Information Behavior and Knowledge Management in Project-Based Learning (PBL*) Engineering Teams: A Cultural-Historical Activity Theory Approach

by

Michael L.W. Jones

A thesis submitted in conformity with the requirements for the degree of Doctorate of Philosophy
Faculty of Information
University of Toronto

© Copyright by Michael L.W. Jones, 2017
Information Behavior and Knowledge Management in Project-Based Learning (PBL*) Engineering Teams: A Cultural-Historical Activity Theory Approach

Michael L.W. Jones

Doctorate of Philosophy
Faculty of Information
University of Toronto
2017

Abstract

This research studies how student engineering problem-based learning teams engage information challenges as they build sustained knowledge-based organizations. These challenges are framed by cultural-historical activity theory (CHAT), a framework that situates individual and collective activity in social and cultural foundations. CHAT notes points of contradiction that can influence a team’s progress towards its intended collective outcome, with different teams identifying and approaching contradictions in different ways.

This research looks specifically at Formula SAE (FSAE) teams, an automotive racing project sponsored by the Society for Automotive Engineers. This research analyzed interview and survey data from 42 respondents in the North American context; 33 from currently competing teams, 9 from faculty advisors, judges and alumni. Results show a diverse range of responses to CHAT contradictions, including calibrating individual motivations to create a team with a diverse range of skills, integrating multiple sources of explicit and tacit knowledge in research and development, negotiating relationships with larger administrative powers, managing knowledge transfer and organizational renewal in a high turnover context, and negotiating when it is best to cooperate with versus compete against teams striving towards the same outcome.

This research situates CHAT as an effective theoretical grounding for similar project-based learning team research, especially for teams operating as long-term knowing organizations. This research highlights best practices that could inform student team leaders in this and similar
engineering problem-based learning team contexts. It is also hoped this research gives school administrators guidance on how to support such teams and integrate their core activities into curriculum. Future research directions include expanding to the international FSAE community and how the FSAE experience influences alumni career goals over an extended period of time.
Acknowledgments

It has been a long and often frustrating journey to get to this point. For lack of a better organizational schema, I will acknowledge those who deserve acknowledgment in reverse chronological order.

I would like to thank the members of my committee who provided excellent feedback and guidance from the moment they became involved. Kimiz Dalkir was an exceptional external appraiser, providing detailed and supportive feedback that reflected a deep reading of this dissertation. Rhonda McEwen was a unanimous choice of the committee for internal examiner for good reason. Both Rhonda and Anthony Wensley have provided professional and personal guidance as I balanced dissertation work with teaching responsibilities in CCIT. Kelly Lyons provided detailed critique of this work and was instrumental in developing it through multiple drafts – I can only dream to be as good a respondent and editor as you. And Chun Wei Choo is everything one could ever want in a committee supervisor– he has been thorough, patient and insightful from day one. His winning the J.J. Berry award for Doctoral Supervision in this latter stages of this process was well deserved. I am blessed to have learned from his expertise.

I would also like to acknowledge the support of the iSchool’s and School of Graduate Studies travel funding to support conference presentations related to this research, the SGS research travel grant to support visits to the Michigan and Nebraska competitions, and the professional and personal support of my fellow colleagues in the doctoral program.

Doing this work while working full time in the UTM/Sheridan CCIT program was no small challenge. I would like to thank Sheridan’s tuition assistance and professional development programs for financial support and my teaching colleagues, managers and support staff, who graciously extended patience as I balanced dissertation and teaching responsibilities.

This work was initially started during my time at Cornell University. As this is time for positive reflection, I will skip naming those responsible for the worst of times. However, this
work would be not have been possible without my experience as a participant observer and team member of Cornell’s FSAE team. Not only did I learn an exceptional amount from my fellow team members, you were a welcome relief from the dysfunction, dishonesty and incompetence of my home department. Particular thanks to FSAE faculty advisor Al George, who supported me through a rocky and ultimately impossible journey – your status in the FSAE community is legendary for good reason.

