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Work in Progress: Implementing a Tiger Team in a Capstone Design Course

Alan Cheville
Bucknell University, rac039@bucknell.edu

Stewart Thomas
Bucknell University, sjt015@bucknell.edu

Stu Thompson
Bucknell University, mst008@bucknell.edu

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Work in Progress: Implementing a Tiger Team in a Capstone Design Course

Prof. Alan Cheville, Bucknell University

Alan Cheville studied optoelectronics and ultrafast optics at Rice University, then spent fourteen years as a faculty member at Oklahoma State University working on terahertz frequencies and engineering education, developing resources in photonics and engineering design. After serving for two and a half years as a program director in engineering education at the National Science Foundation, served as chair in the Electrical & Computer Engineering Department and secretary of the faculty at Bucknell University. At Bucknell he helped found the Maker-E, an electronic MakerSpace for students.He is currently interested in engineering design education, engineering education policy, and the philosophy of engineering education. He has served as associate editor on several journals, an ABET PEV, and on several national-level advisory boards.

Dr. Stewart Thomas, Bucknell University

Stewart Thomas is an Assistant Professor in the Department of Electrical and Computer Engineering at Bucknell University in Lewisburg, Pennsylvania. He received the B.S. and M.Eng. in Electrical Engineering from the University of Louisville in Louisville, KY. and the Ph.D. in Electrical and Computer Engineering from Duke University in Durham, North Carolina. He is a member of ASEE and IEEE.

Prof. Stu Thompson, Bucknell University

Stu is an associate professor and chair of the department of Electrical and Computer Engineering at Bucknell University, in Lewisburg, PA. His teaching responsibilities typically include digital design, computer-related electives, and engineering design. His research focus is on the application of mobile computing technology to interesting problems. My broadly he is interested in the continued evolution of engineering education and how the experience can help create graduates who will go on to make substantial change in the world.

Work in Progress: Implementing a Tiger Team in a Capstone Design Course

Abstract

This paper reports on the initial implementation of a two student "tiger team" in an engineering capstone design class. A tiger team is a small group of individuals that covers a range of expertise and is assigned when challenges arise that helps address the root issues causing the challenge. The term was coined in the 1960's in the Cold War; tiger teams are used in industry, government, and military organizations. While tiger teams in these situations are usually formed around an issue then disbanded, in the capstone class the tiger team was formed for the duration of the two semester long class; details on formation and the larger context and organization of the class are discussed in the paper. The rationale for the tiger team was the observation over many years of a capstone class that as projects are functionally decomposed and subsystems assigned to individual students, a not insignificant fraction of students become "stuck" at some point in time – the concept of "stuckness" is further derived in the full paper. The result is that if delays accumulate on critical parts of the project, teams often struggle to get the project back on track and end up with a cascading series of missed deadlines. The rationale for the tiger team is to help teams identify when parts of the project are getting behind schedule and to have additional, short-term help available.

In the initial implementation described here, the tiger team was two students—one from electrical and one from computer engineering—who volunteered for the position and were confirmed in that role by the other students in the class. Initial data shows that during the problem identification phase of the project the tiger team attended team meetings, helped evaluation project milestone reviews, worked to solve individual and team issues, and regularly met with the faculty. Early in the semester the two tiger team students described their role as unclear and worried their technical exposure would be limited. Later, as the teams developed technical representations, the tiger team provided independent feedback and addressed multiple technical challenges. Finally, as teams started to build technical prototypes the tiger team role again shifted to helping individuals with specific aspects of their project; this role continued throughout the remainder of the year-long course. This in-depth case-study of the experience of implementing a tiger team draws on observations from students, faculty, the tiger team members, and an external ethnographer. This work may help other capstone instructors who may be considering similar interventions.

Introduction and Background

This work-in-progress paper reports on observational action-based research on initial attempts to integrate a tiger team in a capstone design class. The origin of the term "tiger team" is not clear but it seems to have arisen in the military to refer to teams that were assigned to test the security of existing military installations. The use of the term became more widespread following adoption in the 1960s by NASA managers when used to refer to small teams of experts tasked with solving difficult and pernicious issues; 'tiger team' in NASA was defined as: "a team of undomesticated and uninhibited technical specialists, selected for their experience, energy, and imagination, and assigned to track down relentlessly every possible source of failure in a spacecraft subsystem or simulation" [1]. For example a tiger team was formed during the Apollo 13 emergency to get the astronauts of the damaged module back to earth. As with the original usage, tiger teams are still used for security assessments by testing an organization's defenses against spying, industrial espionage, or its computer systems [2]. Tiger teams are also used in government to assess compliance with health and safety, environmental, etc. regulations.

