Creating a successful senior design project: lessons learned across ten years of teaching

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ABSTRACT

Interdisciplinary capstone design projects are a required part of many of the engineering programs across the US, and have been proven to be highly impactful for preparing students for industry. The University of Arizona College of Engineering program places 5-6 students on a team sponsored predominantly by industry partners. Over the course of the academic year, students work to meet the requirements of the industry sponsor and ultimately present their results at a celebratory event called Design Day. The authors have been students, mentors, and now sponsors of projects through BAE Systems (formerly Ball Aerospace). This paper describes our general philosophy to designing a great project that will challenge and grow the students on the team, and give them a taste of what work at our company is like. The paper will give several example projects across the past years to showcase what went well and what can be improved, as well as summarizing general roadblocks students consistently experience for other mentors to be aware of.

Keywords: education, capstone project, design, engineering, mentoring

1. INTRODUCTION

A senior capstone project is required by the Accreditation Board for Engineering and Technology (ABET) for engineering programs.[1,2] For most students, this is their first formal experience working with other engineering disciplines. Programs like these are not just required, but have been shown to have a large impact on student success in industry.[3–6] At West Point, the capstone program covers the final semester, with several students on each team on projects sponsored both by faculty and industry.[7] At Rose-Hulman, capstone projects were credited with all students reporting a better understanding of optics concepts and realizing their importance to industry shortly after adopting a capstone program.[8] Decades later, the capstone projects continue to be a cornerstone of the undergraduate learning experience at Rose-Hulman as they tailor them to best prepare students for the workforce.[9–11] At the University of Michigan, these projects were noted as chances for students to develop their teamwork skills, and to gain the experience of tackling broader, open-ended problems.[12] At the University of New Mexico, students prepare a large final report and are judged by an interdisciplinary panel of engineering faculty.[13] Topics such as optomechanics are frequently best seen in action rather then on a slide deck, which multiple authors noted the impact of the practical experience of senior design to improve students' understanding.[14–16]

The University of Arizona College of Engineering is no exception, and has a well-run and successful interdisciplinary capstone program. This program, which has operated since 2000, brings Biomedical, Biosystems, Electrical and Computer, Engineering Management, Environmental, Industrial, Materials, Mechanical, Optical, Software, and Systems Engineering majors together on teams of 5-6 students. A typical year will have around 100 projects sponsored predominantly by companies, with a few projects from campus faculty as well. Over the course of the academic year, students start with requirements at the beginning of the fall, go through several detailed design review presentations, and end their year with completed hardware to show off at a large event called Design Day. This all-day event gives students a chance to be judged for a final grade and their shot at $49,000 in prize money.[17]

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BAE Systems Space and Mission Systems, formerly Ball Aerospace, has a long history of being involved in the community through supporting various STEM programs, including sponsoring projects through this course since 2017. This paper will summarize our philosophy for creating a great senior design project, and discuss the last three years of projects to examine what went well and lessons learned. In addition, it will summarize common roadblocks that student teams encounter to give teachers and sponsors things to look out for.

2. UNIVERSITY OF ARIZONA PROJECT STRUCTURE

2.1 Course structure summary

A brief summary of the structure of the University of Arizona College of Engineering Interdisciplinary Capstone design course, ENGR498A and B, will be given here before diving into project specifics.[18] Sponsors submit their potential projects during the summer before the fall semester begins for review by the course administrators for feasibility. Submitting a project requires a short abstract, a list of which engineering disciplines are desired, a list of specific skills that will be needed for success, and details on how intellectual property (IP) generated during the project will be handled. The first week of the semester, students see the list of projects posted on the College of Engineering website, and can rank their favorite projects. Project sponsors are invited to attend an open house event, where students can meet with sponsors, hear about the project, and offer their resumes. Sponsors are allowed to offer positions on the project for up to two students, and can list two alternates if the first picks do not choose to accept the offer. The students again rank their favorite projects, and the course places them according to their project preferences to the best of its ability. Giving students a chance to be involved in a project they are excited about has been noted to be a large factor in the success of a project.[11]

Once the project kicks off, the students proceed through several modules in the fall and spring, as summarized in Fig. 1 below. The fall semester focuses on setting requirements and making design decisions, and the spring semester dives into integration and test. Practically speaking, many teams end up making final design changes at the start of the spring as they catch mistakes, improve ideas as they learn, and potentially play catch up from insufficient design work in the fall.

