Drones for a Project-Based Learning (PBL) Capstone Design

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Stephen Wilkerson (swilkerson@ycp.edu) received his PhD from Johns Hopkins University in 1990 in Mechanical Engineering. His Thesis and initial work was on underwater explosion bubble dynamics and ship and submarine whipping. After graduation he took a position with the US Army where he has been ever since. For the first decade with the Army he worked on notable programs to include the M829A1 and A2 that were first of a kind composite saboted munition. His travels have taken him to Los Alamos where he worked on modeling the transient dynamic attributes of Kinetic Energy munitions during initial launch. Afterwards he was selected for the exchange scientist program and spent a summer working for DASA Aerospace in Wedel, Germany 1993. His initial research also made a major contribution to the M1A1 barrel reshape initiative that began in 1995. Shortly afterwards he was selected for a 1 year appointment to the United States Military Academy West Point where he taught Mathematics. Following these accomplishments he worked on the SADARM fire and forget projectile that was finally used in the second gulf war. Since that time, circa 2002, his studies have focused on unmanned systems both air and ground. His team deployed a bomb finding robot named the LynchBot to Iraq late in 2004 and then again in 2006 deployed about a dozen more improved LynchBots to Iraq. His team also assisted in the deployment of 84 TACMAV systems in 2005. Around that time he volunteered as a science advisor and worked at the Rapid Equipping Force during the summer of 2005 where he was exposed to a number of unmanned systems technologies. His initial group composed of about 6 S&T grew to nearly 30 between 2003 and 2010 as he transitioned from a Branch head to an acting Division Chief. In 2010-2012 he again was selected to teach Mathematics at the United States Military Academy West Point. Upon returning to ARL's Vehicle Technology Directorate from West Point he has continued his research on unmanned systems under ARL's Campaign for Maneuver as the Associate Director of Special Programs. Throughout his career he has continued to teach at a variety of colleges and universities. For the last 4 years he has been a part time instructor and collaborator with researchers at the University of Maryland Baltimore County (http://me.umbc.edu/directory/). He is currently an Assistant Professor at York College PA.

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Andrew completed his Bachelors in Mechanical Engineering and Management (Business) at McMaster University in 2006. In 2011, he completed his Ph.D. in Mechanical Engineering at McMaster in the area of estimation theory with applications to mechatronics and aerospace systems. Andrew worked as a post-doctoral researcher at the Centre for Mechatronics and Hybrid Technology (Hamilton, Ontario, Canada). He also worked as a Project Manager in the pharmaceutical industry (Apotex Inc.) for about three years. Before joining the University of Guelph in 2016, he was an Assistant Professor in the Department of Mechanical Engineering at the University of Maryland, Baltimore County. Andrew worked with a number of colleagues in NASA, the US Army Research Laboratory (ARL), US Department of Agriculture (USDA), National Institute of Standards and Technology (NIST), and the Maryland Department of the Environment (MDE). He is an elected Fellow of ASME, is a Senior Member of IEEE, and is a Professional Engineer of Ontario. He is also an Associate Editor for the International Journal of Robotics and Automation and is a reviewer for a number of ASME and IEEE journals and international conferences. Andrew earned the 2019/2020 University Research Excellence Award for the College of Engineering and Physical Sciences based on his research activities at the University of Guelph. He is also a 2019 SPIE Rising Researcher award winner based on his work in intelligent estimation theory, and a 2018 Ontario Early Researcher award (ERA) winner based on his work in intelligent condition monitoring strategies. He was also awarded the 2019 University of Guelph Faculty Association (UGFA) Distinguished Professor Award for Excellence in Teaching in the College of Engineering and Physical Sciences.

