves planning and project management. Making specific, attainable, and realistic milestones that do not interfere with the student's academic responsibilities is key. The students will gain confidence and motivation as they work through and complete a milestone. The last challenge identified was accounting for the inherent lack of knowledge that undergraduates have. The proposed solution to this was multifaceted in that early work on the project was focused on hiring second-year students so that they had multiple years to gain knowledge and that they could make mistakes and start again with their work. This worked to provide them a sufficient amount of training and were more productive when it came to meeting the final goals of the research. Similar challenges were met in the conduction of research for the authors of this report.

Boniak[4] reported that undergraduate research improves a student's self-motivation and self-directed learning since they are required to learn new skills on their own. This outcome becomes necessary, and creativity in reaching this is key, since availability for most faculty members to provide one-one-one time with students is at a premium. Students generally want to do the experiments because they are "fun" however, there needs to be a base-foundation of knowledge instilled in them before they can work on their own. This is a necessary step to reduce confusion to maintain their enthusiasm. Learning by doing for the students was found to help students learn and retain knowledge. Some of the challenges the authored were also with the student's lack of time and experience since many students were simply unprepared for research and therefore needed a large amount of mentoring at the beginning stages of research. The authors solution to the challenges faced were to vary the learning approaches utilized to motivate the students, such as research-informed, inquiry-based, and problem based knowledge with the result being that the students took responsibility for acquiring knowledge and applying it effectively.

Mapolisa and Mafa[5] reported on fostering undergraduate-level research to eventually enhance the level of research brought forth by graduate-level students. They identified three main categories of challenges that effect how successful a student's research experience is; mentor-student, student-related, and institution-related. The mentor-student challenge comprised the level of engagement between the advisor and student, advisor availability, and student interest in the topic. The students-student challenge identified personal issues in the student's lives that could affect their level of research, such as financial issues, motivation/commitment, and lack of knowledge. Lastly, the institution-related challenges stemmed from overcoming hurdles like lack of research materials and workshops to help foster a student's computer literacy. Institution challenges aside, the common theme of spending dedicated time between the mentor and student was critical to maintain enthusiasm in the research and to provide a positive research experience.

This study poses an introductory analysis into undergraduate research and the benefits this type of opportunity provides. It will focus specifically on undergraduate engineering research. In this setting, students worked hand-in-hand with their research advisor on an engineering topic related to their advisor's field of interest. The study follows the research of four undergraduate students; two from a 4-year, research-oriented university (School A) and two students from a 4-year, teaching-focused college (School B). The students were asked to quickly learn how to conduct useful technical research with a minimal amount of background in the relative subject areas.

Outside of returning useful research data, the incorporation of undergraduates into research enables the advisors to foster excitement for the world of engineering that may seem more of an abstract thing early in a student's academic career. Undergraduate research is also a way for students to gain real-world engineering experience, which will be beneficial when they transition into the workforce. Lastly, it provides the students exposure to the type of problems facing today's engineers. With these clear benefits, undergraduate research does come with its own set of challenges as well. The students had little to no background in their assigned research area, making it necessary for the advisors to teach them enough about the topic to get them productive early in the process while still maintaining their excitement. Time also became an issue, both with balancing the research advisor's and the student's course schedule. Finally, these two areas led to challenges with pacing and how to effectively transition the students from training to ownership of their prescribed research process. These benefits and ways to address the challenges of undergraduate research will be explored and described herein. These results were similar to previously published works and highlight the need for refining the undergraduate research process.

Study Details

The sample set is four students, so overarching themes for conducting undergraduate research will be limited, but an analysis on the strengths and weaknesses of this type of experience for these students can still be made. As mentioned, two of the students were from a 4-year, research-oriented university (School A) while the other two students were from a 4-year, teaching-focused college (School B). For the students from School A, one began research during his junior year and continued with it through graduation and into the proceeding summer, for approximately two years of total research experience. The other student from School A started in his freshman year. This student performed one year under the author's guidance, who was a graduate research assistant at the time, and then a second year continuing the research after the author's graduation. At School B, one of the students started his freshman year and worked with a research advisor for a year while the other student started as a sophomore and worked with his research advisor for a semester. All four students were male, the two from School A majored in Materials Engineering and the two from School B majored in Mechanical Engineering.

