Project Based Capstone Design Projects Amidst Covid-19 Restrictions

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by Stephen Wilkerson

During the past three semesters, the COVID-19 pandemic has brought about unprecedented changes and restrictions on how courses are taught at U.S. colleges. In particular, courses that heavily depend on labs and hands-on learning activities have been radically affected. This paper examines how faculty and students in the engineering and computer science capstone course at York College in York, PA, have dealt with some of these changes and restrictions while attempting to preserve course objectives and Accreditation Board for Engineering and Technology (ABET) goals.

In the spring of 2020, most colleges transitioned from in-class instruction to online instruction in about 1 week. For Project-Based Learning (PBL) courses, such as the engineering and computer science capstone course at York College, this transition meant leaving some projects half-built and others completely unfinished. These unfinished projects included the Baja and Formula capstone design projects and other community-based initiatives. The spring of 2020 also represented the end of a 1-year capstone program. The spring semester was one-third complete when the COVID-19 interruption occurred and forced a combination of in-class and online instruction. The subsequent summer semester (which was the beginning of the next year's program) was conducted entirely online. Both semesters, of course, posed a new set of challenges for both instructors and students. The final spring semester had additional restrictions and made use of Hybrid[1] classes.

In particular, the unexpected COVID-19 restrictions significantly affected the ability of the capstone design class to work on and complete its major community focused projects. These included the drone and the radio telescope projects. The Drone project required multispectral analysis of local farm crops, as well as building and designing drone aircraft while the radio-controlled telescope project required considerable fabrication work. Traditionally, these projects have been heavily dependent on students working together in teams and having access to the school's considerable manufacturing abilities. However, with the emergence of COVID-19, students were immediately denied access to school facilities and their ongoing work, which forced instructors to quickly come up with creative alternatives to enable students to continue to complete their important capstone efforts.

[1] Hybrid classes are a combination class were some students are attending in person while others attend via zoom due to classroom occupancy restrictions.

Capstone Design Overview

The York College capstone design project is a design-and-build effort in which senior students use what they've learned over the previous 3+ years to solve problems in a specific area. These projects include Formula, Baja, and some community-based projects. In the first semester of the project work, the students design and prototype a solution to a problem. In the second semester, they build their design then test and experiment, which requires the use of York's shop and tools. When students were sent home in the spring of 2020, however, the shop was immediately closed. This closure essentially ended any hopes of building either of the two subject vehicles.

In response, instructors quickly looked for ways to allow students to be able to continue their capstone work remotely. The first issue that needed to be tackled was how to have students collaborate on teams when separated. As discussed in Orrill [1] and Ng et al. [2], team collaboration and "face-to-face" interactions are known to be a vital part of hands-on PBL efforts such as these, and there are numerous online tools available to support this type of collaboration. In addition, the diversity of these online tools has greatly increased over the past year, with Zoom,[2] Google Hangouts,[3] FaceTime,[4] and Skype[5] being but a few of the current options for online face-to-face meetings and collaboration. E-mail as always was crucial to these projects.

While the college remained closed to students, the faculty—which continued to have access to the buildings, shops, and other facilities—used Zoom as its primary mode of communication and collaboration with the students. Some face to face off campus interactions with students were required as well, as were other online collaboration methods. In addition, student-to-student collaboration also included texting, e-mail and, in some instances, direct student to student interactions.

Tomkinson et al. [3] also discusses the problems associated with a lack of face-to-face meetings in PBL, but this problem did not prove to be a primary obstacle for us. The Tomkinson assessment was outcomes-driven rather than process-driven. Our process was the reverse. The Tomkinson study relied on the Blackboard collaboration tool to support their virtual learning environment. The Tomkinson study also encountered student resistance to the change of venue, and we also had considerable student resistance to the changes we tried.

Nonetheless, the primary issue for us turned out to be the fact that the students no longer had access to the college's shop and its facilities. This limitation made fabrication of parts difficult, especially for the telescope project. That said, not having access to the machine shop didn't seem to be as crucial of an issue for the drone project, as most of the work in this project required 3D-printed prototypes, laser cut parts, soldering, and electronics work. We simply sent 3D Printers, soldering and other electronic equipment home with the students to mitigate the difficulties.