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I am a PhD student focusing on Intelligent Systems at the University of Guelph under my advisor, Dr. Andrew Gadsden. I did my undergraduate degree at the University of Maryland, Baltimore County (UMBC)

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In this paper, we examine the learning objectives of building drone aircraft for a variety of uses. We detail some of the design and learning challenges that the students take on and the results of the student's efforts. This course is formulated for project-based learning (PBL) and self-regulated learning (SRL). In particular, the program is a Capstone Design 2-semester course that additionally has an Accreditation Board for Engineering and Technology (ABET) design and build criteria as a requirement. Completion of this project is a requirement for graduation, and students usually take the capstone design course in their senior year. For this particular capstone design, most of the topics covered are outside of the student's comfort zone and require research and decision making to arrive at a final project. We examine student motivations and difficulties. Students were allowed to set their own goals and timelines within the constraints and requirements of the project. In this paper we detail the requirements for this past year and the paths the students took. We examine the team interactions and final outcome and how this impacts their long term thinking and approach. The process of how we evaluate their learning activities as well as how they rate one another's efforts is also detailed.

Introduction

This paper details the outcomes of the work done by engineering students in a 2-semester capstone design program. Semester one is in the summer with the following semester in the spring prior to graduation. In between these two semesters is a co-op program where the students work for engineering companies in the greater York area. These students are mechanical, electrical, and computer engineers, and computer science majors. Students are given the choice between Baja, Formula, and Community-based service capstone design projects. The Formula and Baja programs are highly structured and have students focus their attention on specific sub-projects within the scope of the overall effort. Additionally, the Baja and Formula students usually have strong backgrounds in the area they will contribute. On the other hand, the Community based capstone design programs are more random and may incorporate technologies and sciences that are completely outside of the student's comfort area. For these programs, student motivation and Self-Regulated Learning SRL [1,2,3] are paramount. In all of the programs the requirement of design and build are part of the ABET[1] criteria. This paper focuses on a Drone project intended to help farmers better understand their fields and crops and the effects their best practices are having on the environment. Our experiment is an ongoing endeavor and will begin its 4th year at the start of the 2020 summer. The capstone design is a 2-semester program. Complicating this program is the issue that the semesters are separated by a *Co-op*[2] semester long requirement in between. The program begins in the summer semester and completes in the spring with students being off campus for the fall.

The program is multidisciplinary in nature drawing from mechanical, electrical and computer engineering curriculums. When this program began, there were more electrical and computer engineers than mechanical. However, in recent years this ratio is typically 50-70% mechanical engineers and a mixture of electrical and computer engineers. The computer and electrical engineers tend to gravitate toward working on control and electronic issues while the mechanical engineers focus on aircraft design, aerodynamics and experimentation. For the multispectral analysis there is usually an equal mix from both groups.

While the traditional capstone design projects (Baja and Formula) provide established goals and a very structured environment, the program is quite rigorous and requires a considerable commitment of time and effort. For some students this makes the alternative community-based programs more attractive. However, the grading process for the capstone design is the same for both. The capstone programs are evaluated in several criteria shown in Table 1.

Weekly Notebook Entries	10%
Weekly Progress Reviews/Demos	15%
Milestone Presentations & Demos	20%
Summative Technical Report	20%
Capstone Expo Poster	5%
Effectiveness in Engineering Team and Professionalism	30%

[1] ABET is a nonprofit, non-governmental agency that accredits programs in applied and natural science, computing, engineering and engineering technology, https://www.abet.org/accreditation/

[2] Coop is short for the cooperative agreement we have with business partners in the area who hire our engineering students for a semester to help them solve their real-world problems

Peer review: multiplier

Table 1 Capstone grading rubrics

Students are to keep a notebook of their work that is reviewed bi-weekly. Weekly presentations are done by the students, usually in groups or teams to provide a progress report. These also allow the instructor and other teams to see what is being done while helping resolve problems and technical problems as they occur. Milestone objectives are typically set by the students giving them specific time goals as well as allowing them the opportunity to manage the outcome of their project. Effectiveness in engineering team and professionalism grades are provided by the instructors. However, the peer review by the other members of the project is a direct multiplier and is also important. All students are required to provide a peer multiplier for all other students as well as themselves and these scores are summed and normalized before multiplying their total score. Interestingly, students who are most critical of their peers are usually equally critical of themselves. Sometimes students putting in considerable extra effort can be highly critical of their peers if they feel that anyone has not performed enough work or contributed to the group as a whole. On every capstone project where there are enough students to have teams this becomes a factor that can result in a student repeating the course and staying at the school for an additional year. Nowhere is this truer than with the traditional car capstone projects and students are well aware of this. None the less, as the Drone capstone has grown in popularity so has the pressure to perform or be negatively judged by the other students.

