



From Serious Leisure to Knowing Organizations: Information and Knowledge Management Challenges in Project-Based Learning Student Engineering Teams

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Introduction

Critiques of contemporary engineering education have highlighted issues of limited applied and “soft” skills development [5], retention issues in STEM education [13] and concern about a mismatch with industry demands for graduates [1].

Facing similar challenges, medical and nursing schools have leveraged problem-based learning (PBL) strategies where students engage medical cases collaboratively and independently, with faculty serving as facilitators of a student-led learning process [12].

Engineering educators have adapted similar PBL approaches such as capstone design projects and engineering student design teams to complement the more traditional, basic-science based engineering curriculum. Project-based learning (noted as PBL*) team opportunities are qualitatively different than traditional PBL efforts in one demonstrable way. Engineering project teams tend to engage more complex design challenges over a longer period of time compared to in class PBL investigations commonly used in medicine[2]. This qualitative difference creates two organizational challenges unique to engineering project-based learning teams.

Student PBL* teams must sustain team motivation throughout a long and often arduous process of design and development. Much of this effort is not explicitly rewarded – indeed, it often cuts into time and effort normally spent on other curricular and social activities. For many participants, PBL* teams are serious leisure opportunities [15], shaped by intense intrinsic motivation, considerable personal sacrifice, strong self-identification with the task at hand, and considerable investment of energy and resources.

The extended time period and complexity of investigation in engineering student design teams also requires that engineering teams develop into effective and sustained knowledge-based organizations. In doing so, student members and leaders engage organizational knowledge management challenges rarely formally taught in the traditional engineering curriculum, including effective sense-making, professional knowledge creation, and effective and timely decision making [3].

This paper describes a larger effort to build a model of the organizational and knowledge management challenges project-based learning team participants face. This effort leverages cultural-historical activity theory (CHAT), a complex, dialectical analytical model of situated collaborative action that highlights the contradictions student members and leaders face in realizing a team’s end objectives and goals.

While these contradictions and challenges are arguably applicable to all engineering student project teams, specific attention will be paid to Formula SAE (FSAE), a design

competition series with a long history and worldwide reach, now including nearly 500 collegiate teams in over 20 countries worldwide. Early research from the author's participant observation with one team is discussed in this paper, and is presented as a foundation for future research within the global FSAE community and similar PBL* teams.

Engineering PBL* Teams as Serious Leisure

PBL* teams provide engineering students with opportunities to apply academic learning to a variety of applied contexts and gain valuable practical experience with “soft skills” such as teamwork, project management, interpersonal communication, conflict negotiation, and management. A range of structured, sustained efforts regulated by external bodies have emerged across the engineering curriculum to help support such efforts (e.g., interuniversity competitions such as RoboCup, Mini Baja, Formula SAE, Solar Decathlon, Concrete Canoe or DARPA Grand Challenge, to name a few.)

PBL* teams are fueled by the energy of intrinsically motivated students. Most such projects are organized and led by students, with faculty playing a mentorship role. Committed students self-organize to discern project requirements, set interim deadlines, establish required organizational structures to meet those requirements, and make appeals to internal and external partners for financial and resource support. While some competitive teams may receive some token curricular reward for their efforts, the time and energy spent on such projects dwarf what students would normally spend in formal classes, and many teams don't receive any formal curriculum acknowledgement. Such projects are largely a work of love realized by passionate and driven students, primarily on a voluntary basis.

Robert Stebbins' concept of *serious leisure* is an appropriate frame to examine such activity in a range of informal and voluntary settings. According to Stebbins, people engaged in a serious leisure effort show the following characteristics:

- a) perseverance to accomplish the task at hand;
- b) the ability to progress along a career-like path;
- c) the investment of significant investment of personal time, money and energy;
- d) achievement of an intrinsic and highly personal benefit;
- e) strong personal self-identification with the pursuit, and;
- f) identification with a shared ethos and community of practice with those who share the activity. [15]

Serious leisure studies have covered a range of committed but voluntary efforts, including sports fandom [8], gourmet cooking [7], lifelong learning communities [11] and volunteer firefighters [17].