The idea of integrating a tiger team into a capstone class had been percolating in the author's mind for some time. With several breaks, the author has taught capstone classes for over two decades and during that time has repeatedly observed a set of individual and team behaviors that can best be described as "stuckness". Stuckness is best defined as a multifaceted concept that captures a set of behaviors that introduce delays into design projects; many of these behaviors are listed in Adams and Crismond's *Informed Design Teaching and Learning Matrix* [3]. There are many ways that stuckness exhibits itself in design courses. One way is that an individual student cannot move forward on their portion of the project – their task may be outside their bounds of knowledge, they are under-prepared, or the magnitude of the task seems overwhelming (e.g. 'task paralysis'). Another facet of stuckness is that teams tend to address problems that lie within their capabilities first, leaving more difficult or less-definable problems to be addressed at a later point in time. Eventually progress stalls and teams have difficulty reorganizing their resources to the more research-focused approach that is needed to make progress on the challenging parts of the project. Stuckness also exhibits itself when teams have difficulty in researching and abstracting the given design such that they become focused on a narrow set of possible solutions that does not lead to a workable outcome. A similar situation arises when teams do not put sufficient thought and effort into creating design representations (see below) which results in poor project organization and planning. Failing to reassign team members to the most pressing tasks and jumping too early into project implementation is another way teams become overly focused on unproductive pathways, which also can lead to stuckness.

Stuckness has been a perennial issue in the capstone course described here, leading to non-optimal project outcomes in many cases. Stuckness not only affects projects, but individual students as well. Students' mental health can be negatively affected by the shift to less structured problems that often occur in design courses; stuckness seems to exacerbate frustration, burnout, and disengagement. Various methods have been used in prior courses to address stuckness. One successful method is holding individual meetings or consultations with students who are stuck, however this is time consuming for faculty since the program described does not have graduate teaching assistants. Weekly meeting with team project managers (see below) can be effective to help teams think through how to shift time and effort, but are less effective in getting individual students unstuck from the various issues that affect their work on parts of the project. The perennial nature of this issue led to the idea of setting up a student tiger team who would be able to contribute effort and insights to teams who are stuck and additionally provide an outside perspective.

Context

The tiger team was implemented in a one-year long capstone design course in the electrical and computer engineering programs at a private liberal arts institution. The institution is predominately undergraduate; with no graduate students able to serve as teaching assistants the course is managed by two faculty – one electrical and one computer engineer. The course is organized around external projects sponsored by regional and national companies. Projects are undertaken by teams of mixed electrical and computer engineers. Most projects are subject to non-disclosure agreements. The year-long, two-credit capstone course occurs at the end of a four-year design sequence consisting of a one-credit course in the first year, a half credit course in each of the second and third years, then the capstone sequence in the fourth year. Note that one course credit is equivalent to four credit hours.

The course is roughly organized around a generalized "V-model" for systems development [4], Figure 1, but also integrates a considerable number of agile design elements. The course is divided into seven design phases, each with a set of deliverables that correspond to the V model stages. In the validation phase which occurs in the fall semester student teams create design representations as they divergently explore their problem and possible solution approaches. In the spring semester the teams enter the verification phase and begin to converge towards a prototype solution which is delivered to the client at the end of the course. At each phase of the design a formal check-in provides feedback to the team.

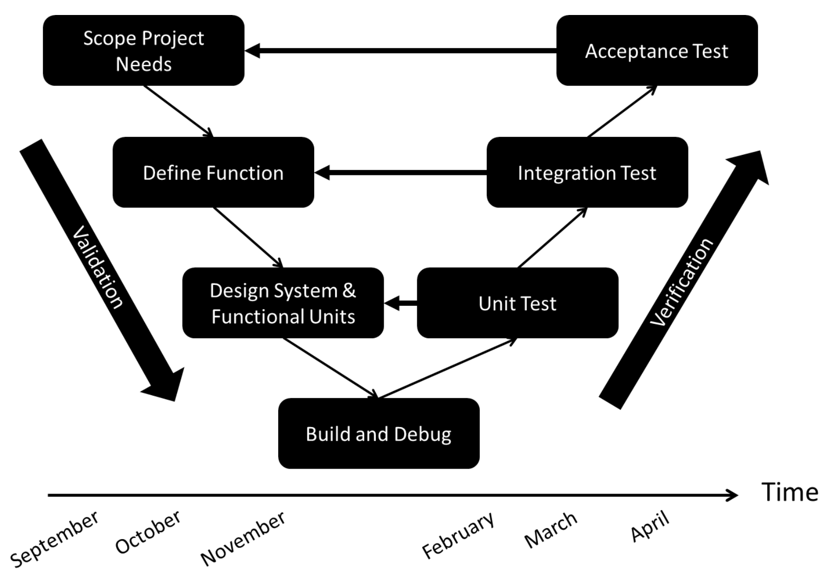

Figure 1: Representation of the V-model on which the capstone class is loosely based.