The two students at School A worked approximately 20 hours per week with about half the time being spent working with their mentors. The two students at School B worked between 10 to 15 hours each week with about half that time, again, being spent with their mentors. The rest of the time, in both cases, the students were given tasks to complete and to report on. The students did not earn course credit for their research work. The two students at School A were paid hourly through their research advisor while the students at School B were not paid.

Upon completion of their undergraduate research, the students were asked to complete a 29-question survey, based on a 5-point Likert scale, describing their undergraduate research experience. The survey was based off of the Summer Undergraduate Research Experience (SURE) survey, developed by David Lopatto at Grinnell College.[6]

The areas of research that the four students studied covered three highly technical areas. For the two students at School A, they were tasked with the synthesis, testing, and analysis of biodegradable, electroactive polymer bending actuators. Their aim was to characterize the actuators time-dependent electromechanical behavior under a constant DC voltage. This was conducted under various temperatures, ionic salt concentration, and film thicknesses. For one of the students at School B, his research revolved around space mechanics. The first-year student spent one semester learning how to use and program the relevant orbital ephemeris and maneuvering equations into MATLAB. He spent the second semester aiding in competing the Global Trajectory Optimization Competition[7] where over fifty international teams competed for developing a solution for deorbiting 123 pieces of space debris in the most optimized method possible. Lastly, the other student at School B did an experimental and computational study of the Clark-Y airfoil. He used a wind tunnel to measure lift and drag on the airfoil over a wide range of angles-of-attack (AOA). He used an in-house computational-fluid-dynamics code to predict lift and drag on the airfoil over that same range of AOA. His simulations were inviscid, turbulent, and turbulent with transition modeling. The hope was that transition modeling would enable a better prediction of the onset of stall. Flows are usually assumed to be fully turbulent, which can lead to inaccuracy in boundary layer predictions.

SURE Survey and Results

The four students were asked to complete a modified SURE survey[5] once they completed their work with their research advisor. **Figure 1** shows the averages from the four students for comparative learning gains and their assessment of how they have internalized their research experience (~questions 1-14) and how they feel that the research has affected their ability to communicate their research to others (~questions 15-20). The figure also shows how their results compare to the national averages for the survey. With these limited results, the averages are above that, compared to the national average. As the analysis of undergraduate research continues for the authors, the outcomes of their research will begin to normalize and a more direct comparison with the national averages can be made. Of note, is that the research experience instilled confidence in the students wherein they averaged 5s for learning lab techniques, being able to work independently, interpreting experimental results, and understanding how knowledge is gained/constructed. These are valuable traits as an engineer, and being able to express that knowledge and background to a potential employer will only help their employment chances. Further inspection of the figure shows a dip in the students' perceived benefits in their oral and written communication skills. They come in close to the national average and the reasoning for the dip may be due in part to there having been minimal requirements for them to present their work. Future work with undergraduates will look to include more chances for them to communicate their research efforts.

Lopatto[8] conveyed that undergraduate research fostered students' communication skills, teamwork, ability to understand primary literature, and their intellectual skills. This conclusion was a result of his developing the SURE survey which provides data on short-term research experiences. One effect he mentioned, that is still unclear, is how undergraduate research impacts their choice of career. Typically, students that conduct research are in their third or fourth year when they are more or less reaffirming their path. Current trends are pressing research starting at the first year or even in high school to offer a way to shape the student's interests into a career. This was the case with the authors of this report. One of the students from School B, a first-year student, knew he wanted to be a mechanical engineer, but did not know specifically what area. After conducting research at the end of his first semester and through the second in space mechanics he had determined that this was the direction he wanted to take. Since then, he has decided to add aerospace studies as a minor and is pursuing internships with NASA. His undergraduate experience had a direct effect on this decision.