Wilkerson et. al. [4,5,6] details some of the technologies required to build a drone program. Goldberg et. al. [7] discusses the level of student-centered learning and the role of the student in their own education. We also use a model similar to the Goldberg model where the instructor takes the role of a facilitator in student learning. These techniques require collaborative, cooperative, problem/project-based learning. Dunlap et. al. [8] further points out how PBL is an “apprenticeship for real-life problem solving” and this approach sets up the student for success in their future engineering careers.

While the students set objectives (with guidance), the drone project allows for latitude in purpose and outcomes. Important in the drone project is the requirement necessary to develop a drone platform for gathering data. To help better understand this aspect of the program, a brief review of the goal of the program and the technologies required are provided. Students are required to set goals, milestone events, and self-assess their own progress. As in life they will need to self-assess how successful they were and how things might be done differently next time. We also require them to help the incoming class on the same project each following year in order to continually improve. While the project as a whole is an example of PBL, so are each of the subtopics within this project. The outgoing students also provide faculty with suggestions and recommendations for subsequent classes. The faculty in its role as facilitator, provides oversight and evaluation that includes observations of the student professionalism. By and large the topics and goals of this program move the students outside their typically academic comfort areas, but not always. There are numerous examples, but the examples described below are typical of the topics that are covered.

Multispectral analysis of crop health is paramount to this program. Nowhere in a typical ME, CE or EE curriculum are they even exposed to these topics. These PBL topics include, cameras, drone use, farming practices, and other technical skills. Not surprisingly, they need to read papers on these subjects and research how other professionals are tackling these difficult topics. When using software or developing their own software techniques, they can utilize numerical analysis, computing skills, statistics, calculus, physics and other subjects they have been exposed to in-class. Nonetheless, this is a growth area for the typical student and moves them out of their comfort zone. Each of these PBL topics must be researched, mastered and used to solve the overall goal of the project to help farmers with meaningful data analysis. No less important are the fundamentals of SRL clear, than when students decide how much information is enough to make an informed decision and then move the project forward.

Another example uses the efficiency of the aircraft. Many aspects of the design affect the aircraft's efficiency. For example, the weight, lift and drag related to the surface area and its roughness are among areas that can be researched, as well as the batteries motors and props. Last year's group decided for the later and needed to learn how to test and analyze motors, props and batteries. They latter built an experimental apparatus and purchased specialized software to look at the batteries, props and motors. Students really had no background in the area of motor efficiencies or prop design. In contrast, this year's team spent more time on Computational Fluid Dynamics (CFD)[3] analysis and less on testing. because the students already had experience doing CFD in our lab with our wind tunnel. In both cases the faculty did not specify or push the students in a particular direction, but rather acted as passive observers and advisers. Assessing these outcomes is discussed in the student outcome section.

Background on Project Requirements

In the first year of the project, the idea was to design and build a drone that could use a multispectral camera to image a farm crop. In particular, corn was chosen as the primary staple. Corn is abundant in the geographical area of the college and no others were doing drone multispectral surveys in the area. Corn needs nitrogen via chemical fertilizers and urea (ammonium nitrate) is used more often than not. This is a major expense for the farmer as supported by the research indicated that multispectral analysis was being successfully used to reduce this expense for farmers. Not surprisingly there are numerous nitrogen studies in the literature, we reference only a few here [9,10,11].

For a large farm of 1000 acres of corn, the farmer will apply nitrogen twice during the season at about 100 pounds per acre per application at a cost of ~$100.00 per acre. If we could reduce the use of nitrogen while maintaining the same yield by say 10%, we could reduce the farmers costs by twenty thousand dollars. While that reduction does not seem like a lot, the average farm acre produces only about 180 bushels of corn per acre and at that time the cost of corn was approximately $3.60 a bushel or less than $650.00 gross per acre. With the costs of fuel, fertilizer, pesticides, and harvesting the profit margin on an acre of corn is marginal at best, thus cost reduction results in increased profit.