The design representations student teams create guide the project at all stages of the design process. Representations near the top of the Vee capture contextual elements of design while those near the bottom of the Vee are more detailed and technical, e.g. block diagrams, flow diagrams, and schematics. As student teams navigate through the design course their designs become represented in increasing levels of detail during the fall semester with the overall goal of decomposing the project into functional modules. In the spring modules are built and tested, integrated, iterated, then the project finally undergoes an acceptance test. While the V-model is intuitive for those with design experience, as a project management model it does not accurately the reflect the actual and iterative work of design so it needs to be implemented flexibly and with significant scaffolding.

Because capstone courses can be very time-intensive for faculty, the instructors have developed a significant amount of scaffolding over time using an action-based research approach [4] (see next section). This has resulted in a "hands-off" approach where students have responsibility for most project decisions. While successful in avoiding faculty burn out over the decade the course has been developed over, it does require a shift in student mindsets to be given an unfamiliar level of agency and responsibility for their project. This shift in student attitudes is one of the desired outcomes of the course, which the faculty sometimes jokingly refer to as a 'seven step program' designed to transition students from a school to employment environment. This shift is supported by several structural aspects of the course. One of these is the use of flipped classroom methods supported by Perusall [5] whereby students work on design representations in class to get feedback from the instructors. Another support is liberal use of 'mock' design check-ins to get feedback and make corrections prior to completing each phase of Figure 1. Design check-ins are scored using the same rubric over the course of the year to give teams feedback on their progress. The rubric monitors the team's progress on eight 'facets' of design: help people, understand the context, choose useful functions, design transparently, build to last, improve performance, create value, and act professionally. Team function is monitored using peer evaluations [6], [7] and written reports undergo significant feedback using a competency-based rubric.

Unlike many capstone classes this course uses large teams – typically six or seven students. These teams have defined roles: one project manager responsible for communication, client communication, and project logistics; one system engineer responsible for overall project architecture and interfacing; and four or five design engineers who are assigned to design and implement one or more functional blocks in the project decomposition phase. These roles are chosen midway through the fall semester after teams have been through the norming phase [8] and students stay in the role for the duration of the year. The course instructors meet weekly with project managers and system engineers to keep up to date on progress and address any issues. While this structure is manageable in terms of faculty time, there are periods of the course—particularly during the system and sub-system design, build and debug, and unit test phases—where more one-on-one interaction with the students in the role of design engineers could be beneficial.

This year the course had 23 enrolled students which would have been four project teams of five or six students each, or three project teams of seven or eight students. Experience has shown team sizes of five or eight make teams awkwardly large or small so the idea that had been percolating for some time—having a small tiger team—was implemented. To form the tiger team the concept and potential roles were explained in class and the instructors asked for volunteers with the understanding this was optional. Five students volunteered and then the class was polled confidentially to identify overall thoughts and any concerns with those who volunteered. Based on that feedback, how the students were viewed by their peers, and how individuals had performed in previous classes a two-person tiger team was formed with one electrical and one computer engineering student.

Methodology

This work-in-progress paper reports on the observations to-date of how implementation of a student tiger team has affected the capstone course. The year-long capstone course sequence has been part of an action-based research project for approximately ten years. The course from which results are reported has been iterated over time using an action research approach [4]. Action research engages the researcher(s) as well as other participants in improving or iterating upon the actions taken in a given scenario. Over the ten-year period the course has implemented an annual cycle of acquiring faculty and student feedback during the academic year, having the faculty analyze this feedback over the summer, then implementing selected modifications to the course structure before the next academic year. Over the development cycle ideas from the design literature and other capstone courses [9]–[13] have been implemented into the course as well as ideas from agile start-up businesses learned through the NSF ICorps-L program [14].

After the tiger team was formed the instructors outlined what the goals of the tiger team were—help teams or individuals who were stuck (as described previously)—and then asked the tiger team to work out details of how they were to operate. To support the tiger team they were integrated into weekly meetings with team project managers and system engineers, and they also scored team design check-ins on the same rubric used by faculty, but in an *ex officio* capacity. The goal was to: 1) give the tiger team additional insights on team functioning so they could help intervene when necessary, and 2) to show the class as a whole that the tiger team had full support of the course instructors.