Previous to that, I still have fond memories of the Resonant Communications crowd and Richard Smith at SFU, both of whom unlocked an entrepreneurial spirit that worked well in supporting my FSAE work. I would also like to thank faculty and friends at Queen’s, notably Kathy Golder who is also now involved with engineering education and has provided wonderful input throughout. Also remembering Cynthia Alexander, whose Politics of Information Technology course I took 24 years ago thinking it would be an easy sixth course. It remains the hardest course I’ve ever taken, but I wouldn’t be here if I dropped it. Going back even further, thanking people like Herns Pierre-Jerome at Lawrence Park, who taught dialectical reasoning in Grade 12 so well that CHAT was a natural fit for me decades later.

I would like to conclude by thanking the nearly 200 people from all walks of life who extended congratulations on Facebook for finally completing this journey – and especially my family for putting up with it all. My parents have been a source of never-ending support and love, and I’ve had some of the best and oddest discussions in my life with my brother. I couldn’t have made it here without you. The first draft of this dissertation was completed while visiting my brother out west, and my parents celebrated their 50th anniversary days after defending this, so I’ll dedicate this dissertation to them.
# Table of Contents

Abstract ................................................................................................................................. ii  
Acknowledgments ................................................................................................................ iv 
Table of Contents .................................................................................................................. vi  
Table of Figures .................................................................................................................... ix  
Table of Tables ................................................................................................................... x  
1. Introduction ...................................................................................................................... 1  
2. Literature Review .......................................................................................................... 5  
   2.1 Contemporary Challenges in Post-Secondary Engineering Education .................. 5  
   2.2 Learning from Medicine: Problem-Based Learning (PBL) in an Applied Science Context ................................................................. 7  
      2.2.1 Social Constructivism ................................................................................. 8  
      2.2.2 Experiential Learning ................................................................................ 11  
      2.2.3 Information Literacy and Lifelong Learning ............................................. 13  
   2.3 Project-Based Learning (PBL*) in Engineering Education ................................. 14  
      2.3.1 PBL*: A Long-Term Project Orientation .................................................... 15  
      2.3.2 PBL* and External Regulation ................................................................. 16  
   2.4 PBL* Teams as Knowing Organizations: Information Behavior and Knowledge Management Concerns ........................................ 17  
      2.4.1 Information Behavior in the Knowing Organization ................................... 17  
      2.4.2 Sensemaking in Organizations .................................................................. 20  
      2.4.3 Knowledge Creation ................................................................................... 21  
      2.4.4 Decision Making ...................................................................................... 24  
3. Cultural Historical Activity Theory (CHAT) as an Integrative Theoretical Approach ................................................................. 27  
   3.1 Historical Emergence and Contemporary Relevance of CHAT ............................. 27  
   3.2 Exploring The Core Elements of CHAT ................................................................. 30  
   3.3 Identifying and Negotiating Contradictions ............................................................ 32  
   3.4 Investigating Key Contradictions in PBL* Teams: A Consideration of Research Questions ................................................................. 35  
      3.4.1 Primary Contradictions ............................................................................. 36  
      3.4.2 Secondary Contradictions ....................................................................... 36  
      3.4.3 Tertiary Contradictions ........................................................................... 37
5.4 Research Question 4: Sustaining the Organization Over Time .......................................................... 130
   5.4.1 Building and Leveraging A Team Information Repository .................................................. 132
   5.4.2 Integrating Alumni Experience Through Continued Engagement ........................................ 136
   5.4.3 Recruiting and Mentoring Future Team Members and Leaders ............................................ 138
   5.4.4 Multi-year projects and Systems Integration ........................................................................ 141
   5.4.5 Summary for RQ4 ................................................................................................................. 146

5.5 Research Question 5: Interteam Collaboration and Competition ......................................................... 148
   5.5.1 Contradiction and Collaboration Within the FSAE Competitive Environment ....... 149
   5.5.2 Collaboration and Conflict Between School Teams ............................................................. 155
   5.5.3 Summary for RQ5 ................................................................................................................. 158

5.6 Summary of Findings .................................................................................................................... 160