This was the goal of the capstone design! All that was needed after goal development was to design and build an aircraft to gather the data and figure out how best to help the farmers. The

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[3] Computational Fluid Dynamics (CFD) is a technology for quickly and accurately solving complex fluid flow and heat transfer problems computationally:
https://scholar.google.com/scholar?q=computational+fluid+analysis&hl=en&as_sdt=0&as_vis=1&oi=scholart

initial plan was to achieve our final goal of helping farmers over a period of 3 years or 3 capstones. The progression of the capstones has developed into these PBL sub topics:

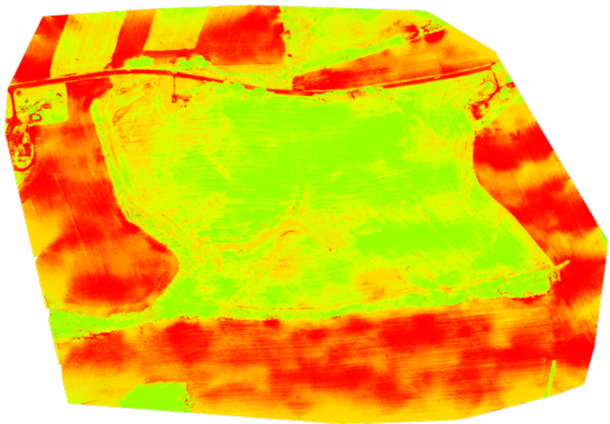
Year	Number of Students	Goals
Year 1	7	• Understand corn and farm best practices. • Design and build a fixed wing aircraft to do mission. • Demonstrate capabilities. • Transfer knowledge to next group.
Year 2	12	• Obtain farmers to work with. • Continue researching corn, gather data. • Master multispectral analysis. • Design and build multiple fixed wing aircrafts types. • Increase efficiency (props and building a battery). • Use 3D technology to help York Water with Dam Project. • Investigate building our own camera. • Make system fully autonomous. • Demonstrate capabilities. • Transfer knowledge to next group.
Year 3	14	• Communicate findings to farmers. • Master other multispectral analysis capabilities. • Count crops to help farmers. • Design and build multiple fixed wing and multi rotor aircrafts types. • Build RTK GPS system for better accuracy. • Conduct soil tests to help gain ground truth. • Build 3D images and topography. • Gather data and use existing systems to further requirements and capabilities. • Demonstrate capabilities. • Transfer knowledge to next group.
Year 4	TBD	• Under development?

Table 2 Major student goals by year

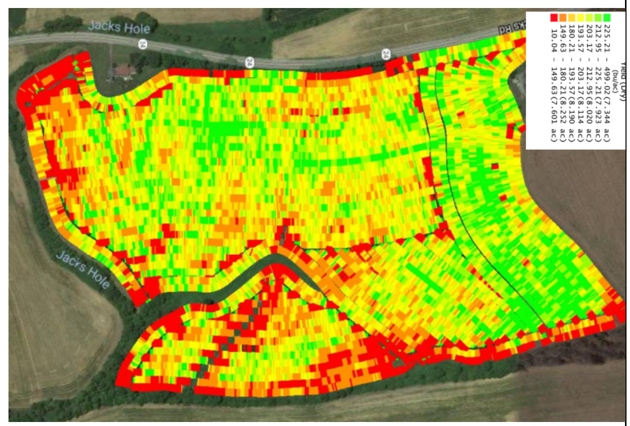
The mission drift[4] has been a natural development as we learn what is needed to provide meaningful data to the farmers. A brief discussion here will contribute to understanding of student outcomes (Discussion in final section) we observed during our 3-year study. As it turned out corn was not a stand-alone crop. Most farmers rotate corn with soybean and winter wheat annually. In many cases, winter wheat is used for cover between soybean and corn and is killed with glyphosate in the spring before the corn is planted. In the first season our analysis showed