Insights into how the tiger team made sense of their work as the capstone projects started came from multiple sources. The weekly meetings allowed in-depth conversations with each team and the opportunity to see how the tiger team interacted with project managers and system engineers. All student teams had a Basecamp site [15] and each student was required to post project updates and reflections at least once a week; Basecamp posts (or lack thereof) affected student grades. These posts gave a window in time to how the tiger team defined its function. Since the work of the tiger team was to address 'stuckness' the regular posts provide a rich history of the thoughts of the team members over time and provide an archive of relevant documents. Each team was required to submit two mid-semester and end-of-semester reports – one on the project and one on team function. The report format did not align with the work of the tiger team, so they negotiated a different format for their report. These reports provide additional insights into the functioning and challenges the tiger team faced. This evidence was supported by observations by the faculty teaching the course on tiger team interactions with other teams, and informal discussions with tiger team members over the course of the semester. Finally an end-of-year group meeting between project managers, system engineers, and the tiger team provided participant feedback and cross-checking on larger themes that had emerged.

This work in progress paper reports on the impact of the tiger team to-date in the capstone design course. At the time of writing the course is approximately 95% complete so the full effect of the tiger team is mostly, but not fully known; updated results will be presented at the conference. However the results to date do suggest several ways that a peer tiger team can address 'stuckness' as well as other issues not anticipated at the start of this intervention. These preliminary results also raise several questions that input from the larger design community can help address. Among the usual confounds to such observational studies, there is one additional factor that complicates the results presented. Several years ago the program made significant changes to the curriculum, more than doubling the number of academic credits devoted to design [16]. This year was the first cohort of students to complete the revised design sequence which complicates comparisons with past years. However since the symptoms of 'stuckness' were still present during the course, the effect of the tiger team on addressing this issue can be reasonably well understood within these limitations.

Preliminary Results

As of this writing the design teams have concluded the acceptance tests (Figure 1) and are preparing for a final public design exhibition. The full extent of the tiger team experience is mostly understood but a key piece of feedback—the whole-class after action review conducted during finals—is not complete so revised results will be reported at the conference. However, after most of the year it has been possible to observe the evolution of the tiger team and its interaction with the seven-person design teams which are described chronologically below.

The tiger team was formed in the third week of the year-long design course. In the first six to eight weeks of the course teams focus on problem identification and definition through a process of data collection from interviews which are summarized in design representations [11]–[13]. As the tiger team did not have a project during this period there was some initial uncertainty about what the appropriate tasks for the tiger team should be. Following a discussion with the course instructors that they were primarily constituted to ensure the success of other teams, they decided that they should sit in on meetings to observe how the other teams' design processes evolved and provide any help they could. Although this process of observation proved to be provide insights into how team's started to frame their projects, over time a level of frustration built in the tiger team as they begin to believe their role would remain non-technical for the remainder of the year.

Thus in the divergent, early stages of the projects the role of the tiger team's work was also somewhat divergent as they sought to understand the processes that were emerging within the three design teams. The tiger team did, however, provide a convergent element to the class since they shared observations of effective practices and other relevant information between teams. For example, one team was having difficulty conducting interviews since the email invitation they used was confusing and poorly written. The tiger team shared the invitation formats from other teams to improve the team's effectiveness in obtaining interviews. As the tiger team struggled to define themselves, the course instructors had them participate in reviews during design check-ins to give them further insight into the design process. While tiger team feedback was not used to assign grades, this served to help calibrate the tiger team to expectations. Having the tiger team help to review other teams may have had a negative impact; as one tiger team member reflected: "*Over the past week we definitely furthered our outsider status to the teams, sitting with the professors and giving advice to the teams on their GMAs and System Maps.*"

About six weeks into the first semester the time required to participate in three team meetings per week began to wear on the tiger team and they reorganized their own processes to be more selective about which meetings to attend. This shift in process was a bit of a crisis moment for the team as they begin to question their own role and value since the other teams were better defining their projects and forming more cohesive teams. Holding a discussion with the tiger team helped recalibrate them to the fact their 'project' was to determine how to help the other team's succeed better than they would have if the tiger team did not exist. After some reflection the tiger team came up with several ways their efforts seemed to be helping teams: identifying from their quasi-outsider perspective assumptions that had become 'baked in' to the projects, sharing best practices between teams, sharing information one team learned that was relevant to other team projects, and engaging in team social events to maintain connections.