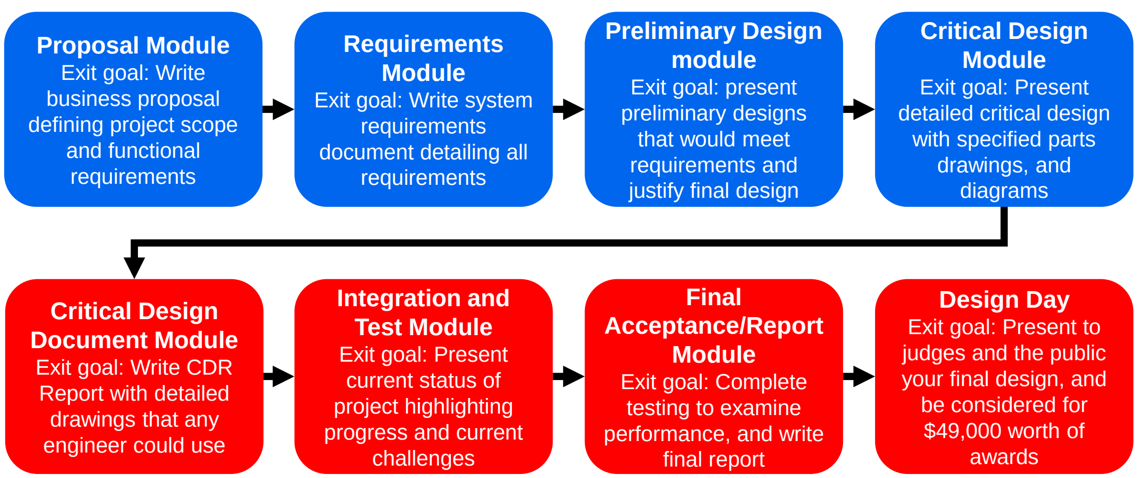

Figure 1. Summary of the University of Arizona ENGR498 course structure. The top four sections comprise the fall semester, and the bottom four showcase the spring semester activities.

2.2 Author experiences with the course

Dr. Cromey took this senior design course as a student his senior year in the 2014-2015 academic year, and helped Prof. Nofziger teach the course during his PhD.[19] He has been responsible for managing BAE System's projects since 2021. Mr. Carr took the course his senior year 2015-2016, helped sponsor a project in 2016-2017 at a different company, and began working with the BAE System's projects in 2022. Prof. Nofziger is a highly experienced lecturer at the University of Arizona, and has taught the senior design course since the 2014-2015 academic year. As a result, the authors have been involved for ten years across all three roles in the course as seen in Fig. 2 below: student, mentor, and sponsor. This gives a broad perspective on the course and capstone programs in general to share in this publication.

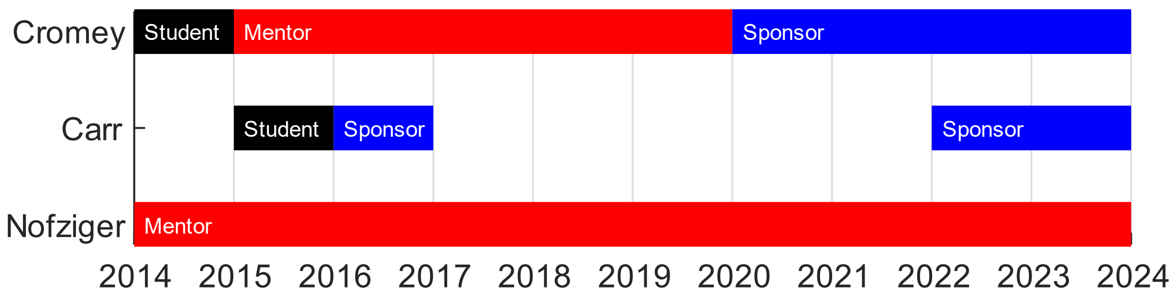

Figure 2. Summary of author experiences with the senior design course, covering ten years of diverse experience across the three key roles in the course.

3. EXAMPLE PROJECTS FROM THE PAST THREE YEARS

BAE Systems has sponsored projects since the 2017-2018 academic year. For the sake of brevity, example projects from only the past three years will be discussed in detail in this publication. For each project, the project problem statement given to the students will be presented, followed by lessons learned for each project. These problem statements are used both to get project approval from the College of Engineering, and to get students interested in talking to us at the open house event mentioned in 2.1. The schematic diagrams for each project (Figs. 3, 5, and 7) were each on a poster presented at the open house to show the students approximately what the project would look like when finished.

3.1 Philosophy for defining a great project

Three core elements define a great senior design project in our experience:

1. **Completing spreadsheet-level design work before submitting the project**. It is very important to create a project that is achievable by the students. As industry professionals, it can be challenging to remember how little can be bought with $4,000 considering the budget range of an aerospace mission is typically in the many millions. Every year before submitting a final project, requirements are set for the team based on spreadsheet level designs. This is typically only first order/geometrical optics level work, to ensure requirements are reasonable for off the shelf parts. In addition, an initial budget (with ≈25% margin) based on that rough design including all critical components is created to ensure the students can be successful with inexpensive parts.

2. **Choosing a project with relevance to the company's products**. This course is an excellent recruiting opportunity for companies, as it gives the sponsor an entire year at almost no cost to see students' abilities to produce both technical work and work in a small team. As a defense contractor, it takes more pre-work on our part to scope a project that is relevant to our business due to International Traffic in Arms (ITAR) and IP restrictions. However, choosing a relevant project is better for sponsors and for students. For students, it allows them to get a taste of the specific kinds of work done at the company. For sponsors, it gives a chance to see if students can quickly pick up the specific skills needed to be successful at their company. At BAE, we have typically chosen a product that we produce, and significantly de-scoped it to make it achievable by the students' budget and level of experience. Relating the project to a real-world system also helps produce excitement in the team as it shows what the technology they are working on in its simple form is capable of.