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[2] Zoom Video Communications, Inc. is a communications technology company located in San Jose, CA: https://zoom.us/.

[3] Google Hangouts is a cross-platform messaging app developed by Google: https://hangouts.google.com/.

[4] FaceTime is a proprietary videotelephony product developed by Apple Inc: https://apps.apple.com/us/app/facetime/id1110145091.

[5] Skype is a proprietary telecommunications application specializing in video chat and voice communications on computers and other mobile devices: https://www.skype.com/en/.

As it turns out, the lack of access to the college shops and facilities was more of an issue for the faculty, who needed to provide many of these services for the students for them to be able to progress further. The faculty ended up taking as much of the school's equipment as possible and sending it home with the students. Furthermore, a 3D printing lab was set up with cameras. Students could submit parts to be made, and the faculty would set up the print runs, which could then be monitored by the students online. Thus, probably the most time-consuming issue in the drone project was for faculty to go to the building, collect the part, and arrange for the students to pick it up at a later time.

Another issue involved the students' individual projects. In this program, students build a working drone aircraft capable of flying for approximately 1 hour while taking photographs of local farm fields. Any given semester has, at best, one or two students who can test fly the aircraft they have built. This is in part due to the skill set difficulty for flying these aircraft as well as the FAA certification required to operate drones in commercial airspace. In addition, most semesters have two competing aircraft that the students design—usually a flying wing and a glider-type design (see Figure 1)—and only one student who can actually fly the aircraft's maiden flight.

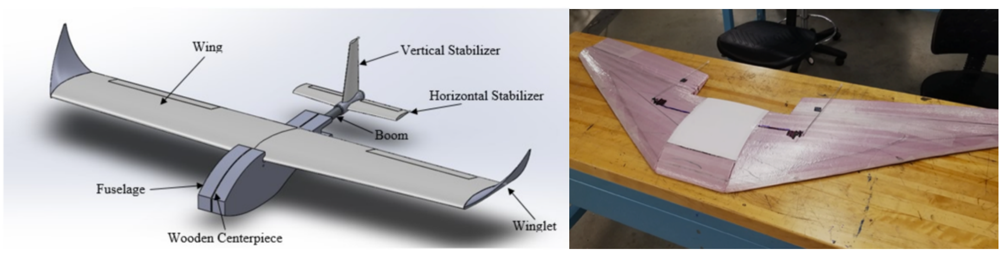

Figure 1. Wing Glider and Flying Wing Drone Concepts.

When the COVID restrictions were put in place last year, both of these aircraft concepts were about a week or two from first flight. However, with the students all being at home (and some being in another state), it was difficult to move those projects forward into the normal testing phase. Fortunately, we were able to anticipate this pending limitation and direct college funds to purchase standard quadcopter drone kits for almost every student (or pair of students who could still work together on the project). These kits allowed the students to independently conduct flight planning and test flights with the autopilots. This technology is far easier with rotary wing drone aircraft then with fixed wing aircraft. In the latter the aircraft cannot hover, so takeoffs, landings, and missions are far more difficult to program. Nonetheless, this helped students learn the basic principles of programming drone missions.

With no way for the students to test fly the fixed wing drones without an experienced test pilot, these two projects were most likely doomed. Nonetheless, the glider was sent home with our one mechanical engineering test pilot, and it was eventually test flown without issue. The other project did not see completion.

The required autonomous operations are usually done by students, who are electrical engineer, computer engineer, or computer science majors at York. For these students, DJI[6] flame wheel

[6] DJI Sciences and Technologies Ltd. is a technology company headquartered in China: https://store.dji.com/?Phclickrefb=1101ldTkoSfW.

kits and Pixhawk[7] auto pilots were provided. These tools allowed them to build an aircraft and program it for autonomous flight, thus eliminating the need for an experienced pilot to perform flight testing.