However it turned out that the sense of being able to help teams vs. feeling useless was to be a recurrent and oscillatory theme during the entire period of observation; as one of the tiger team members said in their reflection: "*All in all, I feel very useless right now, and I don't really feel like I am creating any value to the teams. I feel out of place I guess.*" This oscillation—a sense of helping teams shifting to a sense of being useless—was particularly pronounced at the midpoint of the fall semester when teams begin to shift from the divergent to a more convergent process. At this point teams are struggling to make concrete plans to guide the construction of project prototypes and also beginning to break work down into individual tasks that will be completed by team design engineers. Based on experiences in past versions of the course this is one of the most difficult periods in the course since students have little prior experience in system design and simply need to "sit" with the project for a period to start making sense of the next steps. It is likely this period of uncertainty, which requires teams to start to engage in more rigorous research, did not align with how the tiger team has previously been of service to the teams. To address this feeling of being useless the tiger team created a Google Form for the team project managers and system engineers to share issues they were facing that the tiger team could assist with. This feedback, while somewhat helpful in itself, led to much more productive meetings between the tiger team and the team project managers and system engineers.

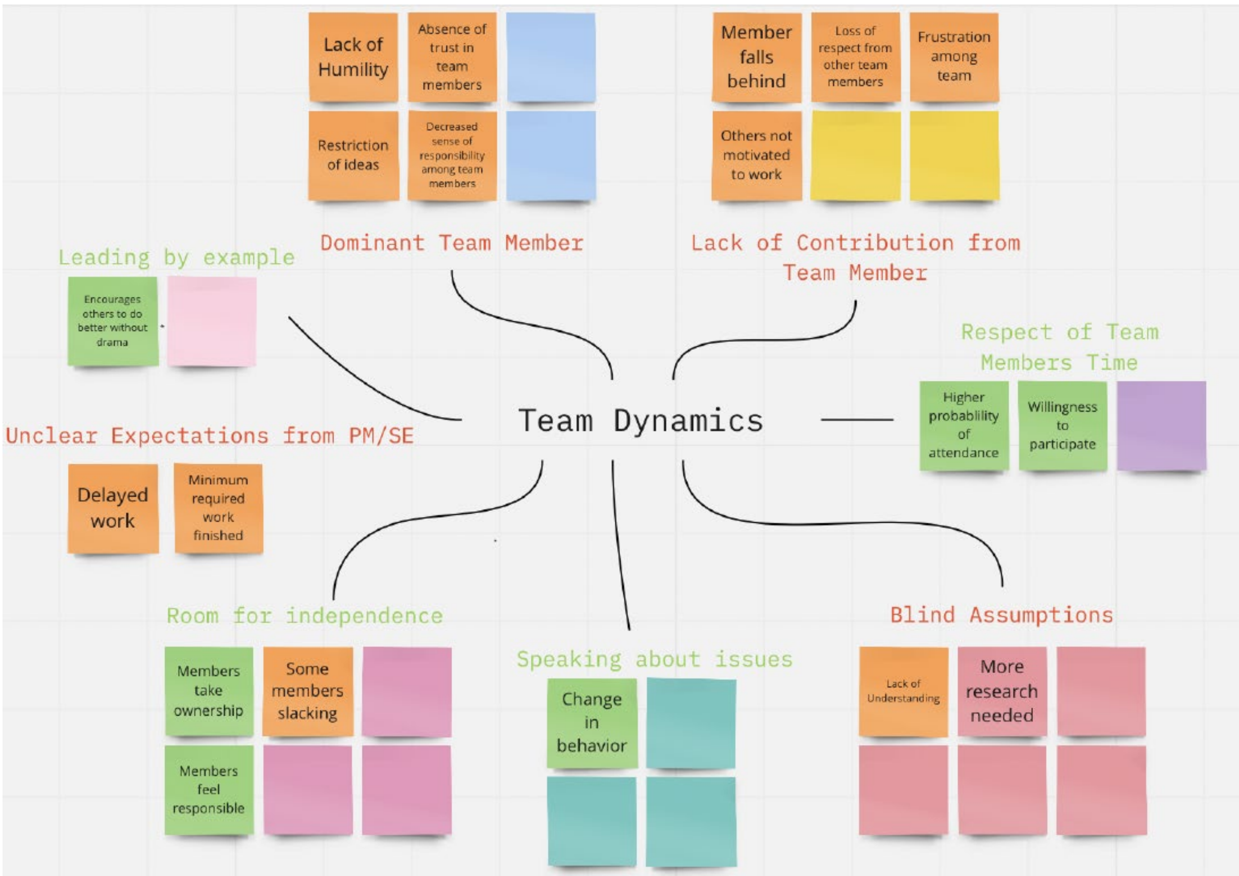

Figure 2: Observations of team dynamics reported by the tiger team midway through the second semester.