This paper argues that the same energy and focus on creation is found in engineering student PBL* teams. Students engaged in such teams must commit to a project far larger than their own personal hobbyist/tinkering efforts and in collaboration with like-minded students. PBL* team members often spend considerable time and energy towards this pursuit – at times to the detriment of their other academic or social commitments.. This sacrifice is only made

possible due to the intrinsic personal connection the student has to the project, and the social bonds and sense of belonging that results from working with similarly engaged students. Non-participants may look upon such commitment as extraordinary, odd, or perhaps both. There are clearly easier ways to muddle through an engineering degree. But the transformative nature of such commitment arguably makes a far greater imprint and impact on the students' future careers than, say, cramming one night to get an B on thermodynamics exam.

From Serious Leisure to Knowing Organizations: A Cultural-Historical Activity Theory (CHAT) Approach

While leveraging intrinsic motivation is likely to engage, motivate and hopefully retain many students in an engineering program, the goal of education is not to simply satiate student motivation but to transform that energy into appropriate and responsible professional practice. Many of the rules and regulations of engineering project team competitions are designed to encourage such professional development and maturation. However, this necessarily creates some potential contradictions between individual passions and the intellectual demands of professional knowledge. How intrinsically motivated students manage to negotiate these tensions is of particular interest in this paper.

Cultural-historical activity theory (CHAT) is an appropriate theoretical frame to analyze such contradictions and tensions in social practice. CHAT is quite compatible with the constructivist pedagogical foundations of problem- and project-based learning, and has been used to frame research in a variety of design and technology domains [10, 16].

The foundations of CHAT were developed by Leont'ev, a contemporary of constructivist philosopher Lev Vygotsky. Leont'ev posited that the foundational element of human activity was intrinsic individual motivation and drive [9]. He qualified this drive by noting that it was shaped by structuring forces in the individual's social, cultural, and political context, leading to necessary tensions between a subject's individual motivation and the eventual outcome of the activity at hand.

Ygro Engestrom is largely considered responsible for the reinvigoration of modern CHAT [4] and its integration into Western thinking. His representation of the dynamics of CHAT is included below:

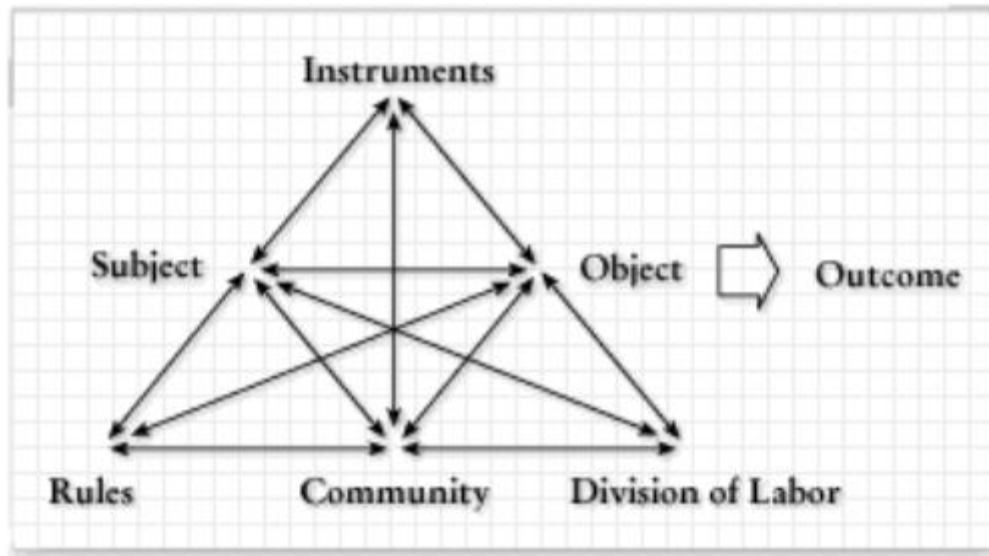


Figure 1: Cultural-Historical Activity Theory Model [4]

This model proposes a dialectical model of conflicts and constraints among the above nodes in the diagram. What follows is a summary of these nodes and contradictions to the end of creating to an operational definition suitable to the topic at hand.

The **subject** is the active individual involved in the activity. He/she is necessarily constrained by the other nodes that influence and shape the effort towards achieving the eventual **outcome**. **Instruments** (also noted as tools and artifacts by some) are mediating influences between an individual's effort and the eventual **object** of activity – a result that may or may not meet the demands of the desired **outcome**. In Vygotsky's initial construction of socially constructed activity, instruments can be seen as similar to media of investigation or expression.