6. Conclusion ........................................................................................................................................ 165
   6.1 Summary of Research .............................................................................................................. 165
   6.2 Theoretical Contributions and Transferability ........................................................................... 171
   6.3 Limitations of Research .......................................................................................................... 175
   6.4 Future Research Directions .................................................................................................... 177
   6.5 Conclusion ................................................................................................................................ 180

Appendix A: Questions for Survey and Interview Discussions .................................................................. 182
Appendix B: Questions for Faculty Advisors and Competition Judges .................................................. 184
Appendix C: Informed Consent Form for Interviews and Surveys ........................................................... 185
Appendix D: Screenshot of Trello Card Deck ....................................................................................... 188
References ............................................................................................................................................ 189
# Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Continuum of constructivist learning</td>
<td>9</td>
</tr>
<tr>
<td>2</td>
<td>Choo's integrated model of information behavior</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>Sensemaking, Knowledge Creation and Decision Making in the Knowing Organization</td>
<td>20</td>
</tr>
<tr>
<td>4</td>
<td>SECI and “ba”</td>
<td>23</td>
</tr>
<tr>
<td>5</td>
<td>Engestrom’s representation of cultural-historical activity theory</td>
<td>28</td>
</tr>
<tr>
<td>6</td>
<td>Individual and collective activity in completing a group student assignment</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>Social software design from the perspective of a system designer as subject</td>
<td>33</td>
</tr>
<tr>
<td>8</td>
<td>Social software design from the perspective of end-user as subject</td>
<td>34</td>
</tr>
<tr>
<td>9</td>
<td>Generalized Model of a Tertiary Contradiction, Moving from “Sketchy” to Rational Decision Making Over Design Cycles</td>
<td>98</td>
</tr>
<tr>
<td>10</td>
<td>Potential contradictions in choosing to purchase a front impact attenuator</td>
<td>100</td>
</tr>
<tr>
<td>11</td>
<td>Spontaneous Creativity as Framed By Choo’s (2006)</td>
<td>103</td>
</tr>
<tr>
<td>12</td>
<td>CHAT roles when subjects have an engaged faculty advisor</td>
<td>110</td>
</tr>
<tr>
<td>13</td>
<td>CHAT relationship where special purpose team facilities are built</td>
<td>115</td>
</tr>
<tr>
<td>14</td>
<td>Changes in activity over time</td>
<td>130</td>
</tr>
<tr>
<td>15</td>
<td>Generalized model of systems engineering challenges in multi-year project</td>
<td>143</td>
</tr>
<tr>
<td>16</td>
<td>Interactions between competing teams</td>
<td>148</td>
</tr>
<tr>
<td>17</td>
<td>Cooperation in the face of competitive rivalry</td>
<td>150</td>
</tr>
</tbody>
</table>
Table of Tables

Table 1: Summary of Research Questions ................................................................. 4
Table 2: Traditional vs. Project-Based Learning in Engineering Education .................. 15
Table 3: Engeström’s outline of contradictions ......................................................... 32
Table 4: Summary of Research Questions .................................................................. 39
Table 5: Summary Table of Participants .................................................................... 49
Table 6: Noted tools and instruments in design, development and testing ................... 82
Table 7: Research Questions Revisited ...................................................................... 167
1. Introduction

“I’ve had the Lakers here. I’ve had the Saints here, the Crimson Tide. I thought we ought to do the same thing for the winners of science fair and robotic contests, and math competitions, [b]ecause often we don’t give these victories the attention that they deserve. When you win first place at a science fair, nobody is rushing the field or dumping Gatorade over your head. But in many ways, our future depends on what happens in those contests -- what happens when a young person is engaged in conducting an experiment, or writing a piece of software, or solving a hard math problem, or designing a new gadget.” (Obama, 2010)

Scientific and technological innovation is important in maintaining competitive advantage in a global knowledge-based economy. As President Obama’s quotation implies, a nation that glosses over science and technology education risks abandoning skills that are increasingly important to that nation’s future economic wellbeing. While improving science and technology education is a noble policy goal, how this is best done remains a debatable question. For example, a key component of Obama’s strategy was to create 100,000 new STEM (science, technology, engineering and math) teaching positions at the at the Kindergarten-Grade 12 (K-12) level. This goal is supported in kind by industry efforts targeting support for K-12 STEM education (Nagel, 2012). However, all STEM careers require undergraduate and often further graduate education. It is at the post-secondary level that future scientists, engineers and technologists emerge – and unfortunately, current practices of post-secondary education has long been a matter of some concern (Fairweather, 2008; National Science Foundation, 1998), especially in engineering and the applied sciences where practical utility in professional practice are important considerations (ABET, 2011).

