Implementing Research Steps in Undergraduate Research

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Abstract

This paper describes an eight-week undergraduate research project conducted at Principia College in Elsah, Illinois during the summer of 2018. The undertaking was distinctive in that it was an engineering research project conducted at a liberal-arts college by undergraduate students enrolled in the college's engineering program. A multidisciplinary research team was assembled, comprised of undergraduate engineering students serving as research assistants; a faculty instructor serving as project director and advisor to the students; and a Principia alumnus serving as an image processing and artificial intelligence (AI) consultant and advisor. The following engineering disciplines were represented by the team: civil, architectural, industrial, chemical and mechanical. The team performed a structural analysis of an historically significant building on campus, the Maybeck Chapel, designed by renowned architect Bernard R. Maybeck. Data collection involved using unmanned aerial vehicles (UAVs), commonly known as drones, to capture aerial photographs of the structure for detailed analysis. The selected methodology for conducting the project was a typical Engineering Design Process used primarily as a teaching tool to demonstrate the value and effectiveness of adhering to a standard, structured method for identifying the project objectives; collecting data; organizing and analyzing the accumulated information; and presenting the findings in both oral and written form. The project was instrumental in teaching the value and importance of the following: (1) close interaction and personal relationships between students and instructor; (2) collaborative efforts and teamwork among the students themselves; (3) organization and discipline; (4) time management and communication skills; (5) openness to research ideas and concepts; and (6) appreciation of the school's diverse curriculum. Finally, the overall goal was to encourage and teach the students how to think, plan, analyze, create, revise or improve what they create, and above all ask questions.

Introduction

This eight-week summer research project, also referred to as the Maybeck Chapel project, was undertaken for the following purposes:

- To engage undergraduate students in the research process
- To demonstrate how what they are studying, and learning can be put to practical use
- To teach the students the value of their chosen field and how it benefits society
- To evaluate the structural integrity of Maybeck Chapel, an historically significant structure that has been a campus focal point for 85 years

The work was performed by four undergraduate students representing each of the major engineering disciplines. One was a sophomore majoring in chemical engineering, and the other

three were juniors: one in civil engineering, one in mechanical, and one in combined architectural and industrial, but leaning toward industrial. The project team was rounded out by: (1) a Principia engineering instructor with expertise in structure monitoring and analysis, who also served as student advisor and project director, responsible for the day-to-day project operations, and (2) a Principia alumnus and business owner with expertise in image processing, coding and analysis, as well as artificial intelligence (AI), who served in a consulting and advisory capacity, suggesting techniques in image capturing and analysis using AI software.

During the course of the project the students were introduced to a typical Engineering Design Process [1] that can be used for conducting most any type of project. Since this process was being applied to a research project rather than a standard nuts and bolts engineering project, it served as a framework only and was modified to suit the purposes of both the research process in general and the Mayabeck project in particular. By adhering to this process, the students learned the intricacies of conducting research, such as:

- Defining the problem to be researched, along with objectives to be achieved
- Developing a plan for achieving the objectives
- Collecting and studying existing research information
- Developing a data collection method
- Analyzing the collected data
- Preparing and presenting periodic progress updates
- Formulating results and conclusions
- Preparing a final report and presenting the research findings

In short, these students got a taste of what it's like to work in the real world of engineering, through assigned responsibilities, organizing their workload, budgeting their time, working and communicating with others by sharing ideas and lending a helping hand when needed, getting involved with professionals in the engineering profession, and learning how to present their findings in both written and oral form. They also learned some of the economics involved with project development, especially when it comes to the thorny issue of prying loose the purse strings of college financial support. It was a lot to learn in a short eight-week period, but the students more than met the challenge, gaining the strength and confidence they will need for completing their degree, going on to graduate school, and dealing with the professional world beyond.

The Project

Since the Maybeck Chapel project involved a vertical structure, the research process focused on improving the methods and techniques by which vertical structures can be inspected and analyzed. This was accomplished by using unmanned aerial vehicles (UAVs) for collecting the

research data via high-resolution image capturing. While UAV technology has existed long enough to no longer be considered as “cutting edge,” it is becoming increasingly useful and valuable in structural analysis, removing the need for costly and often dangerous physical inspection of structures by humans. With this in mind, the concept was warmly welcomed and accepted by the student researchers, knowing they wouldn’t have to risk life and limb climbing scaffolds to visually inspect every crack and fissure in the roughly 450,000-cubic-foot chapel. The time savings alone was worth the cost of purchasing the UAVs, not to mention the “cool” factor of having a legitimate reason to fly a drone.