In the last six weeks of the fall semester teams completed project decomposition and assigned functional blocks to the design engineers on each team. The fall semester ends with an exploratory prototype phase where each design engineer creates a series of three “build videos”, spaced two weeks apart, that documents progress on their part(s) of the project. The tiger team found this exercise helpful in confirming which team members would likely need help in the second semester when individual design engineers had to create functional units of the project. To wrap up the Fall semester the tiger team struggled to complete an end-of-semester report. Since the report follows a template which was not suitable for the type of work done by the tiger team, the instructors negotiated the report format with team to create a report template they felt more accurately matched their efforts over the course of the semester. The report gave some insights into ways that tiger team felt they had helped the other teams. Such help included observations of team dynamics that affected the performance of the three seven-person design teams (Figure 2), summarizing ways they felt they created value using Carlson’s NABC format [17] (Figure 3), discussing efforts at improving communication with each team, developing metrics to monitor how each team was performing, and a summary of particular interventions with each team. In summary, the tiger team report for the Fall semester provided specific examples of how they helped to support the three design teams during the early and uncertain divergent phases of design. In particular, the tiger team's access to team meetings provided insights into team functionings that would not otherwise have been visible to the course instructors.

Needs	Approach	Benefits	Competition/Alternative
Develop project to meet team's respective goal	Identify places of team struggle through PM communication	Decreased pressure on team members	Work independently of other teams
Knowledge of what they "Know they don't know"	Technological deep-dives in areas of identified issue	Outside perspective on project issues and assumptions	Isolated ideas/brainstorming
Extra set of hands in time of crisis	Open dialogue with professors about team successes/struggles to determine best path forward	Stimulated communication within team	Underlying issues go unnoticed; fester
			Professors do not know team dynamics; leads to future issues

Figure 3: Self-identification of value for the design teams that the tiger team created.

The role of the tiger team changed significantly in the spring semester in two ways. First, as individual design engineers built functional blocks of the project for their unit tests, see Figure 1, the tiger team was increasingly called to support individuals. Historically it is at this point in the project some individual students run into significant difficulty and "stuckness" occurs. To address this issue the team project managers turned to the tiger team for help, indicating that the attention the tiger team paid to relationship building in the Fall semester paid off. The support given to individual students ranged from essentially creating prototypes for individual design engineers who had struggled in the course to simply sitting down with other design engineers so they could bounce ideas around while they worked. As a reflection from a tiger team member put it: "*That being said, I think the work we did with ###### was the most rewarding. I wouldn't say we really did anything at all, besides talk to him and sit with him for a bit while he worked. We came with a few suggestions, and shared our ideas, but it seemed like the fact that we were there was all that he needed to make a lot of progress. In fact, he said it himself.*" The tiger team reported that they were pulled in multiple different directions by the range of assistance that individual students needed, but after the uncertainty of the Fall semester, the overall sense was that they felt as if they were providing significant support.

The second role the tiger team played was stimulated by the fact that going into the Spring semester each team still had areas of significant misunderstanding about their project. The course instructors met as a group with the tiger team and system engineers, projected their technical block diagrams on a large monitor, and methodically worked through areas that had not been completely thought through by the teams. Past experience indicates that areas of the project that are more difficult or involved are often ignored or postponed by design teams in order to focus on areas they feel they can make more immediate progress. However if these difficult areas are ignored too long they create significant issues for the team. Once areas of the project that needed additional research and effort were identified, this provided another "road map" for the tiger team to help individual teams. In this case team project managers and/or system engineers approached the tiger team to help address particular aspects of the project that were necessary, but not on their immediate development path, or for which they did not currently have a design engineer who could be assigned additional work. In these tasks, which generally involved learning material that the undergraduate students had not been formally introduced to in classes, the tiger team was generally successful and, on the advice of the instructors, pre-negotiated deliverables which marked the end of their involvement in particular aspects of the project. As one member of the tiger team commented in their reflection: "*I think the outside perspective of the tiger team was pretty useful during that meeting. It seemed like one of their main issues was that they simply did not know what was going in and out of their various blocks. Because of this, the design engineers cannot really do anything. It seemed like they eventually agreed on some things, and after they agreed on this, we were able to provide some help in terms of Matlab code that will generate random signals*."

Over the remainder of the spring semester the tiger team continued to oscillate in how much its services were utilized. It emerged during the end-of-year group meeting that the less active periods of the tiger team corresponded to the periods the design teams were most actively working on project integration. During times when design engineers had to work on their individual aspects of the project were when the tiger team was most active since individuals often needed help with particular tasks or benefitted from simply talking through tasks.

There was one particular incident where the tiger team provided value by acting in a way that aligned with expected role of tiger teams in government or industry. One of the design teams was working with a software defined radio (SDR), and had integrated it into their project without putting sufficient effort into understanding the theory by which it operated, and as a result had become stuck, unable to move past built-in software functions or demonstrations. The tiger team had been asked to look into the SDR and demonstrate some basic functions needed for the project. Perhaps given that their understanding was less contextualized by the project, they did gain a solid grasp of the theoretical underpinnings. The difference in understandings emerged at a meeting where the tiger team posed some conceptual and detailed technical questions the team was unable to answer, thereby demonstrating the gaps of understanding the team held. While uncomfortable at the time, this turned out to be a pivotal moment for the team, and they pivoted their efforts significantly.