3. **Setting clear expectations with the students on working relationships**. Students enter this course with varying expectations on how sponsors (the team's customer) and the team are meant to interact. Some of them treat sponsors as though they are their teachers, expecting the company to have a "correct" answer on a design that they are designing to. It is important to clearly define this relationship early on with the team. This also helps give the students a more realistic interaction with their "customer" to prepare them for the real world. The team should also be encouraged to have these conversations with themselves early on to set their own internal structure for working relationships.

Many sponsors may not come from a traditional teaching background, and as such may not be familiar with how to approach the unusual tension of the customer/mentor role this course asks sponsors to fulfill. The sponsor naturally desires that the project be successful, necessitating times where the sponsor will exert their influence to resist poor design choices. However, as the ultimate goal is a learning experience for the team, a good sponsor will invariably allow design problems to persist in order to give the students a chance to learn lessons for themselves, rather than just being fed the correct answer. Various useful resources on teaching philosophies are available for a quick read on how to best engage a team of students.[20]

3.2 Project 22009: Low-cost Drone Tracker

3.2.1 Problem statement presented to students

Drones present an increasingly sophisticated threat to civilian airports and armed forces abroad. These low-cost and low-flying aircraft are nimble and small, making them difficult to detect with traditional radar. A network of low-cost optical drone tracking stations distributed around a monitored airspace could fill a critical hole in the warning system. The team will design and build a prototype drone detection system. The system shall automatically scan for and detect drones, recognizing them in comparison to other airborne objects. The system shall track the drone and report the direction of motion in real time through a computer interface. Several stretch goals of drone identification, threat detection, and more precise speed and distance measurements can be considered depending on the ambition of the chosen team.

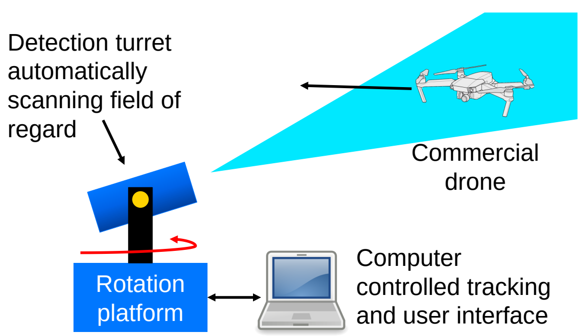

Figure 3. Schematic diagram presented to students of the drone tracker concept of operations.

3.2.2 Results and lessons learned

This team's completed hardware and imaging results can be seen below in Fig. 4 below. This team provided an excellent example of the power of geometrical optics. The team decided on a two-camera architecture: one wide FOV camera to handle the requirement of scanning from 20° from the horizon up to directly above to detect objects, and a narrow FOV camera to handle detection and recognition, using the Johnson criteria as a guide for pixel counts needed.[21,22] The two-camera design can be seen in Fig. 4 (a). The team used a geometrical optics spreadsheet model to choose the camera and focal lengths that would give enough pixels in object space to see the drones at their required maximum detection distance of 220 m. Each camera was placed on a motorized tilt platform, both of which were on a rotation platform to scan for drones. Software was written by the team to control the stages, and react to potential objects within the field of view. Fig. 4 (b) and (c) show the images that were captured in testing looking for a 1 ft cross-section drone, showing the team was successful in detecting and capturing good images of drones. The team thought cleverly and used their budget wisely, incorporating an inexpensive barstool as the primary structural component to the design, as one example.