Maybeck Chapel, shown in Figure 1, was a good fit for this research. Completed in 1934, it is the oldest building on the Principia campus. Due to its age and the possibility that it might exhibit some structural defects like cracks, delamination, discoloration, etc., it is more than suitable for structural health monitoring, analysis and predictions.

Figure 1 - The Maybeck Chapel at Principia College

The drones used during the project were carefully selected, based on an extensive review of UAV literature [2] and products by both the students and the project instructor. Two DJI models were selected: the DJI Spark, shown on the left in Figure 2, and the more expensive DJI Phantom 4 Pro, shown on the right in Figure 2. As a note of interest, the logo in the lower right-hand corner of Figure 2 was designed by one of the students working on the project. ERA stands for Engineering Research Assistants, the actual title each student carried as part of the research team. Developing a logo for a graphic wasn’t one of the project requirements; however, it shows the

level of commitment these students made to the project and the amount of pride they had in being part of the research team.

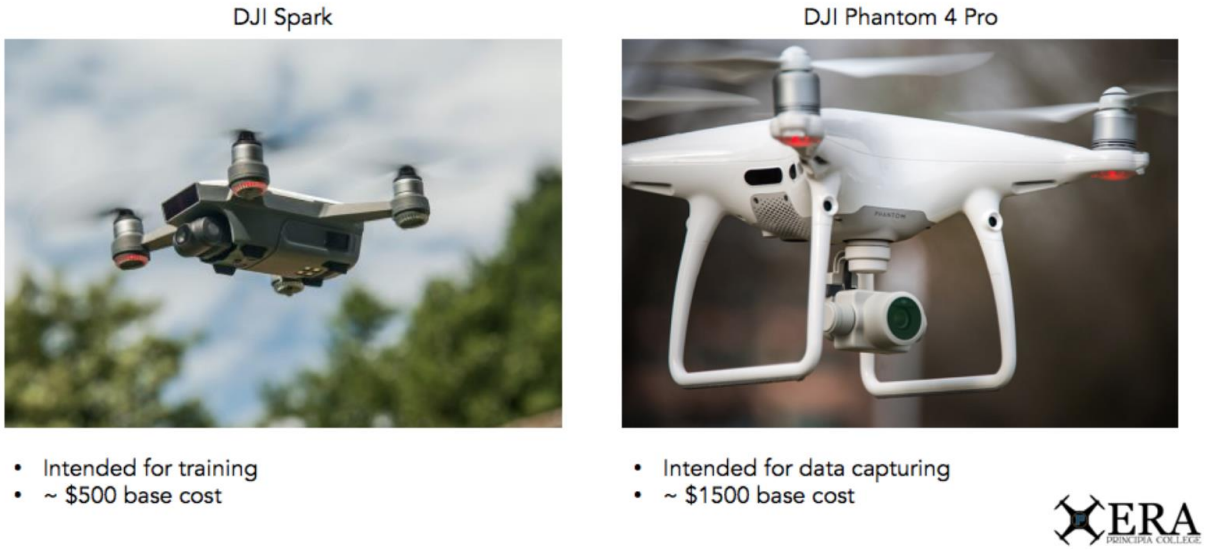

Figure 2 - Training and Data Capturing UAVs

During the drone selection process, the students delved into the intricacies of UAV technology and focused their attention on the flight handling characteristics, performance capabilities, and image capturing technology of the Spark and Phantom 4 Pro. Due to its better viewing angle and range, higher resolution, and longer running time, the Phantom 4 Pro was chosen for capturing the precise images required for detailed analysis, while the Spark was used for flight testing and training purposes. The students also studied and learned the details of FAA regulations pertaining to drone operation and gained first-hand knowledge of how to develop and compare various flight patterns for photo imaging.