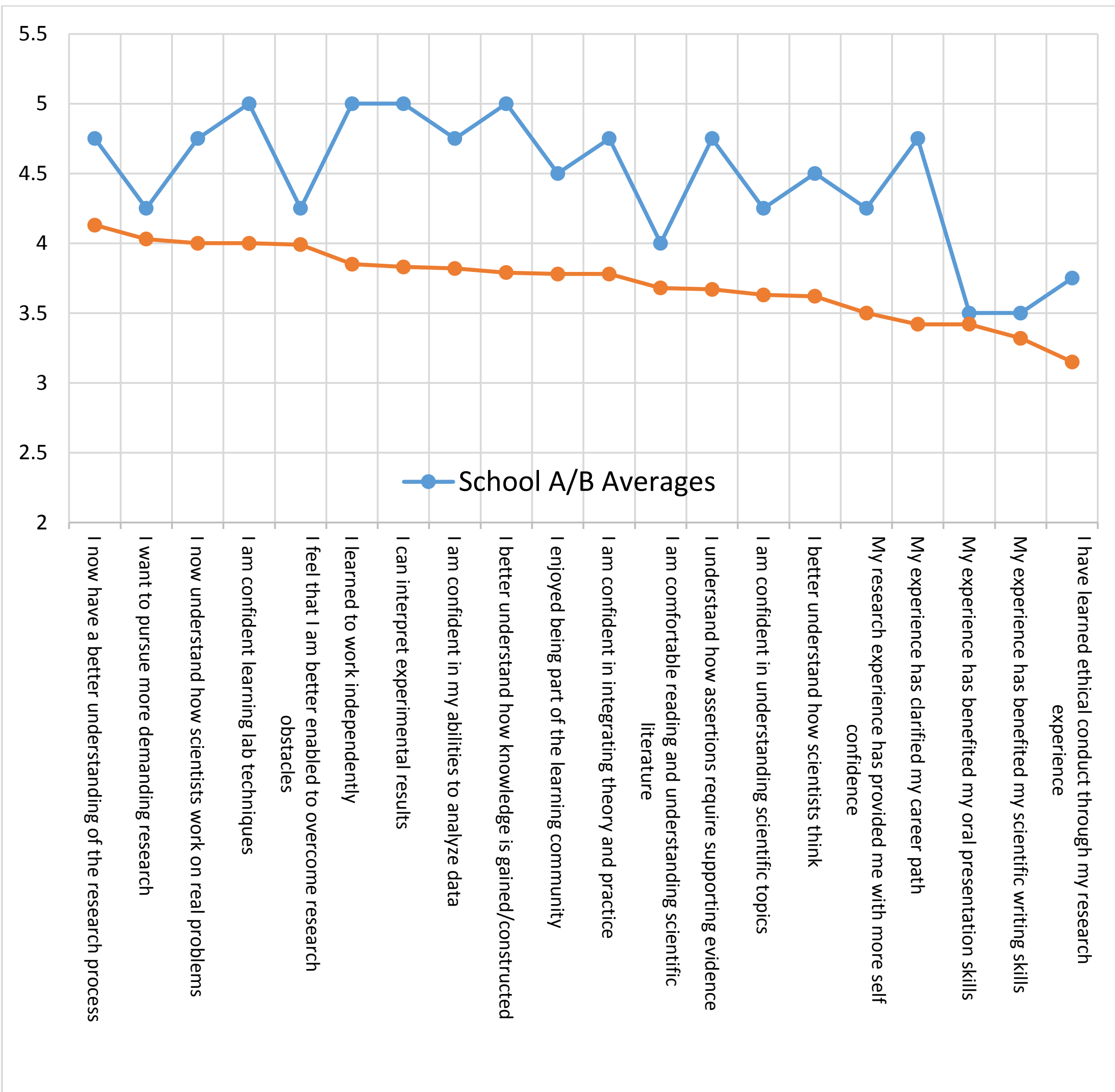

Figure 1: Comparative learning gains with the national averages reproduced from ref[6]

Through this survey, it was found that 100% of the students plan on pursing some type of postgraduate education and **Figure 1** shows that their research experience clarified their field of study. Currently, one student is applying to engineering master's programs, one is applying to industry positions, and one is in his second year of undergraduate study, but is planning on pursuing a PhD program. The last student is currently in an engineering PhD program. There he continued the tradition engineering education and spent a year being funded under a National Science Foundation GK-12 fellowship where he taught biomedical engineering courses at a local high school.