Figure 2 shows the operational glider after its first flight. As mentioned, the glider flew well and showed promise. This project was able to be completed because it involved the class's only pilot. On the other hand, the flying wing design never flew, though the student experiments on it were videotaped and shown at the end of the project during a presentation to industry partners.

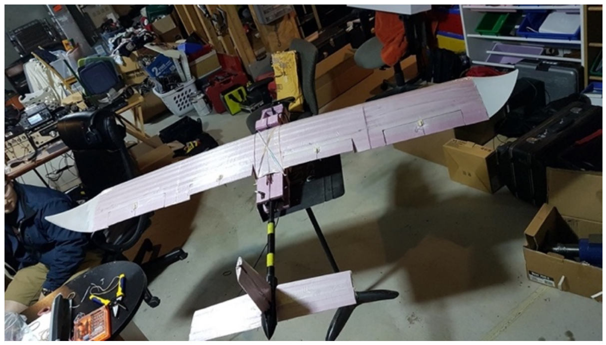

Figure 2. Drone Wing Glider.

One of the primary goals of the drone PBL capstone project discussed herein was to design and build a flight system that could not only fly, but do so autonomously, take photographs over a farm field, and then have those photographs analyzed to provide useful data for farmers. Unfortunately, with the COVID situation separating the individual project components (as well as the teachers and students) from one another, fully achieving this goal was not feasible. The faculty nonetheless wanted to provide the students with the overall design and build experience as much as possible. So, the following subprojects are provided to demonstrate how the class improvised during the COVID restrictions.

One of the biggest issues of this agricultural drone project every semester is having the drone fly autonomously, including during take-off and landing and within specific mission parameters. Fortunately, these aspects of the project fall under the umbrella of software design, which can be accomplished individually. Moreover, the flight parameters for stability, control, fail-safe, and mission planning can be conducted with the drone kits that were purchased for the students. This enabled students to design, build, and test their work.

Figure 3 (left) shows some stability setup parameters that needed to be programmed into the radio for flight stability, control, and fail-safe. Figure 3 (right) shows mission planning parameters. Farm fields are typically broken into grids, and the cameras (typically five) are set to take pictures at different pre-established locations, making a mosaic of the field. Then the images are stitched together for further analysis. These missions can be done with rotary wing drones on a small scale. Here they were practiced with the DJI kits and Pixhawk controllers, not the actual drone the students were attempting to design and build.

[7] PX4 autopilot is an open-source autopilot system oriented toward inexpensive autonomous aircraft: https://pixhawk.org/.

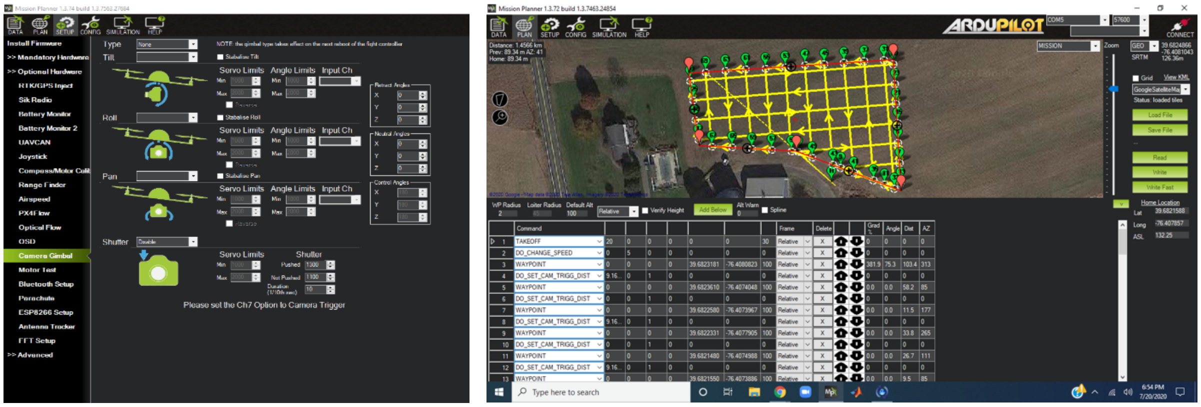

Figure 3. Autonomous Stability Setup (left) and Flight Planning (right).