During the eight-week research period, the students became proficient in operating the drones, capturing the photo images, correlating the raw data, and processing it for analysis and interpretation. They were greatly assisted in the image processing aspect by the Principia alumnus mentioned earlier, who owns and operates an AI business called Optar AI [3]. The students downloaded the captured digital images and transferred them to Optar AI for decoding by the company's software program. The result was production of clear, distinct, high-resolution pictures which could then be reviewed for detailed analysis of every crack or fissure, allowing for precise measurement of width, length and extent of spread.

Based on the images that were captured and analyzed, the chapel did show signs of minor limestone deterioration and discoloration which will require more detailed study and analysis at a later date.

Throughout the project the students kept track of their efforts through written notes and were required to provide periodic progress reports and presentations. Their work was also reviewed by the project instructor on a regular basis. At the conclusion of the project, they were required to compile their findings in a final written report and to give an oral presentation of the research results and recommendations.

The Students

As mentioned earlier, four undergraduate students participated in the Maybeck Chapel research project, representing each of the major engineering disciplines. These students worked long, dedicated hours to accomplish their tasks and fulfill their responsibilities to the team. They were exposed to situations, ideas and concepts outside their usual realm of experience; they studied, examined, explored and asked questions; and most important of all, they LEARNED.

Below is a first-hand account of one student's involvement with the project: a junior who at the time of the research was studying both architectural and industrial engineering, but who is now focusing solely on an industrial engineering degree. Her detailed account describes what she learned, how she felt about the overall research opportunity, and what her future aspirations are. As you will see, this student was highly qualified for the project and made a major contribution to its success.

I am currently an Industrial Engineering major in my junior year at Cal Poly SLO, and I plan on getting my MBA sometime in the future. I am considering doing the blended BS and MS Industrial Engineering degree here, but as of right now I am only pursuing my BS. My role on the SERA** team was to act as the lead research assistant/ project manager. I helped plan the [UAV] flight missions and made sure we followed our protocols correctly. I also documented a lot of our findings and initiated the relationship with Optar AI [Artificial Intelligence].*

From this research experience, I learned how to properly make flowcharts, how to present material clearly and concisely to those not in the same field, and most importantly how to manage a diverse team of intellectuals. I have always been passionate about leadership and optimizing systems and processes, and this research gave me opportunities to excel in both. In the future, I know I will be involved in management and leadership within the companies I work at because of how much I enjoyed it throughout my research at Principia. The presentation opportunities encouraged me to improve my public speaking abilities and solidify my visual presentation skills.

To me, the most fascinating component of our research was the opportunity to partner with and form a relationship with an up-and-coming image-analyzing artificial intelligence company. I feel that oftentimes [that] many companies or schools doing similar things see each other as competition, yet when we work together and pool the vast variety of knowledge we have, we accomplish so much more. The prospect of forming relationships within [the engineering] industry should be [of] huge interest to undergrads looking to do research because it gets your foot in the door and can lead to even bigger opportunities down the line.

I have many academic and personal life goals that stemmed from the education I got at Principia College (as well as from Cal Poly). Currently, my main academic interests are ergonomics, lean manufacturing, and sustainability/zero-waste. I hope that when I graduate, I can do something along the lines of...supply chain management and increasing productivity for a company that revolves around those academic interests.

* California Polytechnic State University, San Luis Obispo, CA
** Summer Engineering Research Assistant

Formation of the Student Team

Prior to starting the summer research, a proposal was submitted to the Academic Special Programs Office (ASPO) outlining all aspects of the project, including the number of undergraduate research assistants required. Due to the wide range of expertise needed to fulfill all of the project's requirements, the proposal requested that the students be drawn from each of the following major engineering fields:

- Mechanical: for the sophisticated operational components and capabilities of the UAVs
- Civil and/or Architectural: for the basic components of structural analysis, along with architectural analysis and design
- Chemical: for analyzing the chemical effects of any discoloration, degradation, etc. exhibited on the structure.

After the proposal was approved, one-on-one interviews were conducted with applicants having strong academic records in the fields of expertise just described. The students were asked about their interest in the project, based on their understanding of the project overview. They were also quizzed about their basic knowledge in their chosen field of expertise and how they felt this knowledge could be applied to the project. The applicants were informed that they would be part of a multidisciplinary team, working closely with students representing each of the major engineering disciplines. They were further advised regarding the necessity of interacting and cooperating with those whose background, experience and expertise differed from their own. Finally, the applicants were queried about their availability for the summer and whether they could commit to the entire eight-week project term. Once the interviews were concluded a final selection was made, the successful candidates were notified, and a team was formed. The rest is history.