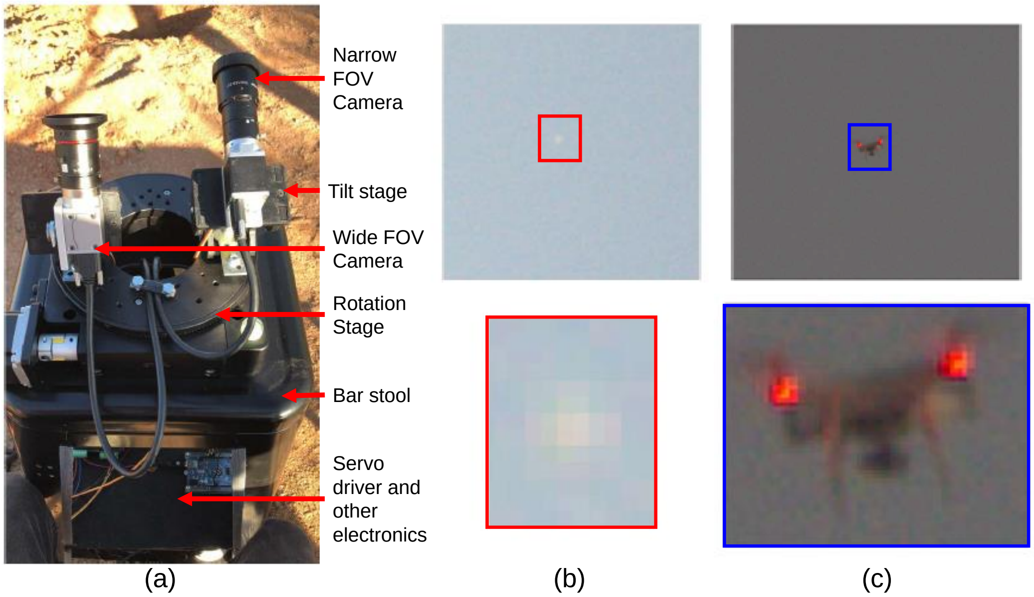

Figure 4. Results from Project 22009, Low-cost Drone Tracker. (a) Picture of final hardware with labelled key components. (b) Cropped image of the drone at the required maximum detection distance with the wide FOV camera. The design succeeded in having at least 2 pixels to accomplish detection as seen in the close up. (c) Image of the drone at the required maximum detection distance using the narrow FOV camera. The narrow FOV camera had 26 pixels on target, which exceeded the minimum 14 pixels required to accomplish object identification, as seen in the close up.

This team's main oversight was considering the time-based requirements. In order to capture the drone flying through their field of regard (FOR) within the required time, the system had to scan fast enough to see the drone in the FOR, point the narrow FOV camera at it, and run image processing to discern if the object was a drone or other airborne objects. While the team did train an effective custom neural network to sort between drones, planes, helicopters, and birds, they did not consider until too late in the project the processing power needed to do this computation in near-real time. Their system met most of their requirements, while being unable to fully track and identify objects in real time. All in all, this was a fairly successful project. An excellent student was hired from this team to work at our company first for an internship and then full time afterwards.

3.3 Project 23019: Optical Scatterometer

3.3.1 Problem statement presented to students

Stray light is a light path that does not follow the intended design of a system. These paths of light can come from the intended source, but follow paths other than intended, or may be from a light source outside of the field of view that scatters onto the detector. Knowing how light will interact with a surface is crucial to predicting the stray light paths in a design so the impact can be mitigated. Measured data in the lab can be fed into optical design software, leading to accurate models and predictions of impacts on system performance. The team shall build an optical scatterometer to accomplish these measurements. The system shall illuminate the sample with at least one laser source and measure the scattered power bouncing off of the sample. The sample and the detector will both need to rotate to gather a complete data set. A computer program shall be developed to automate these measurements, and shall process the results into a format readable by optical design software.

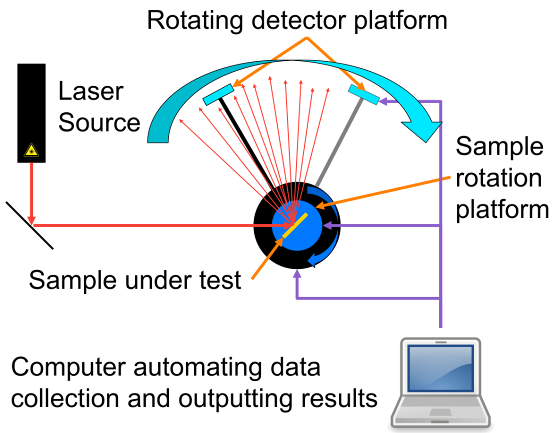

Figure 5. Schematic diagram presented to students of the scatterometer concept of operations.

3.3.2 Results and lessons learned

This team used a pair of fold mirrors, a spatial filter, and a focusing mirror to deliver a HeNe laser beam to the sample under test (seen in Fig. 6 below). A pair of stacked rotation stages control the orientation of the sample under test and the detector separately. The optical scatterometer was only required to make measurements within a single plane. The team utilized 3D printed parts effectively as a cost-saving mechanism, designing and building their own chopper system for use with a lock-in amplifier to reduce noise in their measurements. The team was also effective at reusing discarded components from labs in the College of Optical Sciences. Software was written by the team to enable the user to enter test parameters and automate measurements. The team succeeded in meeting their hardware footprint requirements, alignment requirements, and driving the motors with software as dictated by commanded test conditions.