Underlying Vygotsky's initial subject->instruments->object dynamic are forces that are more social, cultural and political in nature. Rules, community and division of labour were concepts Leont'ev added to Vygotsky's model of socially mediated activity and are more collective in nature. **Rules** can be either formally prescribed (e.g., laws, regulations) or serve as unwritten expectations (e.g., organizational culture, practices and norms) and can be either internal to an organization or imposed by outside agents or governing bodies. **Community** envelops the concerns of all those not directly engaged with the activity but who are nevertheless potentially affected. Negotiation and resolution of conflicts is represented by the **division of labour** node, and can include negotiation of internal roles and responsibilities (e.g., the formation of an organizational hierarchy) as well negotiating with external authorities and jurisdictions, and coping with power inequalities among given parties.

Engestrom expanded the activity model outlined by Leont'ev by highlighting four types of contradictions inherent in the realization of human activity: primary, secondary, tertiary, and quaternary. **Primary** contradictions exist within specific nodes – for example, if one subject has a particular interpretation of a problem, but another has a completely contrary view, both will have to negotiate their differences to continue working together.

Secondary contradictions are conflicts among nodes in the activity model. There are many potential conflicts that may arise in this model. Individual subjects may choose different instruments to engage activity and end up with divergent objects as a result. Individuals may engage in behaviors that contradict formal rules or generally assumed norms of behavior. Community interests may either enable or constrain individuals and teams in their pursuit of a given outcome. These and other potential relations have to be negotiated to assure appropriate progress towards the eventual outcome.

Tertiary contradictions involve changes in the activity and its context over time. For example, organizations that rely on a strong organizational culture that maintains an ethos of “how things are done around here” may run into considerable problems if changes in the problem context require a new approach or way of thinking. As Snowden notes in his Cynefin model of organizational change, predictable behaviors based on best practices may work well in stable and predictable environments, but if the surrounding problem context evolves to a complex or chaotic state such previously valid activities may be invalid or even counterproductive[14]. Changes over time may also include demonstrable changes in budget or human resources.

Finally, **quarternary** contradictions are conflicts among competing activities – e.g., when one organization is in direct competition with another attempting to achieve a similar outcome. There are many possible outcomes to such a conflict, from cut-throat competition for limited resources to a cooperative model where competing organizations choose to operate in synergy to realize their mutual goals.

Formula SAE as an Exemplar of PBL* Student Engineering Teams

As a theory, CHAT is incredibly helpful in charting out the many obstacles and pitfalls a student engineering project team may face towards the realization of their intended outcome. It is, however, a rather obtuse read that makes more sense when demonstrated in practice. What follows is an investigation of some contradictions the author noted while acting as a participant observer, team member and leadership consultant for a particular team competing in the Formula SAE (FSAE) competition.

Formula SAE: An Overview

FSAE is a long established engineering project-based learning competition with wide global reach. FSAE competitions have been run since 1981 and at present involve nearly 500 teams in approximately ten annual competitions worldwide [6]. The goal of an FSAE team is to design, manufacture, test and run a fully-functional one-seat open-wheeled racecar. FSAE cars must conform to a stringent and detailed set of competition rules that ensure student-built cars are safe for operators and spectators alike and define particular systems (e.g., power plant, fuel options, cost restrictions) to level the playing field among competing schools. The end goal of a FSAE team is to enter their vehicle in an FSAE competition, with the ultimate goal being to beat all other competing schools in a series of static and dynamic events. Successful teams maximize their potential to earn points across the many competition events – those teams that focus unduly on one event find themselves struggling considerably in others. And, of course, some good

fortune is involved – in the final endurance run, if something is bound to go wrong, it usually does. A minor oversight or flaw in design, build quality or routine maintenance can scuttle an entire year of hard work in seconds.

My Experience as a Observer, Participant and Team Member

My experience with FSAE happened somewhat by chance – I returned from summer vacation to my research lab to discover we had entered into a research contract with our school's FSAE team to assist with issues of team dynamics and communication. I was working with a colleague who had difficulty accessing team leaders and members due to her work schedule, so I became the point person on site. I quickly felt my own intrinsic passion for the project develop to the point I adopted the team as a potential dissertation project.