The Teaching/Learning Experience in a Research Setting

As anyone involved in education knows, teaching and learning is a two-way street. Instructors not only teach their students, they often learn from them, too; and students not only learn from

their instructors, they sometimes impart information the instructors may not have known. From the start, the Maybeck Chapel project was a collaborative effort between students of different backgrounds and engineering pursuits, their instructor/advisor, and the AI consultant mentioned earlier. Being a former Principia student herself, the AI consultant was able to mind-meld with the students throughout the project, giving them insights on both a professional and student level. A strong bond of respect and understanding was forged among the entire team which contributed significantly to the research and the educational processes. Described below are some of the insights gained from both the teaching and learning aspects of this project.

- The instructor was impressed by the ease and speed with which the students learned the technological aspects and capabilities of the drones used for photographing the Maybeck Chapel. This was also a learning experience for the instructor who had to learn the UAV software components and make the bridge between the software and hardware communication systems. For instance, the drones (the hardware component) had to communicate with the control and interphase components (the software) for capturing and viewing the photographic images of the structure. Due to the students' rapid learning curve with this technology, they ended up providing the project instructor with insights regarding drone operation, image capturing, and image processing software that he didn't have previously.

- None of the students had ever been exposed to the steps involved with the research process. They had no clue where to start, how to start, what the process entailed, how to record and analyze the data, or how to report the findings. This was both a teaching and advisory opportunity for the instructor and a definite learning opportunity for the students.

- Despite their lack of information processing and presentation skills, the students quickly became proficient in using tools of the trade such as PowerPoint and Computer-Aided Drafting and Design (CADD) hardware and software. They benefited considerably from the instruction, guidance and advice received from their instructor.

- The students were exposed to the critical concept and realities of time management through having to meet strict deadlines, something with which they had little or no prior experience. During the research period, some of the assignments they undertook had very short turn-around times; some as soon as the very next day after starting them. The instructor was able to share his first-hand knowledge and experience in this regard, and the students demonstrated remarkable grit, dedication and determination in mastering the concept

- The students were excited about the opportunity of presenting their research findings and the possibility of having their efforts recognized through publication in technical journals or even public exposure in the media. This would be an unusual honor for undergraduate

students, since such exposure has traditionally been the realm of graduate students. Once again, this was a unique learning experience for the students carefully planned and monitored by the instructor.

- The students were impressed with the professional and technical knowledge the instructor and AI consultant possessed and shared, especially in regard to orchestrating the project and explaining the practical application of the work they did.

- The students were also excited about working with the AI company and forming a relationship with the AI consultant. In fact, the industrial engineering major whose comments were presented earlier said that this was "the most fascinating component of our research." This experience was a valuable "real world" learning tool for the students who will eventually be facing the challenge of dealing with outside consultants, vendors, joint-venture partners, etc.

- The students were more than happy and enthusiastic about being able to share certain information and things they knew that the instructor didn't. It made them feel like full partners in the undertaking and proved that no matter who we are or how old we are, we can always learn something new or impart knowledge to others.

At the conclusion of the project the students had a much better understanding of and appreciation for the research process and its value. This also carried over to their feelings for the instructor and AI consultant, and what it takes to plan, coordinate and carry out a project of this scope. The experience gave them the pride of knowing that they made a contribution to the research community. It also gave them the confidence that they can undertake any other research opportunity in the future. The instructor, especially, came away with a healthy respect for the willingness and capability these students possessed for undertaking challenges totally foreign to their educational and personal experiences prior to the project. The instructor also learned how to blend teaching with guiding and advising young minds, helping them to adapt to the realities of the adult world. And most important of all, both the instructor and the AI consultant learned to listen to the students, communicate with them as equals, share knowledge and experiences, and prove that undergraduate research is a worthy and worthwhile endeavor to be expanded and improved upon.