[4] Mission drift references refers to the tendency to solve problems outside the stated goal.

promising results for understanding the influence of nitrogen in corn. Figure 1 shows a comparison between crop predictions found using multispectral analysis and an NDVI[5]



NDVI Image



Harvest results

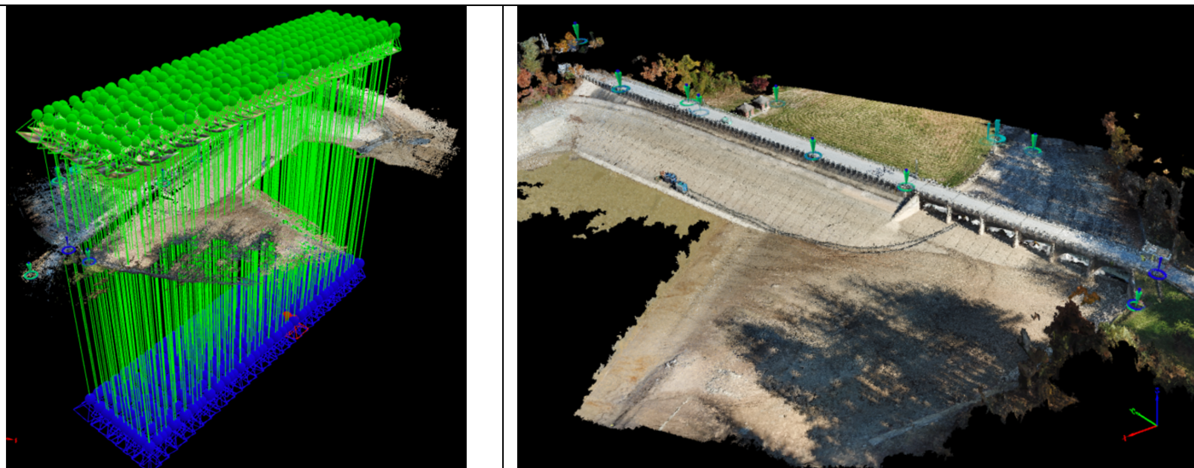
Figure 1 Comparison of HDMI shortly after emergence and harvest Blue Valley Farms

plot and the yield results from that same field during harvest. The results look promising. However, some interesting details were discovered during the process of obtaining these results. The students quickly realized that we did not have the software or all of the tools we needed to reach the original goals. This in part resulted in the modification of the original end goal to keep with the ABET requirements while still contributing toward the end goal. Year 2 students adopted sub goals to improve the aircraft design efficiency and image accuracy, all of which will benefit the end goal of helping farmers while meeting the ABET requirement of design and build.

Other opportunities for drone technology were also found during this project. One such application that can be done with drones is aerial photography (i.e. is the ability to make a 3D image). This was another PBL opportunity that required students to research and develop requisite skills in spite of little or no prior knowledge of the technology. These aerial images are very accurate and can be used to estimate volumes and produce survey maps. A service opportunity occurred in the second year of the project where participants could help the local water works company. The water works company was draining a reservoir to replace a drain and the dam needed to be strengthened at the same time. The project's surveyors needed accurate data on the topography around the dam. Since the dam's face had been underwater for nearly 100 years the topography was not well known. Once the reservoir was drained the terrain was exposed and aerial photos were taken. The results of the aerial survey produced very accurate comparison points, but poor predictions of exact locations. To remedy the inaccuracies, surveyor points can be included in the analysis and the accuracy becomes acceptable to the surveyors. Figure 2 shows how the image was adjusted using the surveyor points. Prior to the adjustment our image was shifted about 6 feet in the horizontal and due to an error in the drone software 100 feet or more in the vertical. After the adjustments we were able to obtain accuracy of roughly ~1