While I was unable to complete dissertation research at the time due to issues in my home department, I did immerse myself deeply into team culture as I moved from passive observer to participant observer, team member and management consultant to team leaders and the team's faculty advisor. I played a variety of roles over the context of five years, helping the team win four FSAE competitions in that time.

This shift in engagement was necessary to truly understand team culture. As I became involved in design, manufacturing and testing, team members initially wary of my presence started opening up about their work and the team's many unobservable practices (e.g., the existence of a mailing list called "nasty", an aptly named outlet for sophomoric humor and juvenile banter.) The more I volunteered, the deeper I was able to tap into the true dynamics of the team and its practices, and the more my meddling in those practices was tolerated.

The experience also led me to personally experience the profoundly transformational nature of project-based learning pedagogy. Until I joined the team formally, I had never taken an engineering course in my academic career. By the end of my time with the team, I could engage in considerable and detailed conversations about vehicle design with colleagues, design judges and competing teams. (On visiting Toronto's lab one year, I engaged in over two and a half hours of "shop talk" until finally being tripped up on a question on the optimum Ackermann steering angle.) This transformation was similarly evident in other team members, who quickly learned team practices and were able to represent the team's activities to interested parties after exposure and experience.

Coping with Contradictions: Lessons from the Field

As CHAT notes, the path from a subject's intrinsic motivation towards an eventual outcome involves negotiating a series of challenges and contradictions, many of which can be quite complex with no evident right answer. Team members have to learn how to work with others effectively and balance individual, organizational and outside groups' priorities in an effective manner to reach the team's desired outcome. The embodied knowledge and skill sets developed are extraordinarily valuable in professional development and practice, and are not (and arguably cannot be) well covered in traditional engineering pedagogy.

What follows is a small sample of specific instances of contradiction noted in my time working with the team. Discussion of these instances are informed from field notes taken during my time with the team, three management reports written to team leadership, and a comprehensive email archive of team communications (as part of research, I was given access to leader and subteam email lists, as well as “nasty”, where I became a rather regular contributor.)

“We’re in danger of becoming the best organized 35th place team in history.”

As teams mature, they develop their own mores and rules that serve to focus – and at times constrain – the energies and motivations of individual team members, some of whom may not appreciate such change.

The above observation was shared to me privately by a valuable but rather complex team member. The team was undergoing a shift to a more bureaucratic management model, driven by a team leader who started to implement a range of organizational reforms to streamline team administration, thus creating a secondary contradiction between individual subject motivation and team rules and practices.

Her passion for organization proved very fruitful –organizational processes were established and tracked at a level never before seen in the team office, leading to efficiencies in scheduling, fewer administrative errors, fewer misplaced or forgotten orders and more transparent team budgeting. Such attention to organizational governance did, however, run afoul with team culture, which was not accustomed to such processes. This was particularly problematic with the more creative engineers, who began to resent such interference in their work. Minor battles around filling out forms escalated into an active tension among a valuable section of the team and the team leader, decreasing morale and motivation. My friend above was conspicuously absent for a few team meetings, preferring to stay in the lab and work while what he perceived as administrative nonsense droned on.

Even I started feeling the pinch – one evening, I entered the team office to request the purchase of some rivets for an aluminum crush zone I was fabricating. The formal purchase process required team leaders sign off on all purchases, which would then be procured by the business team through our chosen suppliers. I argued that such a minor purchase (approximately \$2) was not something requiring sign-off and shipping delays. My request was denied - so I went to the hardware store and paid out of pocket. I was dressed down for violating procedure.

These tensions were eventually resolved through building a mutual understanding of the benefits of organization and the necessity of sustaining a free and creative work environment unencumbered by procedure and forms to the fullest extent possible. Some people (including myself) would serve as liaison to the business team so that creative talent could simply do their work without undue interference.

“They made YOU coordinator of safety and professional responsibility?!”

A considerable challenge faced by PBL* teams is their relation to their supporting school. The goals and objectives of teams such as FSAE are at times divergent from those of

administration, who rightly are concerned with operational, liability and safety concerns, creating the potential for secondary-level contradictions between team objectives and university administrative requirements.

Later in my time working with the team, I was hired by the College to assist engineering project teams with issues of safety and professional responsibility. Those who know of my participation in various late-night missions found this rather amusing. But it was a role I took seriously – I wished to protect the creative culture of these teams from what I perceived to be an encroaching and conservative school administration, all the while defending the College's very real concerns.