Presentation of Findings and Final Research Report

During the eight-week research period, the four research students conducted two oral presentations and prepared a final written research paper describing the project and its findings. This was done in compliance with requirements imposed by the Academic Special Programs Office (ASPO) at Principia College, which funded the Maybeck Chapel project. The ASPO

funds all summer research programs at the college, as well as other research or academic programs that fall outside the typical college curriculum.

The first oral presentation, given during the fifth week of the project, consisted of a project overview and a progress report of what had been accomplished up to that point. The second oral presentation occurred sometime around the seventh week and allowed the students to describe some of the available results of their research findings. These presentations were a valuable learning experience for these students, giving them the opportunity to compile and organize their findings, and to hone their presentation skills. It also gave them the opportunity to meet with engineering professionals and the general public, further improving their communication skills and directing a spotlight on the value of undergraduate research opportunities.

Throughout the project, each student maintained a portfolio in which was recorded the student's individual research assignments and a description of the work accomplished on each assignment. These portfolios were periodically examined by the project instructor/advisor and were collected at the end of the project for final review. The students also compiled a summary of their top ten assignments and the lessons learned from completing them. All of this information was then used to prepare a final research report that was submitted to the ASPO for review and approval.

Summary

Based on the preceding information, it is safe to say that this research project featured several distinctive aspects: 1) UAVs were used to capture photographic images which in turn were compiled into usable data for vertical structure analysis, 2) a multidisciplinary team of undergraduate research students, representing every type of engineering profession, participated in the project, and 3) the project was conducted at a small liberal-arts college, one of the few in the U.S. offering an engineering program leading to a four- or five-year engineering degree.

A lot was accomplished during the short eight-week time frame, providing invaluable research experience to the participating students. Each student was given 10 assignments to complete, as shown in Figure 3. As noted in the preceding section above, each student maintained a personal portfolio documenting every aspect of his/her work and involvement on the project. At the end of the project the student used this information to compile a summary of the assignments and the lessons learned from completing them. This information is depicted in Figure 4.