Figure 2 shows the students rating of their overall experience compared to the national averages. These results are more or less on par with the national averages. The only significant dip for the students from School A and B was that the research experience was not what they had expected. Their takeaways from the research are detailed below, so this result is not a negative one for the study. In all, the students found it to be a valuable experience.

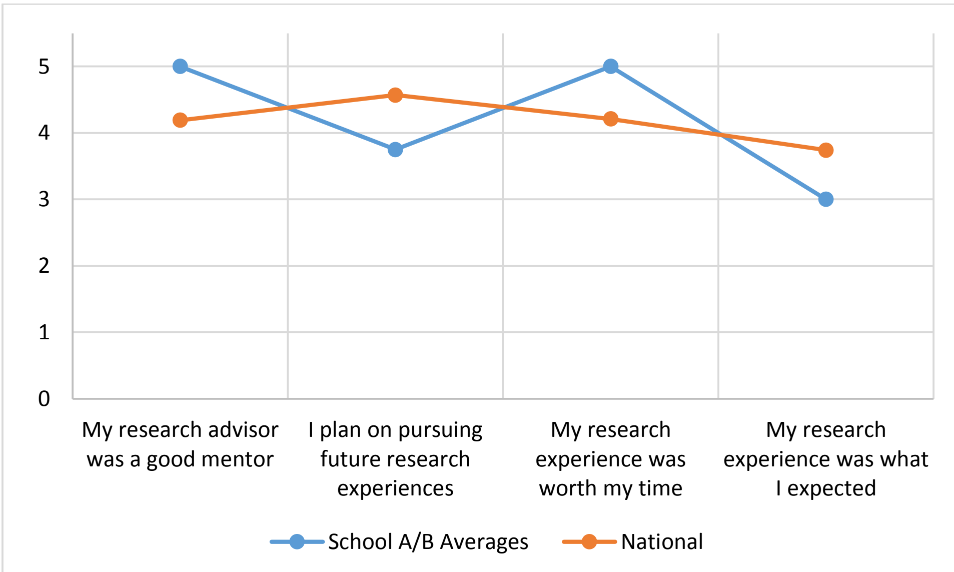

Figure 2: Student rating of overall research experience with national averages recreated from ref[6]

An additional result from undergraduate research are publications. These students contributed to six academic and engineering education journal and conference proceeding publications. Also, one of the students from School A received a research fellowship to continue his work at School A as a paid undergraduate researcher. This type of recognition validates their hard work wherein what they have accomplished has been accepted by experts in the field as valid work and publications mark a quantifiable result that they can put on their resume.

Benefits and Challenges

There are many benefits that accompany conducting undergraduate research. Firstly, obtaining relevant engineering experience is a hugely marketable asset. Companies will see that the student has taken it upon themselves to find current engineering-related projects to spend their time with outside of their course curriculum. This helps separate themselves from their peers and it also provides them with hands-on familiarity with the tools, equipment, and processes necessary for solving engineering problems. This type of exposure provides the student with the opportunity to learn problem-solving techniques. They have the chance to see how experiments are developed, tested, and analyzed and can begin to develop their own research methodology. By allowing the students to participate in and expand their knowledge with these methods will help the research advisors foster excitement for the research process.

Students from School A conducted largely hands-on, physical research. They were involved in the sample evaluation process from synthesis, to testing and data capture, to analysis. The theory behind the work was explained to them, but the students were largely responsible for conducting experimentation and providing results. Conversely, students from School B conducted their research through computational processes, and utilized software programs like MATLAB to conduct their work. This approach took a slightly different look. The students were asked to read about the theory behind the equations used, then ask questions, then generate their own code. For the student involved with GTOC, he was included in on the majority of the team meetings and helped provide possible solutions to errors in the code.

In each case, the students were eager to learn and contribute. It was found that allowing for ownership of a process, whether that was evaluating samples or generating their own code for a particular process, allowed for them to take it upon themselves to find a solution.