The work environment the project teams shared was a very creative and dynamic space, buzzing with activity at all hours of the day. A bunch of engineers with various tools at their disposal roaming the halls at 2am after working all evening can invent all sorts of things, from useful to the bizarre.

One evening, I went to the lab to find a group of students attaching industrial blue garbage bags together and inflating them with a tank of helium that had been "found" in the loading dock. I watched for a while until I realized what was going on – they were making a very large floating penis. (My contribution to the project was recommending that they weigh down the testicles – they were floating upwards, and an upside-down penis has little iconic or symbolic value.) On completion, a number of people walked the 20 foot phallus through town, ending at a parking lot where we released it and watched it take flight.

This was of course a remarkably silly effort, and only one of many side projects borne of sleep deprivation, stir-craziness, and puerile humor. But it was emblematic of the culture of the team and comes part and parcel with an environment designed to foster and stoke creativity. A facilities manager would never approve (and likely inquire where the helium came from). However, I argue that killing off such opportunities for spontaneous creativity, silliness and fun would affect the overall creative impulse of the team. Those behind the penis project were among the best of the group – laying down the law to such individuals would likely demotivate them from doing anything at all. A 20-foot phallus is a small price to pay for a creative work environment.

It should be noted, however, that this creative environment is also fraught with danger. There are multiple ways a team member can harm themselves or others, from high-voltage electric circuits to industrial chemicals. Safety is a key concern of university administrators rightly concerned with university liability. However, it is difficult to get student engineers to be serious about their own safety and the many dangers they face. The common institutional response of formal training is perhaps the least effective way to reach your average young, indestructible engineer - it may satisfy the university's concern of relaying key information, but very little of that information sticks.

This may create an adversarial relationship between rules and a creative community seeing such rules as arcane and byzantine. Mandated institutional compliance may lead to an illusion of a safe environment, but it may be simply for show. The year before I was charged

with safety issues, rumors spread about the possibility of a spot check by government regulators. Administration instituted internal checks for all lab spaces and trained team members on the importance of compliance. One day, the spot check happened. While team leaders were checking down the list of code violations, someone came to my car with a box of assorted chemicals. Much of the MSDS binder had not yet been completed, and these chemicals were of dubious origin. I stored this contraband in the trunk of my car and was told not to return until the coast was clear. I went to lunch, wondering how safe we were actually being.

As safety and professional responsibility coordinator, I attempted to bridge this contradiction by matching the nature of team culture to the spirit of the law to the best level possible. It was not an easy task. One somewhat successful strategy leveraged a tactic implemented by the FSAE faculty advisor. He rightly noted that professional automotive paddocks are clean because wasting time trying to find a particular wrench can lead to disastrous consequences. The team understood this intuitively. Tying safety to performance did help improve compliance, at least within the spirit of the law – aiseways may not have been perfectly to spec, but the benefits of not tripping over spare parts can certainly be appreciated by most and cleans up some of the more basic safety concerns.

A more effective technique in stressing safety is framing key warnings in simple, no-nonsense statements. I recently completed training at a local machining shop, and the shop steward was gruff, to put it mildly. The overarching message was “don’t be a dumbass” – something repeated often while pointing out hazardous devices that indeed would be dumb to misuse. I suspect college administration would have found this pedagogical approach borderline scandalous. I also suspect the students in our session learned more relevant information on not being a dumbass than any two-hour seminar on MSDS datasheets.

“OK, I want you to tell me what this Excel spreadsheet means. There’s no title. No author name. The rows are not labeled. Half the columns aren’t either. This is useless. And it’s in our design folder. Why?”

As noted by CHAT, the instruments and artifacts we use to filter and generate information influences the utility of the resulting object and its relevance to the eventual outcome. While engineers are arguably tinkerers by nature and a lot of “back of the envelope” sketches are done in practice, professional engineering knowledge should be a scientific, unambiguous and structured process. Developing such rigor does require some practice, however.