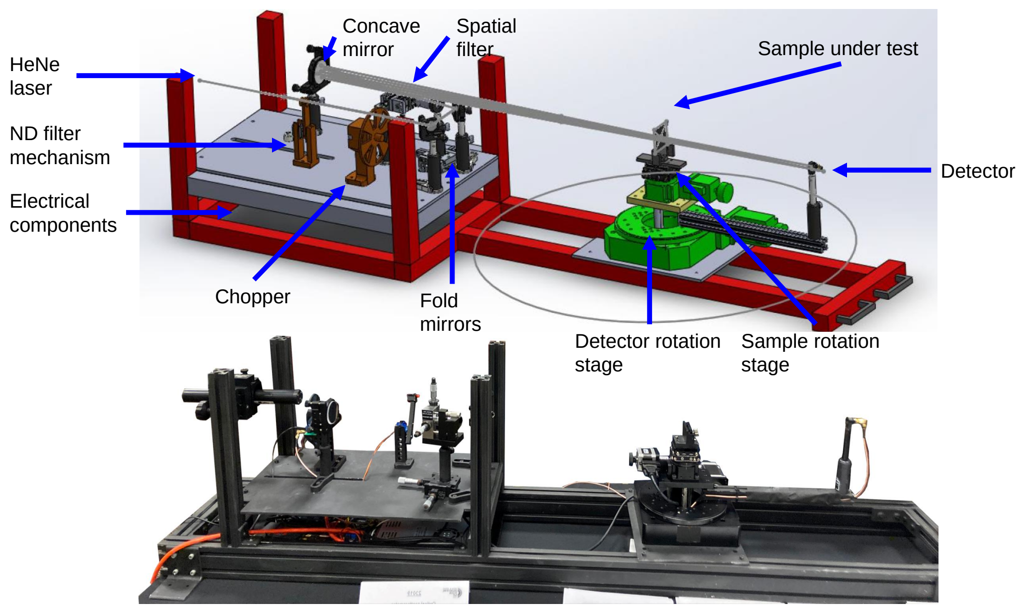

Figure 6. Results from Project 23019, Optical Scatterometer. Top: CAD model of hardware with labelled components. Bottom: Image of final hardware. The team spray painted most components black to reduce stray reflections. A full enclosure was built as well to cover the test area during testing.

Student staffing is not always perfect. This team had to overcome not being staffed with a mechanical engineering student, when it is clear from both Figs. 5 and 6 that many mechanical components and interfaces were key to this system's operation. In this instance it was important to provide more of a teaching and mentoring role as the sponsors to help compensate for this lacking skill set that was no fault of the team. It's important to strike the right balance on when to help the project along with mentoring and advice and when to let the students struggle and problem solve.

This team got off to a slow start. While some early testing was accomplished using available lab components to examine how difficult it would be to align their system well enough to take data in a single plane, key hardware decisions were delayed well into the spring. These delays left very little time to have an assembled system to test. The team did measure low-quality data in time for the final acceptance review. An excellent student was hired from this team to work at our company first for an internship and then full time afterwards.

3.4 Project 24005: Imaging Spectrometer for Defeating Camouflage

3.4.1 Problem statement presented to students

Camouflage is a key part of battlefield tactics to visually disguise personnel and military assets. Basic camouflage is designed to confuse the human observer across the visible spectrum, with more intelligent versions designed to operate across multiple wavelength bands, such as obscuring the heat signature of an engine. The team will design and build an imaging spectrometer that will be used to spectrally discriminate between a camouflaged object and the background the camouflage is designed to simulate. An imaging spectrometer captures data-rich images containing not only spatial information but spectral as well, containing the wavelengths captured in each pixel. The team will write software to both control the imaging spectrometer, and also process the data in order to perform object discrimination. Careful optomechanical design will be necessary to align the system and keep it stable such that the calibration of the system does not drift significantly over time.

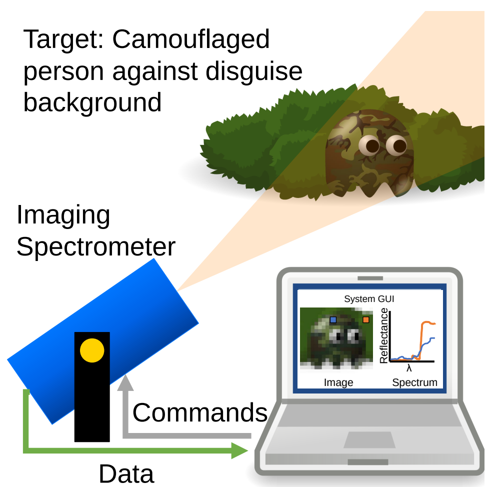

Figure 7. Schematic diagram presented to students of the imaging spectrometer concept of operations.

3.4.2 Results and lessons learned

The completed set of hardware from this project can be seen in Fig. 8 below. This team used a commercial focusing objective for the imaging portion of the device, and a pair of spherical mirrors and a prism for the spectrometer portion of the device. An atypical spectrometer design was pursued by the team, replacing the grating in a Czerny-turner with a reflective prism as a means of avoiding the mode overlap concern with a grating design. A scan mirror at the front of the system controlled the viewing angle entering the imaging spectrometer, controlled by software written by the team that allowed the user to specify imaging capture parameters, and had some features for automatically segmenting the data into spectral bins. A detailed photon budget was created, in order to best predict SNR across the required operating band of 450-950 nm and make hardware decisions.