Conducting undergraduate research is not without its challenges, though, and each challenge offered an occasion to further the student's research know-how. For example, overcoming the student's knowledge gap posed an interesting obstacle. For the students at School A, care was taken to ensure the students knew each step of the sample fabrication and testing process. Though necessary, this proved to be a slow process and it demanded a steep learning curve from the students. However, once through this hurdle, it was found that the students could conduct the experiments and collect data as fast or faster than the research advisor. For students at School B, initial work was theory driven and getting the students comfortable with the material was paramount for initial meetings over them producing results. Theory, in both cases, was provided in small, generalized packets to the students so they could grasp the idea without needing to know how to do the detailed computations. This helped with providing a working knowledge to the students.

Time is another challenge to overcome with getting the students up to speed and conducting experiments. They have to maintain good academic standing, so they have to exercise effective time management. Time is also a consideration for the research advisor. As mentioned, initial training of the students takes a considerable amount of time. The students need to stay on track, stay productive, and stay excited about the research. For students at School B, they also needed to orchestrate their schedule around a demanding cadet curriculum which required large blocks of their time outside of class, further emphasizing the importance of the time they had for research.

Lastly, the pacing of content can be an issue for undergraduate research; too slow, and they can get bored or disinterested; too fast, and it can seem like too much and they may become overwhelmed or disinterested. Striking that balance, then is key. To solve this, it was found that granting ownership of processes to the students, once they were learned, kept them motivated in the research. Once a process was theirs they tended to want to perfect their methodology. For instance, at School A, the students had ownership of sample fabrication. Once they knew how to make the polymer films, the quality of films increased with each iteration. At School B, the coding was broken down into functions and the students were responsible for their piece of the puzzle. Once they were comfortable with the theory, they were more confident with producing valid code that meshed well with code that the research advisors were generating.

Feedback

After completing the survey, the students were asked to identify what they liked least and best about their undergraduate research experience and to provide any other feedback they thought was pertinent to the program. The responses of the students combined with their survey results parallel results elsewhere[1,5,9] in that the students felt that their undergraduate research experience benefited their cognitive and communication skills. They had an overall positive experience, with one saying:

> "[A] major benefit was learning how to analyze larger data sets and find data trends. It is a much stronger learning experience working with data where trends and mechanisms are trying to be elucidated compared to the expected results and more plug and chug type analysis that was typically associated with course work."

Another student remarked on the benefits of his experience as:

> "What I found most beneficial about my research experience was discovering a subfield that I am extremely interested in and would like to devote the rest of my studies towards. Now I know with clarity what I want my academic and career path to be, and am more prepared to pursue it."

For what the students found least beneficial during their research, some important lessons were learned. Time management and understanding the material was a common trend. For one student, it became clear that the format of the weekly group meeting was not as effective as it could be, stating:

> "Group meetings weren't very useful in the format that was used. Projects seemed unrelated and it was more oriented towards "this is what I did this week" as opposed to a more polished presentation with coherent goals."

Lastly, the students were asked to provide any additional thoughts/comments concerning their undergraduate research experience. The students gained an appreciation for the level of detail and complexity that research brings. They also came to understand its value. One response showcased how the experience will shape his future career goals, stating:

> "My undergraduate research experience opened my eyes to a field of engineering that I had no previous knowledge of and developed into deep interest in the field I want to devote the rest of my studies to. Without this opportunity, I would never have discovered such an interest in orbital mechanics, and I would still be unsure of my career path. I am extremely thankful that I had this extremely valuable experience."

Another student outlined his challenges and how learning problem solving skills and developing persistence when repetitively conducting experiments is beneficial to understanding the exact mechanisms of a problem and how to develop a solution to it, saying that:

> "Research is very detail oriented and can be tedious if the scope is small. However, it is important due to its nature to understand areas that are either unknown or previously accepted as fact. Additionally, it develops persistence, problem solving, and technical depth, which are crucial skills to develop in any type of occupation. For undergrads, it is also an opportunity to apply both previously learned and new knowledge."

Conclusions

Undergraduate research provides a way for the students to gain exposure and experience in their chosen field of study and offers a way for their research advisors to excite the students into wanting to know more. The students bring fresh eyes and new perspectives to the research process and their insight can be hugely beneficial to improving an advisors research methodology. Though challenges do arise with overcoming knowledge gaps, time management, and the pacing of topic delivery, the benefits outweigh the difficulties. This report centered on the research experience of four students from two schools and showed that their undergraduate engineering research experience has highly influenced their future career path in engineering.

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