This work begins with an analysis of challenges in engineering education at the post-secondary level. Academics and accrediting agencies alike have critiqued post-secondary engineering education as excessively focused on rote practice of foundational skills, neglecting professional skills development essential for productive employment (ABET, 2011). This approach neglects the practical relevance of the material taught and so-called “soft” skills such as teamwork, effective communication and project management that are essential components of
academic practice. Academic consortiums such as the CDIO Initiative have been launched to respond to accrediting agency concerns by redesigning curriculum in a manner that focuses on disciplinary knowledge, personal and professional skills, interpersonal skills and teamwork and situating engineering practice in social and environmental context (CDIO, 2011).

Facing similar challenges, the medical field moved towards integrating problem-based learning (PBL) into the curriculum. Based in a constructivist, experiential and collaborative pedagogy, PBL encourages student-led investigation of applied problems, guided by faculty that play a facilitative role (Savery, 2006). While there remains some debate about the overall effectiveness of PBL, even skeptics note that PBL increases student motivation and develops key professional skills in teamwork, communication skills, information analysis, and project management (Albanese, 2000; Schmidt, Vermeulen, & van der Molen, 2006).

This research argues that similar student-led engagement with complex problems is a valuable approach in engineering education, and can build from the medical roots of PBL to outline a model specific to the challenges of engineering education. A main distinction is that many engineering challenges – from designing a motor vehicle to creating a mobile software application – are project-based. Project-based learning (noted deliberately here as PBL* to differentiate from PBL) is structured around more complex goals, requires attention to systems integration, and requires sustained effort among a larger team to resolve (Bédard, Lison, Dalle, Côté, & Boutin, 2012; Kolmos, 1996). Of particular interest in this research are projects structured by externally governed collegiate design competitions. Such PBL* teams are formed by motivated groups of students who structure their work around specific rules and deadlines set forth by the competition. Over time, these teams can develop into sustained knowledge-based organizations supporting team goals in an environment characterized by high organizational turnover due to graduation. As such, such teams can leverage information studies research on knowledge-based organizations (Choo, 2006), and a review of some of this literature is provided here.

This work proposes cultural-historical activity theory (CHAT) as a theoretical frame to understand how team members negotiate information management challenges while fulfilling the
team’s objective. CHAT notes that human agency is a core foundation of activity, but situates that agency in social, cultural and historical forces that can pose significant challenges and contradictions (Engestrom, 1987; Wilson, 2009). CHAT provides a multifaceted lens to examine the contradictions PBL* teams face, and has already been demonstrated effective in the framing of information science research questions in similar domains such as human-computer interaction, computer-supported collaborative work and information systems design (Nardi, 1996; Wilson, 2009). CHAT does not provide prescriptive solutions to these contradictions, but does allow a frame to discuss a variety of potential resolutions.

While findings from this research may translate to a variety of PBL* contexts, a particular PBL* context will be studied at depth here – Formula SAE (FSAE) racing, so named after the sponsoring professional agency in North America, the Society for Automotive Engineers. FSAE is a long running international engineering competition with over 500 university teams participating in 10 related competitions worldwide (World, 2016). FSAE teams design, manufacture, test and race a small one-seat open-wheeled racecar. FSAE team members leverage their formal studies to inform the design of well-engineered cars while negotiating the challenges posed by competition rules, financial constraints, regulatory concerns, internal team conflict and the need to continually produce and use relevant knowledge.