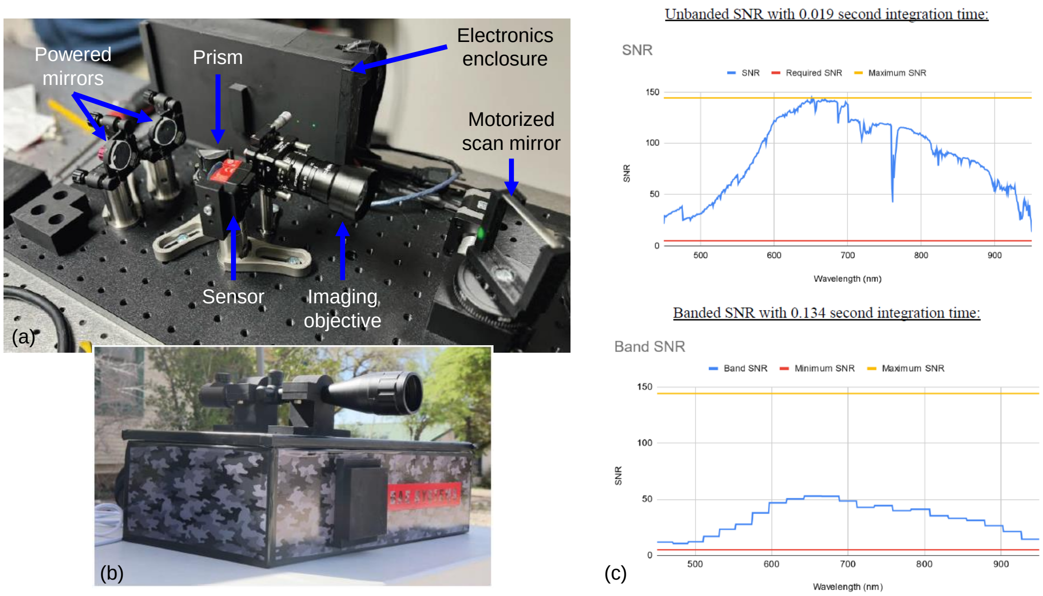

Figure 8. Results from Project 24005, Imaging Spectrometer for Defeating Camouflage. (a) Hardware layout with labelled key components. (b) Hardware enclosure for operating outdoors. The riflescope was used for rough aiming of the assembly at the targeted region. (c) SNR predictions using a detailed photon budget. It presents both the continuous SNR prediction and the "banded" SNR when predicting the per-pixel illumination based on predicted spectral resolution.

This team struggled to get started with the design decision process, causing them to be a month behind all year. This made for rushed design decision making in the late fall/early spring timeline, and a severely compressed integration and test campaign. This was particularly difficult for this project, as the system needed to not only be assembled, but also calibrated in order for the image data to be effectively translated into spectral information. Imaging spectrometer images are typically captured with spectral information in one axis, and spatial information on the orthogonal axis, so without an effective calibration the images were not useful for making quantitative determinations about the scene. In addition, the optical design had challenging alignment from all of the unconstrained off-axis components, making producing in focus images especially difficult. Despite these challenges for performance, the students found the experience to be highly useful, and with many personal takeaways for future designs they would pursue. An excellent student was hired full time to join the company upon completion of the project.

4. GENERAL PITFALLS ACROSS STUDENT TEAMS

This section contains generalized observations made across the past ten academic years from the authors' involvement with the course. Note that the following observations of "pitfalls to project success" have been made by the authors of this paper, and are not necessarily those of every instructor and sponsor in the Engineering 498 course. In our experiences, we have seen these pitfalls, general in nature, apply to students on all teams, from each and every engineering discipline in the course. This section is written with the hope of giving other instructors and sponsors an idea of what issues to look for if they are involved with an engineering capstone project at any university, not just the University of Arizona.

4.1 Time management

The most common issue that teams struggle with is time management. Unlike most other courses where students work individually, this course is entirely teamwork-centered, a format new and often challenging to many in the course. All aspects of this capstone course are team-related: reports, weekly sponsor meetings, all aspects of project design, build and test, and team reviews—all require that teams meet and work together outside of class. Obviously, this takes scheduling, planning and managing everyone's time. Each team has a member chosen as their "team lead" to coordinate all team activities and scheduling. Team leads must work to ensure that their team members are operating in parallel, such that no team members are waiting for someone else to finish giving input before acting.

4.1.1 Time outside of class

The course itself meets 2 days a week, with a total of 4.5 hours of time in class. In both semesters much of this time is available for teams to work on their project, with input from their instructor. Teams must meet with their corporate sponsor outside of class time. Compared to many of their other classes, this seems like plenty of available time to work on their project. The reality, however, is that teams need to spend much more time outside of class working on all aspects of their projects. Instructors make it clear from day one that teams need to schedule this time so all team members can participate. Successful teams embrace this early in the fall semester, but teams that ignore this run into issues finishing their project by the end of the spring semester.

A related issue is students treating engineering tasks like homework assignments. The sponsor's goal is not to provide busywork for the team. It is important for students to address and complete tasks early so that any issues can be resolved. Procrastinating until the deadline of a major design review leaves no time to correct for problems. While the course enforces hard deadlines for certain deliverables, the teams must develop their own internal deadlines to drive progress and stay on task.