Figure 4 shows a typical mosaic of a field and camera locations when pictures are taken over it. The field for this project, located at Blue Valley Farms in northern Maryland, was approximately 55 acres, which required several hundred images. This mission would be impossible for the DJI kits drone to perform.

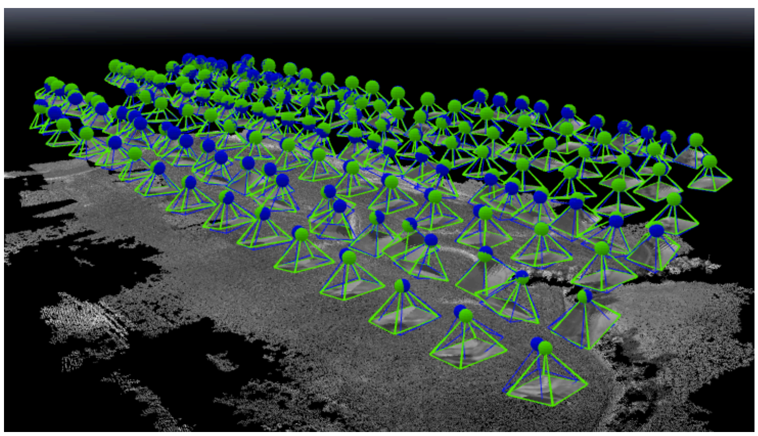

Figure 4. Camera views from Blue Valley Farms.

Camera picture locations (using global positioning system [GPS] coordinates)[8] and the camera's pointing angles (using a flight recording system) are coupled to help the software stitch together the images of the ground. Higher-quality GPS known as differential GPS and ground control points can also be coupled into the analysis to yield finer details and higher resolution in the results. (The students also worked on an RTK[9] system during this project, though those details are not discussed here.)

The particular field images were taken at approximately 390 ft above the ground. The images consist of red, red edge, green, near infrared (NIR), and visible light spectrums. Figure 5 shows an analysis from a June 8, 2020, NDVI mosaic (see Wilkerson et al. [5, 6]). At that point, the corn was near the V3–V5 stage in its annual growth.[10] Fortunately, these images could still be analyzed by the students, but the actual flights to obtain the data were done by the faculty.

[8] Global Positioning System: https://en.wikipedia.org/wiki/Global_Positioning_System.

[9] Real-time kinematic (RTK) positioning is a satellite navigation technique used to enhance the precision of position data derived from satellite-based positioning systems: https://en.wikipedia.org/wiki/Real-time_kinematic.

[10] Growth stages of corn: https://www.pioneer.com/us/agronomy/corn-v3-v5.html.

Of particular interest were some unusual features we discovered in the images when we zoomed in on them. These features, each of which was approximately 30 ft long, signified areas of corn damage (or at least poor corn growth) in the field. As it turns out, this 30-ft dimension was the same footprint as the farmer's planter. And after talking with the farmer, we learned that his tractor and planter had numerous problems in those areas when planting that year, which led to the observed abnormalities in corn growth.

In future analysis, we will look at how much overall corn damage/loss occurred, but just doing a rough count of the number of marks seen in the figure (approximately 30), it seems unlikely that this amount of damage/loss would result in more than a couple percent change in total corn yield during harvest. That said, it's easy to imagine how issues such as this (as identified by the drone) could potentially represent a large amount of income loss for farmers, especially those in the midwestern United States who raise thousands of acres of grain. Hence, the students were able to see the value of their analysis without having actually performing the flights.