The end-of-year group meeting, held after completion of all acceptance tests, provided rich insight into how team project managers and system engineers, as well as the tiger team, saw the overall effect on the year-long capstone class. Insights that emerged that were not discussed previously included the fact that some individual team members were more reticent to use services of the tiger team; the reason for this is not yet understood. Another insight was that the team project managers needed more support and encouragement to utilize the services the tiger team offered, although there were particular places during the year that tiger team help was extremely valuable. These included getting feedback on how other teams performed during design check-ins, gaining external feedback in the fall on the direction of design projects, and working with individual team members. Overall it became clear that an important role that the tiger team played in supporting projects was 'back channel' communication independent of the instructors. By observing team design check-ins, seeing instructor and review panel feedback, the tiger team helped calibrate expectations across the class in a way that students indicated was difficult for faculty to achieve. Another area discussed during the end-of-year meeting was to what extent the tiger team provided a sense of psychological safety, which is important for overall team performance [18] and which students were familiar with through course readings. While the idea of psychological safety did not fully capture the work of the tiger team, team members did indicate that knowing that 'extra hands' were available at need allowed them to take more risks and be less conservative in targeting project deliverables. Finally it was recognized that who the tiger team members were was very important; while the tiger team was very helpful to team project completion this year having a tiger team that sought the role to avoid work or impose their own views was seen as potentially destructive.

Reflections & Conclusion

With about 95% of the course complete as of this writing, overall the impacts of having a tiger team integrated into the design course are mostly positive, with a few negative aspects. As with most educational interventions the positive and negative aspects are inter-related and don't fall neatly into comparative columns. The ways that the tiger team helped the course and potential drawbacks of the approach are outlined below.

The main goal of setting up a tiger team, that is having a peer antidote to "stuckness", was generally a success. On numerous occasions the tiger team worked with individual students or teams to assist them in tasks that seemed overwhelming or fell outside their critical path. Much of this success was due to the tiger team's efforts to participate with teams in the Fall semester and build relationships. There were, however, some students who refused the help of the tiger team even when it would have greatly aided their part of the project. The reasons for refusal are not clear at this point in time. A small minority of other students over-relied on the tiger team, using their work without putting in necessary additional effort to understand it or expand upon it.

One issue that arose was a need to determine the types of efforts the tiger team could or should assist teams with. While "appropriateness" of tiger team effort was identified as a potential concern in early stages of this experiment, there was no a-priori information to establish a policy. As teams sought to engage the tiger team the types of assignments given to the tiger team varied considerably. Some were similar to miniature research projects, where the tiger team had to learn new concepts and instrumentation to prove or prototype a desired functionality. Alternatively, there were cases where the tiger team was asked to undertake tasks that were more like contract labor, to create particular code or hardware, or to run a series of experiments to tight specifications. This best described as assignments that fall at low and high technological readiness levels [19]. Generally, the tiger team was more effective at tasks on low technological readiness levels that involved more research. There was a particular case where a student asked the tiger team to run a specific experimental protocol, but the protocol was problematic and the student received a poor score on their design check-in because they had not engaged more deeply with the issues. After this incident the tiger team was allowed to negotiate a "right of refusal" with teams to understand what reasonable boundaries were, which helped to avoid the issue of 'scope creep'. At the other end of the technological readiness scale one team's project involved a complicated wiring harness, and this task was not prioritized within the team or valued by the team member responsible. The tiger team was able to help make the project more robust.

A factor that was not foreseen when the instructors discussed setting up a tiger team was the degree of ownership that teams felt towards their project. Despite being peers who made significant efforts to connect with teams, over the course of the semester it seemed as if the tiger team's help was not always wanted or appreciated, even when teams were facing significant challenges. Several hypotheses were advanced to explain this observation: that the teams developed a high level of cohesiveness over the course of the academic year and the tiger team was seen as disrupting team function, that the tiger team was associated with the faculty instructors in students' minds, and that the habits of individual work ingrained earlier in the curriculum were simply too strong to overcome during the year-long design project. As discussed above, it turned out that differences in attitudes of individual students and lack of repeated guidance on accessing tiger team resources accounted for much of this observation. Additionally some portions of project timelines (see Figure 1) were more conducive for seeking help from the tiger team.