4.1.2 Underestimation of time-constraints

In general, students have no realistic appreciation of just how much time it will take to complete the tasks related to the actual engineering of their project. They often underestimate the time needed to prepare for major design reviews. Additionally, integration and test is usually treated as an after thought, even though it can be one of the most time consuming sections in a project. This is somewhat understandable, as these projects by their nature are challenging and open-ended, and require large amounts of time that no textbook can teach or predict.

Perhaps unsurprisingly, teams need more help with this at the beginning of the project, especially since a team that starts slowly may never recover in time to pull off their project. However, this is one of several challenging balances that sponsors face, as they must help teams get started effectively without coming across as too heavy-handed in the beginning with sponsor timelines. Sponsors can help the team learn to build their own internal deadlines by asking students to volunteer their own completion times for key activities, and then hold them accountable to promised delivery dates. This method both teaches the students how to better estimate the timelines for their tasks, and reduces the risk of tension by getting the team's buy in on deliverable deadlines. Asking for a draft of their slide deck before a major review is not only a great opportunity for the sponsor to help shape the review into a more effective presentation, it also encourages them to work on it earlier than it is due in time to catch any major omissions.

4.2 Modeling, analyzing, prototyping, and testing

As mentioned in the previous section, students do not always do a complete and thorough job of modeling and/or analyzing initial design choices. One shortcoming is often the lack of doing a first-order analysis based on the fundamental physics of the project. Students seem to want to "jump into" modeling using sophisticated programs such as PSpice, Zemax, CODE V, FEA, etc. when much could be learned from a first-order Excel model. First order analysis should be strongly encouraged by sponsors and instructors. These "simple" models should also be used to justify the results from sophisticated program. Moreover, a lack of a first-order analysis usually leads to fundamental misunderstandings in their more sophisticated models. In turn, this translates directly into an incomplete Preliminary Design Review (PDR) mid-way through the fall semester.

Most of the projects require that actual hardware and software be built and tested. This frequently requires the use of prototyping, something not found in most of their previous engineering courses. Every experienced engineer knows that prototyping requires time and money. Parts need to be selected, ordered and delivered. Parts often need to be machined and/or 3D printed, software needs to be written, and finally everything needs to be built, assembled, and integrated into a prototype model. Ideally, a team would efficiently move through this "design-prototype-test" cycle, learn from their results, and re-iterate the process. However, because of poor time management, teams rarely have time to go through this engineering cycle more than once. By the time they go through each of their prescribed tests and discover issues with their prototype design, they simply don't have time to repeat the process. This often translates directly into an incomplete project at Design Day. It is important to emphasize to teams the importance of allocating time for the prototyping phase. If students can identify the most critical results they want to observe when prototyping, they will be able to maximize their limited time and resources.

The other challenge faced in the modelling process is that students frequently lack an intuition as to when their design is "good enough." In the fast pace of this course, spending several weeks tinkering with mechanical layouts, or fretting about which slightly different power supplies are best when the key performance characteristics are the same, can burn precious time. This is a key area for a sponsor to help the team realize when to exit the design phase and begin to purchase hardware.

4.3 Lack of "hands-on", practical skills

The University of Arizona's Engineering 498 Interdisciplinary Capstone course does a fantastic and thorough job of teaching students all aspects of the engineering process, from defining system requirements to building and testing a complete working solution to the sponsor's proposed problem. As mentioned earlier, teams go through all of the industry-standard design reviews, and are graded on the quality and content of their engineering progress. Homework is given throughout the fall semester to ensure that students actually learn each step of the engineering process.

However, this capstone course also teaches students that there is a huge difference between solving textbook problems and the hands-on skills needed to work through the "design-build-test" engineering cycle. In this course, most projects require "hands-on", practical skills. This includes, but is not limited to, building electronic circuits, making drawings, machining parts, interacting with machine shops, 3D printing, optical alignment, computer programming, and data analysis.

The main reason for the lack of "hands-on", practical skills by many (not all) students in the course is simply lack of opportunities. Unless they have worked in a research lab or have done summer internships, they do not have the 'hands-on' experiences gained outside of the traditional university "textbook" classroom. Again, traditional lab courses simply do not provide most of the skills needed in a capstone "design-build-test" course. Having said that, it is exactly the capstone course experience that gives students of all majors the chance to learn new skills that will be useful in their future engineering careers. Sponsors and mentors can help highlight the benefits of these learning experiences. Of note are students who "step outside" their own majors to not only learn a new skill during the year, but to then apply the skill to help the team be successful. In fact, the "Fish out of Water" award is given to students at Design Day who have made such a contribution to their team!

4.4 All possible engineering solutions

In preparation for Preliminary Design Reviews, teams are required to formulate 3 "back of the envelope" initial designs. These are based on functional and system-level requirements that each team has formulated working with their project sponsor. Teams are required to analyze and model each of their preliminary designs, to be presented at PDR. The goal of PDR is to justify the team's choice of their preferred point design.