The above quotation was from a team leader who was rather shocked to find a metadata-free spreadsheet submitted for consideration to defend the car’s design. It had data –with some conjecture, it appeared likely to be from engine dynamometer testing. This explains somewhat the messiness of this data – recording information while sitting next to a running mounted engine is not particularly easy. But the failure to fill in key information later led her to express frustration with much of the team’s data collection and representation methods. At the next team meeting, she called up various spreadsheets from the team server. In some cases, even the likely author of the spreadsheet could no longer remember key variables. Two tests had to be run again to have useful data to show to the competition design judges.

As with many facets of our team, there was a certain sketchiness about some of the work done (indeed, our email server was named “sketchy”). Such sketchiness is not necessarily bad – sketchiness is a byproduct of creative thinking and active discovery. One year, we made our design posters at 3am in the hotel, printing out graphs and gluing them to poster board crookedly. We managed to place second in design – while the presentation was weak, the results were exceptional, as were the people behind them. Pretty pictures and posters are not a replacement for creative effort and talent.

That said, Excel spreadsheets so barren of metadata that the author himself can’t remember what the data means is useless. Appealing to the team’s sense of urgency to win competition and by making a public display of this failure, the team leader was able to corral the team’s creative energies to create cleanly represented, responsible and rigorous data as befitting an aspiring engineer.

This method of compelling rigorous data collection proved more successful than an alternative proposed by another team member, who became embroiled in both primary-level conflict among individuals, posed a challenge to the team’s division of labor, and created yet another conflict between individual effort and team culture. This team member was a senior member of the team, but not formally in leadership. Team leadership chose to tap his experience by assigning him the task of improving the team’s rigor and documentation of vehicle testing.

As the operations manager discussed earlier discovered, team culture was rather hostile to top-down bureaucratic approaches to management. Unfortunately, the team member implemented such an approach. In order to test any component of the car, one now had to fill out a testing form that specified research methods, hypotheses being tested, methodological concerns, analytical tools required and how data would be represented and recorded.

The spirit of this regulation was entirely proper. However, he mandated everyone follow his procedure in advance of any testing. The team’s response ranged from indifference to outright hostility. Many team members carried on with testing, only to fill in the form later when they were satisfied with results. The team member charged with testing saw such illegitimate testing as an affront to his authority. He became frustrated with the team not following orders, and eventually quit not only the role of managing research, but the team entirely.

It was a sad ending to a promising program that identified a real need to professionalize testing, methods, data collection and analysis. Attempts to mitigate the top-down and centralized nature of the testing regimen and reform his role into a consultant and advisor for individuals who wanted to do testing more professionally were unfortunately rebuffed by the testing coordinator, who appeared only comfortable with a more centralized position of authority. Unfortunately for him, in a team run by a mail server called “sketchy”, sketchiness prevailed at the end of the day. The benefits of spontaneous creative engagement proved to outweigh the potential drawbacks of occasionally having random data spreadsheets to figure out.

Conclusion: A Look to Further Research

These three quotations outline only some of the inherent contradictions and challenges that occur in engineering PBL* teams. Such teams are driven by intensely passionate and creative engineers that must learn how to coordinate and channel that passion towards an eventual outcome, avoiding the potential pitfalls posed by interpersonal conflict, organizational norms and culture, a watchful and wary administration, and the laws and regulations of the land, among other considerations.

This paper marks a starting point of further research. From previous conversations at competition and online at FSAE.com, a global meeting place of FSAE enthusiasts, I know that teams struggle with similar challenges regularly and derive their own solutions to such conflicts and contradictions. I will be revisiting both locations in the near future, and hope that our exchange of stories of primary, secondary, tertiary and quaternary contradictions from the field will lead to the development of best practices that others may use to identify and resolve future team management concerns.

Situating these challenges in the more universal language of contradictions of CHAT should allow for transferability beyond FSAE as a context as well. In my work as safety and professional responsibility coordinator, I was able to help set up two other engineering project teams, and the challenges they faced were very similar. Non-engineering PBL* teams could also benefit from observations framed in CHAT. I am currently monitoring the work of a student group creating and managing an annual entrepreneurship conference, and they face many of the same challenges in channeling individual passions towards a desired professional outcome.

PBL* teams raise many resource and administrative challenges. They are more complicated to arrange and accommodate than traditional classroom based learning. However, for the passionate engineer, they are an outlet of creative expression and engagement and an exemplary professional development opportunity. I hope this research enables and encourages similar teams to emerge and flourish, giving future students the same quality of engineering and professional education as I have been honored to experience.

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