The choice of FSAE as a research context is partially based on my own personal experience. From 2001-2005, I served in various roles with Cornell University’s FSAE team and worked with the College of Engineering supporting other PBL* teams. Building from this experience, I aim to examine how other FSAE teams negotiate CHAT contradictions as they work to build sustainable knowing organizations. This will primarily be done through engagement with two research contexts: a survey of FSAE teams attending the two main competitions in North America, supported by visits to local FSAE competitions and local team facilities. This is supported by interviews with faculty advisors, competition judges and alumni, with supporting documentation pulled from available public documentation from the competition organizers and other online sources.
CHAT was used to identify potential contradictions in the FSAE work cycle, which served as the foundation for the following research questions.

| RQ1: What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations? |
| RQ2: How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction? |
| RQ3: How do PBL* teams negotiate contradictions between team activity and intended outcomes and school administration and established norms of practice? |
| RQ4: How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on knowledge to future generations? |
| RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private? |

Table 1: Summary of Research Questions

CHAT was also used to analyze resulting survey and interview data to examine emergent contradictions in depth. A summary of results can be found in Section 5.6. This work concludes with a look at future research directions in this domain and how findings from this context can inform similar PBL* domains.
2. Literature Review

As noted earlier, public policy and industry concerns often focus on developing science and technology education at the K-12 level. This is a necessary focus – without children being interested in STEM (science, technology, engineering and mathematics) in grade school, the quality and quantity of students in the “pipeline” (Heilbronner, 2009) of future students will certainly be limited. However, full development of an applied scientist requires rigorous studies at the post-secondary level, and there have been significant concerns by both educators and industrial interests alike about the quality of the pedagogical process (Fairweather, 2008; National Research Council, 1996; National Science Foundation, 1998). Two core concerns are noted here – fostering student motivation, and developing applied skills necessary for career success.

2.1 Contemporary Challenges in Post-Secondary Engineering Education

In many schools, especially at the junior levels of undergraduate study, students enter large lecture halls where they passively experience facts, formulas and algorithms in an abstract context. These facts are reinforced through assigned problem sets, leading to testing of conceptual mastery in formal examinations. What is more, early-year courses are often deliberately oversubscribed and designed to weed out low performers. This leads to a high-pressure and abstract environment structured around grade performance, versus one that nurtures innate interest in the field or the possibilities of various professional outcomes.

While mastery of foundational concepts is certainly important, failing to engage its contextual or practical application can be a frustrating experience, especially for learners who believe the relevance of material is important (de Miranda, 2004; Nation, 2008). It is worthy to note that CDIO includes “hard” facts in their syllabus as a first step – but note the value and relevance of context, application and applied social skills as equally important (CDIO, 2011).

Such an abstract and competitive environment has been noted as frustrating student motivation (Behrens et al., 2010; Dunlap, 2005; Vallim et al., 2006). Given the freedom undergraduate students have in shaping their professional future, such frustration may lead to
attrition. Dropout rates in STEM fields have long been a point of concern (Seymour & Hewitt, 1997). A UCLA study noted that the majority of its students who matriculated in its STEM programs ended up majoring in non-science related fields or dropping out of school altogether, with particularly high attrition rates among women and minority populations (Eagan et al., 2010). Grade competition has also been noted as a significant factor in STEM students switching to non-science majors (Ost, 2010; Rask, 2010), which are perceived to be quicker and less stressful paths to higher grades, a factor strongly privileged by the millennial generation (Elam et al., 2007) and reinforced by competition for post-graduate professional study. Given a choice between an easy path to a 4.0 GPA vs. a hard path that might lead to a 3.0, it is not surprising that many students choose the easy path.

Professional associations and accrediting bureaus have noted related concerns about the learning outcomes of applied science education. The Accreditation Board for Engineering and Technology (ABET) does stress traditional science mastery, as should be expected. ABET also insists, however, that graduating students can demonstrate teamwork, professional and ethical responsibility, effective communication, lifelong learning skills, and a broad knowledge of the societal implications of their work (ABET, 2011). These are skills that the rote memorization of facts does not develop, begging the question where graduates are supposed to develop such important skills.