Another unanticipated way the tiger team served the larger course goals was to provide peer feedback and back-channel communications. One of the challenges of teaching capstone is that students often interpret faculty comments as commandments from a higher power, rather than as ideas or suggestions in the way they were intended. Observations of meetings and the follow-on results showed that suggestions from the tiger team were parsed differently by the teams than suggestions from the instructors. Teams seemed to have an easier time rejecting suggestions if they were not appropriate and generally seemed to engage more with insights from peers than they did with faculty suggestions. There could be several reasons for this including power differentials between students and faculty, a more shared language between peers, or other relationship factors that are not visible to faculty in the course.

In summary, while the year-long experiment of implementing a peer tiger team is only mostly complete at this point in time, the results are mixed but generally positive. The tiger team did serve the primary purpose of helping address 'stuckness' by being more accessible to teams and also by providing peer-level support on an agile, at-need basis. For teams that exhibited broader dysfunctional behaviors, the tiger team was able to help demonstrate ways for the team to 'get unstuck' in ways that was supportive of instructor feedback. The tiger team also provided significant insights into how each design team functioned that would not otherwise have been visible to the faculty. The tiger team, by keeping detailed reflections on their activities also helped the course instructors see ways in which course activities, deadlines, and structure did not work for students in the ways faculty anticipated they would. These activities will be evaluated following the course as part of the annual summer after-action review, but early indications are that creating more space to address student questions, providing more scaffolding for the divergent phase of design, and changing the format of design check-ins to create more psychological safety could improve the course.

The tiger team itself had a very different experience than was initially anticipated. In the author's mind the tiger team's primary efforts would be working with individual students who were behind on accomplishing tasks; this view was naïve. The intermittent nature of the tiger team's effort was more tied to the project timeline (Figure 1) than anticipated. While such intermittency is likely part and parcel of being on a tiger team, it did have some negative impact on the students' motivation. There were also frustrations when they provided help to teams that did not always accept their efforts or express gratitude for the help they provided. In alignment with Cech's work on a culture of disengagement in engineering [20] and epistemological dominance of rational-technical narratives [21] team members on the design teams were very focused on the technical aspects of their projects and thus undervalued ways the tiger team contributed if it was not immediately helpful. Better understanding of possible reward structures for the tiger team might help with student motivation as would helping to repeatedly clarify their role. Different ways of structuring the tiger team, perhaps having them be members of each of the team and contributing a fixed amount of time each week, could help address such issues. Overall, the tiger team gained a unique perspective on the course by observing how different teams approached design. Tiger team members indicated it was highly rewarding for them when team succeeded in their goals. However, it is not clear at this point in time how the learning that occurred was affected by the more intermittent and fractured nature of their experience.

Other ways by which the tiger team experience might be improved emerged from reflections and observations throughout the academic year and the end-of-year group meeting. As mentioned previously the tiger team helped teams the most for tasks which were at lower levels of the technological readiness level where their work could inform future work that was undertaken by the team. It was less effective as tasks were more highly structured or defined, often because students assigning tasks had difficulty providing well structured definitions. The tiger team also did not have the tacit knowledge developed on teams to allow effective integration of their work into the team projects and thus more helpful in consultive roles. If tiger teams are used in future courses, focusing their work on lower TRL levels would lead to more effective use of their time and effort. The ability to do research also indicates characteristics of students who might be more successful on tiger teams. Setting more clear guidelines on how to utilize the tiger team and regularly communicating this to project managers was also seen as a way to improve

In conclusion, after observing the evolution of a student tiger team over a year-long project perhaps the biggest take-away is how the author's perception of how the tiger team should function was misaligned with how it actually worked. The author's perception—formed by reading about tiger teams in industry and movies such as Apollo 13—was a small group of students who would work to solve challenges that led to stuckness, mostly among individual students. And in so doing would contribute to improved overall success of the capstone course. As in so many cases the strongly held narratives of what engineering *should be* based on practice in industry and the collective myths, e.g. a "Sputnik moment", failed to match the very human reality that exists within engineering education. The reality is that the tiger team likely did contribute to greatly improved course outcomes—with potential effects of the confounds described previously—but how this happened was not due to technical prowess. Rather the tiger team created a space that had more surplus and less deficit of time than was typical in the capstone course. By visiting individuals and teams the tiger team created a climate with improved communication, better integration of knowledge and expertise across teams, and more trust building. The tiger team served as a valuable "back channel" of communication between teams independent of, but aligned with, the course instructors. While the tiger team did support students who were stuck, these factors likely played a bigger overall contribution.

Overall the initial take-away from one year of having a tiger team is that it was a net positive for the class, but depends very strongly on the individuals involved and setting up a supportive culture. Setting clear expectations and communicating them regularly would improve the impact of the tiger team. This work was funded by the National Science Foundation under EEC-2022271. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation.

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