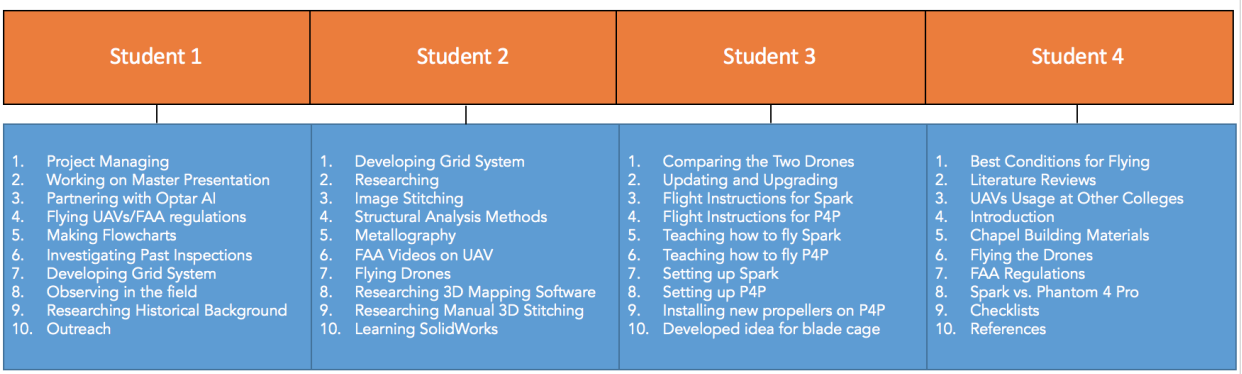

Figure 3 – Top Ten Assignments for Each Team Member

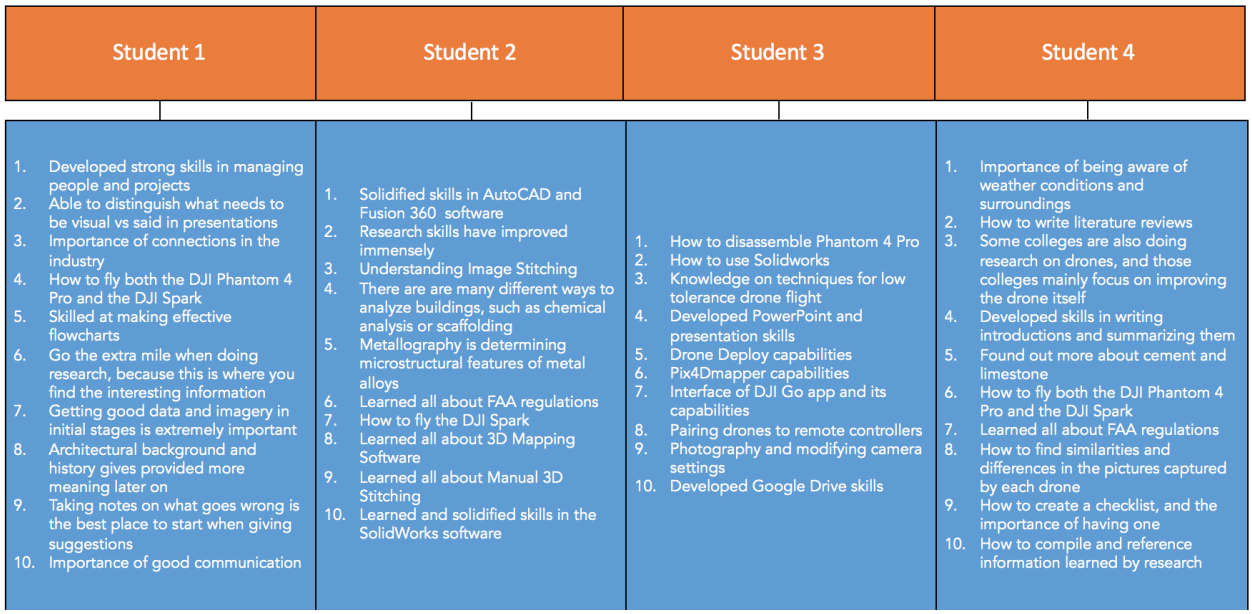

Figure 4 – Lessons Learned by Each Team Member

The lessons the students learned and the skills they developed are priceless assets that cannot be acquired through routine classroom instruction. This knowledge will remain with them the rest of their lives, helping them in all future endeavors, be it further research work or other educational or professional pursuits.

It should be mentioned that a second undergraduate research project will be undertaken in the 2019 summer session to further analyze Maybeck Chapel and to complete tasks that couldn't be completed during the short eight-week time frame in 2018. It will focus on segmental and still-image capturing, which can be used for analyzing cracks, delamination and corrosion in concrete structures. Image analysis software will be used to study these captured images to determine if Maybeck Chapel has any structural deficiencies. It is hoped that the four students who

participated in the 2018 project will return to apply their accumulated skills, knowledge and experience toward successfully completing this second project.

The concept of undergraduate research is one that hasn't become universally accepted or practiced so far, particularly in the United States. The reason is hard to pinpoint. Whether it's from a lack of time, interest, inspiration, money, etc. on the part of college faculty and administrators, or from a lack of interest or desire by students, is inconclusive. It could be both. Solving the first dilemma is a matter of internal communication, decision-making, and perhaps some arm twisting among faculty and administrators. Solving the second dilemma is a matter of getting the message out to students regarding the value and benefits of undergraduate research to their educational aspirations, inspiring and encouraging them to give it a try, and explaining how research benefits not only the students themselves but also the community at large.

The Maybeck Chapel project was a step in the right direction. Hopefully those involved in the project will spread the word, communicating what is possible when all the various factors come together for successfully conducting any type of undergraduate research.

Conclusion

Enough cannot be said about the value and importance of the Maybeck Chapel research project. It was a perfect fit for undergraduate research, bringing together students from four different engineering career fields who developed a disciplined, well-organized collaborative working environment and functioned as a well-coordinated team in completing assigned tasks and bringing the project to a successful conclusion.

The students were involved in every aspect of the project: identifying the main focus of the research; developing a plan and methodology for achieving the research goals and objectives; selecting and operating the UAVs that were critical to gathering the raw data, i.e., the photo images needed for analysis; conducting the analysis and interpreting the results; and presenting the findings. They did a lot and they learned a lot in a short period of time.

Their hard work paid off in practical terms, certifying that Maybeck Chapel is structurally sound, but also identifying certain areas of concern for further investigation in a future research project. Their efforts also paid dividends in the knowledge and experience gained from the many tasks and responsibilities they undertook. They can be proud in knowing that what they did on this project was a mirror image of what they will be doing and facing in the real world. In fact, this project could just as well have been something a paying client would have requested, expecting the same high-quality work and results.