[5] "**NDVI** is a common measure in remote sensing for **agriculture** capturing how much more near infrared light is reflected compared to visible red. It helps differentiate bare soil from grass or forest, detect plants under stress, and differentiate between crops and crop stages." See: https://blog.mapbox.com/visualizing-ndvi-for-agriculture-ad35d7c5f27e

inch. Figure 2a shows the adjustments in the vertical while figure 2b shows the final image and the surveyor points. The surveyor points are broken into two categories, ground control points and check points. Ground control points are required to adjust the images exact position and check points are used to estimate the error of the process. Typically, 5 to 10 ground points will allow a very accurate image to be produced and 5-7 check points are used to assess the accuracy. The surveyor equipment required to get these points is very expensive and beyond the scope of the project's budget to purchase. For the Dam project the students were reliant on the surveyor to provide these points and unfortunately it was difficult to schedule doing the points and flights together. Therefore, the students in the third year are developing an RTK GPS[6] unit. This RTK unit and



(a) (b)

Figure 2 a) Adjustment in altitude b) surveyor points

ground markers will benefit future surveyor projects as well as the farm project for corn. The unit has a ground station and a roving device. The roving device is shown in Figure 3 and consisted of the RTK unit, an Arduino controller, communication links, and a 3D printed case.

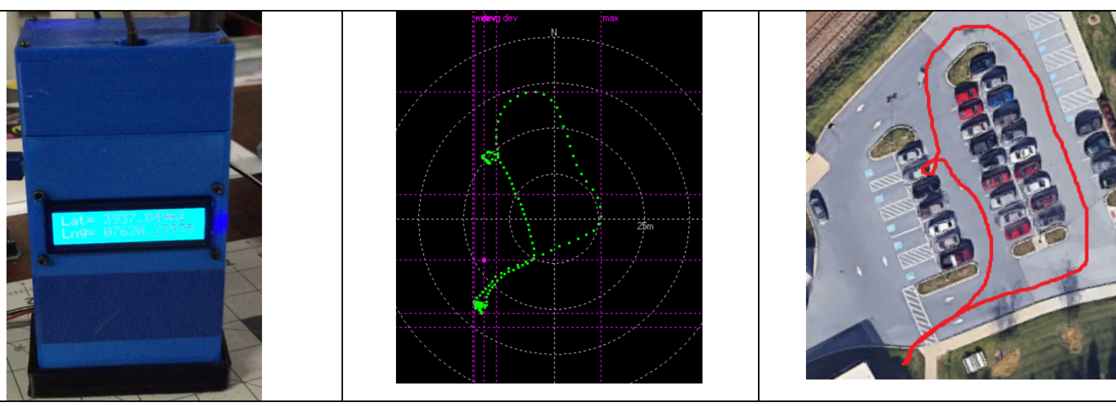


Figure 3 GPS roving unit

[6] RTK stands for Real-Time Kinematic. The system provides accurate ranges and positions that are orders of magnitude more precise than what could be found on from a cell phone or other low-end device.

Figure 3 shows some results from the initial experiments using the RTK ground and roving stations. The accuracy of the unit is evident from the figure. A series of precise experiments will be performed by students in the coming months to get a more accurate estimate of the unit's average accuracy and to develop best practices in its use. In all there were numerous opportunities for the students to contribute to the project in a meaningful way while meeting the design and build ABET criteria. Another example involved students building their own battery systems. Experiments proved that the weight to energy ratio they were able to obtain was about 1.85 that of a normal lithium polymer *Radio Control* commercial battery. There were numerous sub PBL topics[7] within the overall goal that could be cited here, but the main focus of this paper is to highlight a few of these accomplishments and then discuss the results in terms of student outcomes in the next section. One of the questions we are trying to assess is how these activities help the students in their future career?