Professional organizations and accrediting agencies have strong external forces in influencing applied science instruction, encouraging a broader educational experience with well-rounded skill sets applicable to industry and the greater needs of society (Albanese & Mitchell, 1993; Florman, 1988; CDIO, 2011). The concerns of accreditation agencies are cited as a driving factor of implementing active learning techniques (Crosthwaite et al., 2006). Such change is not easy – it requires institutional, administrative and financial support (Henderson et al., 2011), customization to disciplinary requirements (Ferrini-Mundy & Güçler, 2009), and handling resistance from professors more comfortable with the clear authority structures traditional education models provide (M. Rosenfeld & Rosenfeld, 2006). As will be seen below, the medical education community has shown that transformative change of a discipline is indeed possible.
2.2 Learning from Medicine: Problem-Based Learning (PBL) in an Applied Science Context

Medical education has a long history of educational innovation, including a wide adoption and integration of problem-based learning (PBL) as a paradigm (Albanese & Mitchell, 1993; Bédard et al., 2012). The field of medical education has documented many of the challenges associated with problem-based learning, and it is worth examining this history briefly to build a solid foundation for similar approaches in other disciplines.

McMaster University is widely cited as the founder of problem-based medical education (Neufield & Barrows, 1974). The McMaster approach emerged as a reaction to medical education evolving too far towards a basic-science based approach. In 1966, McMaster shifted towards a model of instruction that encouraged team-based problem solving centered on a series of clinical case studies, which demand students retrieve and apply relevant scientific information to solve the problem. This approach started spreading from its modest roots to find voice in established medical schools like Harvard (Dienstag, 2010).

Given the emergence of PBL in medical schools and debate between PBL and traditional education advocates, there have been many opportunities to investigate the effectiveness of PBL. Multiple quantitative meta-analyses of PBL effectiveness in health education have been conducted (Albanese & Mitchell, 1993; Dochy, 2003; Hoffman et al., 2006; Strobel & van Barneveld, 2009; Walker & Leary, 2009), with intriguing results. With respect to performance on standardized tests, results show slight positive results from PBL (Albanese & Mitchell, 1993; Prince, van Eijs, Boshuizen, van der Vleuten, & Scherpbier, 2005; Ravitz, 2009), although with a weak effect size (Albanese, 2000; McParland et al., 2004). It should be noted, however, that evaluating new educational methods using testing methods from older modes of education does lead to confused correlational arguments (H. Barrows, 1986). Generally speaking, PBL education has not shown a significant effect in tests based on multiple choice questions (Albanese & Mitchell, 1993; McParland et al., 2004) but has shown a statistically significant effect on tests based integrative questions and clinical tests (Prince et al., 2005).
An intriguing limitation is a continued perception that PBL graduates have not been exposed to the “right” knowledge. Even with a growing number of medical schools adopting PBL as an instructional approach, there remains a bias that PBL students lack in fundamental knowledge (Schmidt et al., 2006). The roots of this phenomenon are not clear - meta-analyses of PBL vs. non-PBL education do not support any conclusion that PBL students are lacking in mastery of fundamental knowledge. It is suggested that this gap is temporary – as generations of PBL graduates transition into clinical practice, perceived mistrust and unfamiliarity with this emergent form of education may dissipate (Prince et al., 2005).

When one looks beyond standardized test measures of basic science knowledge, PBL education shows considerable promise. PBL learners score higher in motivation and positive attitudes to learning (Albanese, 2000; McParland et al., 2004), a phenomenon acknowledged even by detractors of PBL (Cohen-Schotanus et al., 2008). This is especially noted in student groups prone to dropout in traditional education (Ferguson, 2005; McParland et al., 2004). With respect to performance in clinical practice, PBL-trained doctors have fewer adjustment issues, stronger project management abilities and better communication and reporting skills than their traditionally trained peers (Ferguson, 2005; Prince et al., 2005). PBL learners also show improved critical thinking skills on the job (Ferguson, 2005; Tiwari et al., 2006). While the long-term effects of PBL on professional education are understudied, early evidence suggests PBL learners show considerable confidence in early practice years in most core competencies of clinical practice (Schmidt et al., 2006).

While there is considerable diversity in PBL practice, there are common intellectual foundations to consider. These include: a) social constructivism, b) experiential learning, and c) lifelong learning and critical information literacy, all of which are briefly outlined below.