Overall, these students came away from the project with a working knowledge and basic understanding of many components of the Engineering Design Process, learning how to:

- identify the problem,

- research existing literature,
- select and develop a project approach,
- test, evaluate and operate the project equipment; i.e., the UAVs and image-capturing apparatus,
- operate the project software program,
- analyze and evaluate the accumulated data, and
- formulate and communicate the results.

They also learned how to think logically and analytically, organize their time and efforts, work with and interact with a variety of different personalities and temperaments, and use their communication skills, both orally and written.

In the final analysis, the Maybeck Chapel research project was an unqualified success. However, it also involved a few challenges, mostly from funding and project management aspects. These need to be pointed out so that others contemplating a similar venture can be aware of the situation and plan accordingly. These challenges are described below.

Funding: Funding for the project was provided by the college's Academic Special Programs Office (ASPO). While the money was helpful, it was also very limited, due to the fact that the office is responsible for funding all summer research projects at the school, which totaled 10 during the summer of 2018. The funds were enough to cover project materials, equipment repairs and weekly compensation to the four participating research students. However, there was no funding at all to pay the $250 cost of the FAA-required flight instruction and tutoring and the $250 examination fee for the pilot's license, both of which are necessary for becoming a qualified UAV pilot. Ultimately the expense was met, but it had to come from the faculty advisor's department budget. Consequently, he was the only one who had the means for the required funding for a certified UAV pilot's license. Originally it was hoped that at least two of the four students would become pilot certified; so, this is an area that needs to be addressed for special funding in the future.

Research Time Frame: The project was limited to just eight weeks, since this was the maximum amount of time the ASPO would compensate the four research students. At the end of the eight weeks it was estimated that 10 to 12 weeks would have been more appropriate, due to the amount of work to be done and the complexity of doing it. In fact, research of this nature could conceivably go on for several semesters or even a couple of years. Therefore, planning for similar future projects should take this into consideration when dealing with both time frames and funding.

Task-Dependent Project: This means that one specific task had to be completed before another task could begin. So instead of working independently to complete his or her own assigned tasks, the students helped each other to complete the first task that had to be done, then moved on to the next task and so forth until the project was completed. While this wasn't exactly a time-saver, the lessons the students learned in regard to teamwork and task coordination were

invaluable. And for future endeavors, this aspect needs to be factored into scheduling and time constraints.

While these challenges weren't insurmountable, they indicate the high degree of planning and organization required for successfully completing a research project of any kind. On a positive note, the challenges described above were mitigated to some extent by the advantages of undertaking such a project at a small liberal-arts college, versus a large, highly structured and often intimidating four-year engineering university. These advantages included:

- a more relaxed campus atmosphere;
- more direct and easier access to administrative personnel who oversee project approval and financing;
- better interaction and closer relationships between students and instructors;
- closer student relationships, due to smaller enrollment in the engineering program and the college as a whole; and
- a more open-minded student attitude toward research ideas and concepts, resulting from their exposure to the school's diverse curriculum.

Based on the outstanding results of this project, it's easy to see the value and importance of undergraduate research. The Maybeck Chapel project was a trial balloon for Principia's engineering program; and the positive student response and sound engineering and research practices demonstrated during the eight-week session prove that the program is on the right track. With this experience under the belt, more and better research projects can be planned and undertaken by the college in the future and will hopefully attract more student participants. It is further hoped that Principia's success will inspire other small colleges to pursue similar undergraduate research endeavors.

References

[1] S. Khandani, "Engineering Design Process," Saylor, Pleasant Hill, 2005.

[2] "Shakhatreh, H., Sawalmeh, A., Al - Fuqaha, A., Dou, Z., Almaita, E., Khalil, I., Othman, N. S., Khreishah, A., and Guizani, M.," Department of Electrical and Computer Engineering, New Jersey Institute of Technology, Newark, 2018.

[3] A. Mackenzie, "Optar AI," Optar AI, 1 January 2018. [Online]. Available: https://www.optarai.com/. [Accessed 5 April 2019].