Student Outcomes

Krajcik et. al. [12] points out that a focus on learning through investigation is key to PBL. The structure of the Capstone project is such as to is such as to facilitate opportunities for group and individual investigations and research. With the Formula and Baja teams this is very straight forward; they are broken into teams and each team determines what new feature they might investigate and try to incorporate into the design. For example, the frame team needs to build a frame for the car. However, they may want to look into a better suspension system than the previous year's team. With the drone capstone we (students and faculty) had no knowledge of how drones for agriculture were designed and built. This was in part why we structured our goals so that it would take multiple years to have a complete program from designing and building to actually help farmers. In the first year we knew we needed a multispectral camera. That alone took up ½ the total budget for that particular year. They also knew that they needed to design and build an aircraft to fly the missions. It was important to initially research was what had other people done and how did they do it[8]. In the first year the summer semester research and design spilled over into the second semester where building and testing were to be the focus. Nonetheless, the students did organize the efforts into 4 focused areas for future years. These categories included multispectral analysis, drone design, autonomous control, and an FAA licenses to fly the drone. All of these topics where dominated by the need for research skills and the ability to solve an unknown problem. Without question, key to this program is the need for investigation, research and experimentation as is pointed out in [12].

Further, Krajcik et.al [13] discussed pedagogical and or psychological motives, student motivation and outcomes. This was found to be individual based. Not every student that chooses one of the community-based service projects was really committed to community service. Their choices may have had more to do with not wanting to work on cars than the project as a whole. The Drone program is no different. Just the same, one observation that persisted was during the student's final presentation. They had pride in what they learned and what they had accomplished, and they wanted to talk about it to others. We typically invite our industry partners in to view and critique the projects. Even the most reluctant learner throughout the year will present their work with a healthy degree of pride. If for only that reason, one would describe PBL as a success. Moreover, students are more than willing to help the next year's

[7] Subtopics include 3D maping, making our own camera, gps research and the like.

[8] Most agriculture programs purchase a commercial drone and gather data using that platform's software and hardware. We had a design and build criteria so that approach wouldn't work for us.

team get up and started even though they have little time for it in their final summer semester before graduation[9]. This has proven invaluable for the progression of the project and the originally stated goals.

Nelson et. al. [14] discusses how better to achieve success using 3 tier criteria: on time, within budget, and, meets goals. Certainly, this is a criterion for success, but it might be argued that it is seldomly achieved. One area of discussion in any capstone project might be what constitutes a successful project? Do we need complete success for a student to have learned from the process? Does meeting the goals constitute pass versus fail? The capstone design program in this paper uses a number of time constraints to provide the students with a framework for success. The budget[10] is more or less rigid, they only have a certain amount of funds. However, most projects including the well-structured car competitions seldomly meet goals or requirements to anyone's complete satisfaction. There is always more to do, something that failed and usually something that succeeded. Is PBL more applicable to a teachable moment in the development of the students and faculty? It has often been said that students learn more from failures than successes. In both regards PBL builds character and reinforces problem solving skills that will serve engineers throughout their careers. Failures with drones more often than not result in loss of aircraft and force students to rebuild. What has been observed is that when this does occur the results are far more beneficial than the time lost rebuilding the drone. Usually students will adopt new strategies that prevent future failures. They will almost always improve the last design in the second or third iteration further proving the value of spiral development. As this occurs it is evident that the prototype is improving in appearance, reliability and functionality.

Yeung et. al. [15] suggests that students move toward independent learning as a result of problem-based learning. Hmelo et. al. [16] further points out that students often leave school without the skills for Life Long Learning (LLL) and Self-Directed Learning (SDL). This capstone program coupled with 3 co-op work study semesters goes a long way in addressing this limitation of a traditional engineering program. In the drone program, there is structure provided for evaluations and course corrections throughout the year. However, we do not seek to dictate the absolute focus of each team's efforts during the course of the year. This also leads to a certain amount of mission creep while resulting in functional accomplishments when the end goal remains just out of reach. Faculty usually makes recommendations to the students. Students will sometimes follow the directions and other times go their own way. Additionally, students will come up with their own goals during the year. Examples of this are frequent with the airframe design, but occasionally ideas like building their own batteries are pursued. The independent battery design idea seemed a bit far-fetched to the faculty but proved to be very important. After a few spectacular failures the battery pack was dramatically improved with little or no input by faculty members. The final battery pack was based on batteries similar to those used in a *Tesla*[11] automobile.

In summary, data is taken using bi-weekly reports, a final technical report, presentations, milestones, a professionalism assessment and the peer multiplier performed by the students. As

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[9] Student at this school graduate at the end of the 4th year summer semester so there is overlap between the incoming seniors and graduating seniors.