In an ideal world with unlimited time, money, and experience, teams could do a complete and thorough job of arriving at an optimum point design (within system requirements and budget). They would have considered every part of design-space for their project, and would have analyzed and modeled all combinations of all design variables. This of course is not possible for student teams, for two reasons; time constraints being an obvious culprit, as discussed. However, the other reason is more problematic. Students do not have the experience to recognize and consider all possible engineering solutions to their project. They (understandably) lack the knowledge and experience that teams of seasoned engineers would have, and therefore they often lack awareness of available hardware solutions, that sometimes even fall within their budget. More problematic are projects for which best-engineered hardware solutions fall way outside of the team's budget. One answer might seem obvious—enlist the help of the instructor and sponsor to "dictate" solutions based on their experiences. But this crosses a fine line in the course, as neither the instructor or sponsor are the "boss" of a team. Similar to what was previously discussed in Section 3.1, a good sponsor (and instructor) will therefore sometimes allow students to choose design solutions that work, but might be less than ideal. It is important that students "buy into" their own decisions about their point design. It is, in fact, a key part of the learning process.

Frequently, students are not asked to invent something novel. Engineering in general frequently relies on existing ideas reused in clever ways, or even just slightly updated from previous versions. However, students frequently rely on their own intuitions first rather than search the science/engineering literature, or even textbooks, for inspiration. This frequently causes teams to pour their initial wave of enthusiasm into more difficult directions. To use their limited time wisely, teams should first consult the literature for both inspiration and common design forms. There are often reasons why design forms are common across applications, they are proven in performance, and easier to use in practice.

4.5 Sourcing parts

Most of the projects require that hardware be assembled, and therefore that parts be purchased and ordered. Teams fill out purchase requisition forms, and the course has dedicated university staff to handle the actual purchasing and budget-tracking for each team. Logistics made easy! However, the problem that most teams face is their lack of knowledge of what parts are available, from what companies, and at what price points. Once again, this is mostly due to lack of experience. This, coupled with the limited $4000 budget previously mentioned, can make finding and choosing parts a challenge.

Here is where the experience of the instructor and sponsor can be of immense help. Again, the role of the instructor and sponsor is not to tell teams exactly what to purchase but to point them "in the right directions," giving them choices. Creative thinking and knowing the surplus markets are often keys to helping teams be able to buy parts within their budget. Technologies produced and sold for large-scale consumer markets have become very affordable and available in the hobby markets. 3D printing has made prototyping so much more cost-effective. Obtaining custom printed circuit boards is now as easy as designing one and uploading a file. Off-shore sourcing of parts has become incredibly cost-effective (but be aware; lead times can often be weeks to months). While these solutions may not be appropriate in the world of "corporate" engineering, they are perfect for the prototyped projects that make up a senior capstone engineering course!

4.6 Student-sponsor relations

As mentioned in 3.1, students frequently struggle with how to manage the relationship with their customer. This is not surprising, as for many of them this will be the first time they have had to navigate this sort of pseudo-contractual relationship. This can lead to a variety of issues, such as the team relying too heavily on the sponsor to drive deadlines and progress, rather than setting their own goals. In addition, teams often rely too heavily on sponsors for ideas. While this rightly recognizes the greater experience sponsors have compared to the students, this can lead to sponsor suggestions being taken as the "correct" answer, rather than just a suggestion. Indeed, a good sponsor will avoid choosing a project that has a "correct" answer, but will be aware of several common design choices that will lead to success.

This course has a traditional grading structure for the student's grade, and meeting system requirements is based on pass/fail. However, teams are often genuinely surprised to find their sponsor holding them to meet requirements not just qualitatively, but to within quantitative margins. Students can become frustrated when they have undeniably worked diligently attempting to meet a requirement, only to have their sponsor point out they were, in fact, unsuccessful in the end. This is part of why it is important to work together with the team at the beginning of the project to help develop the full requirement list. It both helps the sponsor teach the engineering process to students, and it gives students a sense of ownership as to what requirements they agreed to meet.

5. CONCLUSION

This paper was written with the hope of encouraging other companies to serve as sponsors, and to provide guidance on how to create a successful senior design project. Example projects from previous years were presented here, showcasing the highs and lows of each project, as well as sharing the general pitfalls student teams tend to fall into to aid future sponsors as well as future capstone teams.

Mentoring a team of senior design students is highly rewarding, and the impact to the students over the year is always clear at the end of a project. Having a student confess to lacking a skill in the beginning of the year, and seeing them produce results confidently later in the course is one of the best experiences one can have as a mentor. Each of these projects began with just initial concepts in the fall semester, and ended as a physical product (hardware and software) to demonstrate at the Design Day event at the end of the spring semester. Several of these projects earned the teams some nice prize money at Design Day. Even if the team was not successful at meeting their requirements, if a project was well designed, the students will exit with tremendous learning opportunities and new skill sets to use for the rest of their careers.

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