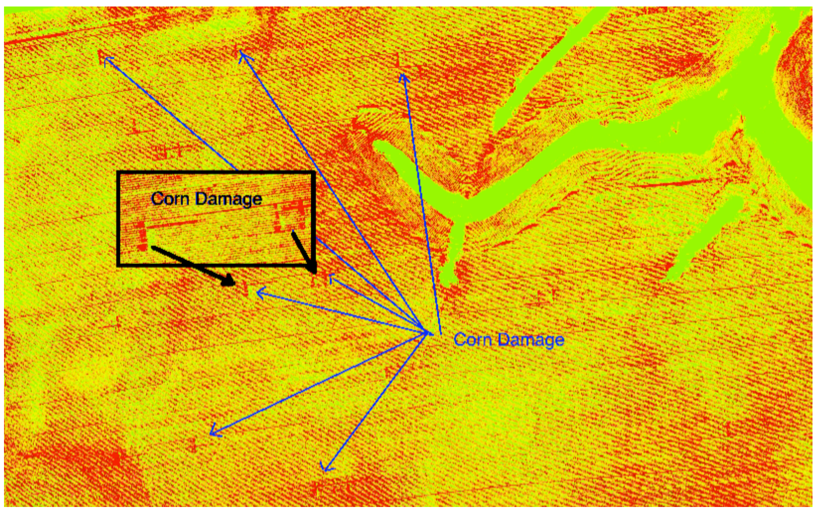

Figure 5. Corn Damage Discovered During Analysis of the Flights.

In addition to being limited by the COVID-19 restrictions (and then the current partial restrictions [called Hy-Flex[11]]), our project progress was also limited by an unusually snowy winter. Nonetheless, the current group of seniors was still able to still make progress on some of the filming and field analysis tasks and will be completing their projects this spring.

Student Observations

A short five-question student survey (shown in Appendix A) was used to collect student observations and opinions, including the assessed effects from students not having access to the York College shops and capstone team interactions. Students were also asked to provide their ideas on how they might have done things differently knowing what they know now. The results (which are graphed in Figure 6 and discussed in turn in the following paragraphs) will hopefully be able to help teachers and students in the coming semester should the COVID restrictions continue.

[11] Hyflex is a hybrid class with some students attending while others attend via zoom. This was used in the spring 2021 semester.

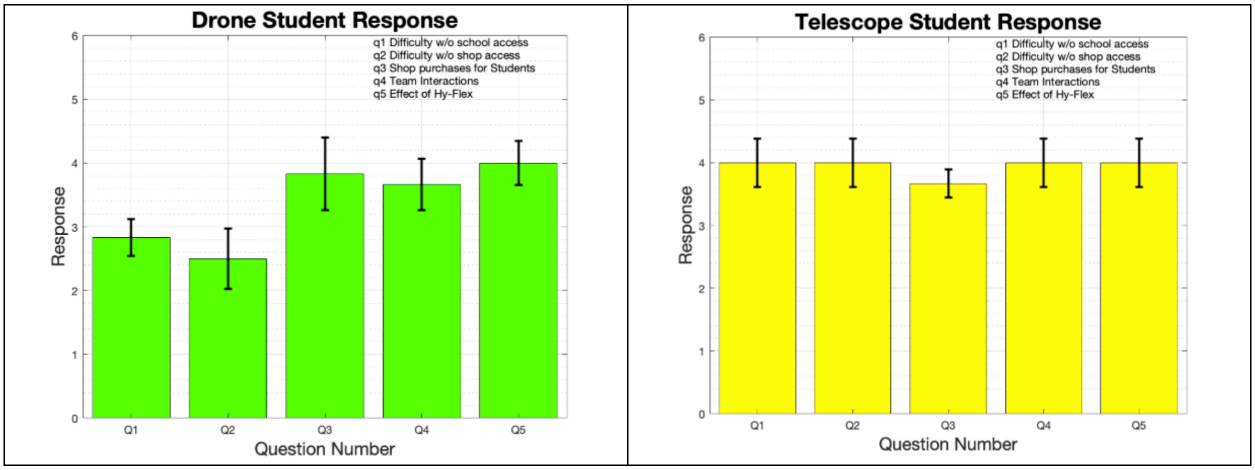

Figure 6. Student Responses (Range 1 to 5)
Confidence level 95%

Question 1 (Q1) was about the relative difficulty of students not having access to school facilities, such as classrooms, workshops, computer rooms, etc. Using an assessment scale of 1 (Made No Difference at All) to 5 (Made It Extremely Difficult), the drone students surprisingly didn't feel this reduced access had much of an effect on their efforts. By contrast, the telescope students felt it had a major effect.