[10] Fun raising has inevitability been done in our capstones b
y both faculty and students, but this drains energy and time from the technical issues and problems of the project. None the less, costs remain a driving factor in all of the school's capstone projects.

[11] Tesla is an electric automobile company founded by the eccentric billionaire Elon Musk: https://www.tesla.com/

the educators become better at the process our results become more conclusive. The overall goal is to provide the students with a project that they research, organize, design and build. This provides students opportunities for self-assessment component of their education not found in traditional course work. Mokhtar [17] et. al argues that PBL has been shown to be one of the most effective tools in an engineering curriculum. He further states that PBL is a student motivator and seems to be well suited for upper class programs. We have certainly seen similar results, but not without outliers. For our program the structure and evaluation program has grown and become more focused. Several notable evaluations are the peer review, program rollout, and professionalism observations. Peer review is critical to the development of young engineers who will quickly find themselves presenting materials to colleagues, management and their peers for adoption. Failing to win the argument for an approach will result in their work not being use, while winning the arguement will result in the responsibility of the outcome. Both build character. The program rollout review is done by our industry partners. For at least the drone program many of our students end up working in the industry as a result of this program. We have Textron[12], BAE[13], the US Army, Sechan[14] and Service[15] engineering all within a 2-hour drive of the college. Professionalism is an observation by faculty and a partial assessment of the student's growth. This measure has gradually improved over the past 3 years. While job offers have not been tracked by the school, they are a good measure of our success and without question our graduates are hired by our industry partners in large numbers.

Conclusions

As our drone program matures it is evident that the end goal is in sight. In this paper, we examined the learning objectives of building drone aircraft for a variety of uses. The program increased in scope as both faculty and students discovered areas that needed further research and development. In many cases we simply didn't know that certain things needed to be done to facilitate the building of a drone for agriculture. At the foundation of the capstone design is life-long learning and self-regulated learning. As the literature shows these skill sets are well suited for project-based curriculums. Students benefit from these problem-solving traits and our graduates are in demand in the local area manufacturing sector.

As stated, this capstone requires research and knowledge in areas well outside the normal course curriculum for an engineering student. In doing this the students are forced to research/investigate best practices and design a drone for the purpose of agriculture research. During the course of study, opportunities to use drones for other purposes also presented themselves and the students were able to adapt their work to accommodate these activities. Student motivations are always an issue for some students, but PBL seems to help motivate students to contribute. Peer reviews also seem to be a concern for most of the students. Team interactions and final outcome appear to influence their overall effort and approach. Students are evaluated based on their performance as detailed in Table 1. However, student outcomes are largely dependent on themselves and how they interact with other students. In other words, they get out of it what they put into it.

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[12] Textron is a company that produces a host of military systems: https://www.textronsystems.com/
[13] BAE is a international company focused on a variety of engineering products: https://jobs.baesystems.com/global/en
[14] Sechan electronics also produces a wide variety of engineering products: https://www.sechan.com/
[15] Service engineering provides a host of engineering products to include drones for customers: https://www.serviceengineering.com/

For our efforts the approach appears sound. As the program matures the faculty and student body are becoming willing to tackle more ambitious projects. For example, students have started pitching capstone programs that are far better suited for schools with robust graduate programs and larger funding profiles. One such example that is likely to be adopted is for a prosthetic limb program. The drone program is also designed along similar constraints. While it is possible to purchase drone products and focus merely on data gathering our program has an ABET requirement of design and build that broadens our focus and lends itself to a PBL and an SRL approach.

Work still exists in getting farmers confident enough in the data that they are willing to change their current best practices. Farmers are most definitely creatures of habit and are heavily tied into the large agriculture companies that supply their GMO[16] seed, pesticides, herbicides, fertilizers and best practices for their fields. Farms operate on thin margins and getting the farmers to try different methods will be the biggest challenge of this capstone design. In the meantime PBO has proven beneficial for this particular capstone design project. Students will begin delivering data to the farmers for consideration this season.

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