Question 2 (Q2) was a similar question but focused on the effect of not having access to the shop and the machinery in the shop, such as lathes, computer numerical control (CNC) machines, laser cutters, and tools. Using the same scale as on question 1, drone students once again assessed that this limitation had little effect, while the telescope students assessed that it had a major effect.

Question 3 (Q3) concerned how much of a difference the school's purchase of drones, 3D printers, and other materials for them to take home made in mitigating the loss of access to the college's shops and facilities. Using a similar 1–5 scale as on questions 1 and 2, both the drone and telescope students seemed to be aware of the benefit from the school's purchase. Without these critical materials, the students would have had nothing tangible to work on, and the entire project would have been based on analysis without any actual design, building, or testing involved. Nonetheless, we were surprised that this was not a 5 for all of the students.

Question 4 (Q4) dealt with the students' assessment of whether the lack of resources or the lack of team interactions brought on by the COVID restrictions had more of negative effect on them. On a scale of 1 (Resources) to 3 (Both About the Same) to 5 (Team Interactions), the students uniformly assessed the lack of team interactions to be a huge negative effect.

Question 5 (Q5) addressed the perceived value of the Hy-Flex partial COVID restrictions. On a scale of 1 (Made No Difference at All) to 5 (Positive), the students assessed the Hy-Flex instructional format as being positive. In our opinion, this somewhat surprising response could be a symptom of the changing times and the use of the Internet as an increasingly accepted form of communication and education. Of course, it might also be a wake-up call for classrooms, PBL, and other traditional educational approaches. If nothing else, it seems clear that college education is becoming more of a hybrid experience overall, with the Internet assets being an increasingly integral part of the instructional approach. And exactly how hybrid learning will change PBL in the future will undoubtedly be a topic of ongoing studies.

Conclusions

During the past four semesters at York College, we have dealt with restrictions that have drastically changed the way our capstone design PBL classes are taught. Hands-on learning activities have, of course, been affected, but not always in the ways we have anticipated. The limited data thus far seem to indicate that not everything the faculty was concerned about ended up harming the students' experience. Rather, students sometimes used these unusual events as an opportunity for creativity and innovation in their approaches.

Without a doubt, capstone projects such as Baja, Formula, and other design-build-test projects are significantly affected by students not having access to the college's shop. That said, these issues appear not to have been as important to the drone and other community-based PBL projects as they were for the car projects. It is also clear that projects such as this rely heavily on students working together, which will make the ongoing development and use of online collaboration tools increasingly important for times when in-person interactions are not possible.

Looking ahead, it remains to be seen what lasting effects the Covid-19 restrictions will have on capstone design projects and PBL in general. No matter what happens, creativity and flexibility among both faculty and students will continue to be important characteristics if meaningful educational experiences and learning outcomes are to be achieved. I believe we had some balance in our approach here. We were fortunate that the school absorbed the expense of these efforts.

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Appendix A:
Student Survey Summer 2020 and Spring 2021

Q1. On a scale of 1 to 5, how much difficulty did you have not having access to the school facilities?

1 Made No Difference at All …… 5 Made It Extreme Difficulty

1 2 3 4 5

○ ○ ○ ○ ○

Q2. If there was difficulty, was it primarily caused by not having access to the shop?

1 Made No Difference at All …… 5 Made It Extremely Difficult

1 2 3 4 5

○ ○ ○ ○ ○

Q3. Did the purchase of the drones and other materials help mitigate the loss of the workshop?

1 Made No Difference at All …… 5 Made a Difference

1 2 3 4 5

○ ○ ○ ○ ○

Q4. If you believe COVID has had a negative effect, was it due more to access to resources or due to the lack of team interactions?

1 Resources … Both About the Same … 5 Team Interactions

1 2 3 4 5

○ ○ ○ ○ ○

Q5. Is this semester being Hy-Flex a positive or negative?

1 Made No Difference at All …… 5 Positive

1 2 3 4 5

○ ○ ○ ○ ○