2.2.1 Social Constructivism

“We now have to consider that the aim of learning at the university level is knowledge, criticism of the world and of oneself, creativity, autonomy, communication and citizenship. The objectives of training are thus to be defined not only in terms of knowledge (‘savoir’), but also of know-how (‘savoir-faire’) and know-being (‘savoir-être’).” (Éugène, 2006, p. 937)
Constructivist learning is the core foundational shift in pedagogical approach advanced by PBL. Constructivist learning traces its roots to Lev Vygotsky’s sociocultural models of individual development and learning (Vygotsky, 1978). Packer and Ogeechee note six themes of a constructivist ontology - individuals are a) constructed, b) within social context, c) through practical activity; through, d) relationships of desire and recognition that, e) lead to a multifaceted and complex persona that f) requires significant negotiation of identity (Packer & Goicoechea, 2000). Constructivism sees learning as a relational process that depends on both a learner’s existing knowledge base, the surrounding social context and environment, and the learner’s ability to integrate and link new experiences into their knowledge network (Norman & Schmidt, 1992). For constructivists, education is a profoundly personal transformative experience – and given this personal transformation, one that should be treated with some care and attention.

Constructivist learning takes on many forms, leading to some confusion about best practice. Golding (2009) addresses this diversity of practice in a continuum of constructivist practice, summarized in this figure:

![Figure 1: Continuum of constructivist learning](adapted from Golding, 2009)

Golding’s preference for the middle ground is certainly defensible. The teacher-directed model is well known to many professors and students – the authority of the instructor is clear and content highly structured, all towards the goal of relaying established truths. Student
engagement outside of these bounds is tolerated at best, actively dissuaded at worst – independent thought, divergent thinking, independent discovery and alternative interpretations are not only distractions to a fact-driven, authority-based instructional process, but a direct challenge to the authority represented in that structure.

“School touches us so intimately that none of us can expect to be liberated from it by something else. Many self-styled revolutionaries are victims of school. They see even "liberation" as the product of an institutional process. Only liberating oneself from school will dispel such illusions.” (Illich, 1971, p. 47)

At the other end of the spectrum, critical education reacted to the authority-driven nature of formal schooling by proposing in its place a radical constructivism that destabilizes all hegemonic power (Friere, 1967). While appealing to some, radical constructivism may not be effective in applied science or medicine where truth claims can be subjected to evidence-based inquiry. Contemporary controversy around an alleged but disproved link between the MMR vaccine and autism should give us pause to unleashing medical knowledge to crowdsourced amateur knowledge generation. Replacing the authority of the medical academy with Jenny McCarthy does not bode well for the future of public health (Eggerston, 2010).

Golding’s “community of inquiry” provides a middle ground between the excesses of both poles of the continuum. In doing so, it allows for a framing of a key tension in social constructivism – achieving a new balance between teacher authority and student engagement.

“…it is the PBL tutor’s role to facilitate and activate the group of learners in much the same way as a symphony conductor does an orchestra. Barrows describes this as ‘modulating the challenge’ of learning. By guiding and supporting students’ learning, the tutor becomes both the steward of the group process and the metacognitive coach.”(Papinczak et al., 2009, p. 379)

In PBL, students should be empowered to engage their own information discovery. Faculty/tutors should serve as facilitators of knowledge exploration versus authoritative purveyors of information – a shift from being the “sage on the stage” to the “guide on the side” (King, 1993). This represents a shift of power and responsibility from faculty to student leadership, which may create role conflicts for both. Some instructors are quite uncomfortable with such a role, and respond to the PBL challenge by creating elaborated and rigid learning
processes (e.g., Feldon et al., 2010; Harden et al., 2000; Kasman, 2004). Not only is this not appreciated by students (Papinczak et al., 2009), such top-down structures rather defeats the point of PBL by reducing problem solving to following provided explicit instructions.

While centralized control over the learning experience is a faulty implementation of the spirit of PBL, a laissez-faire mentality is also not advisable. Students in a PBL environment are attempting to resolve issues that are - at least for them – complex. This causes some discomfort and confusion that can confuse judgment and delay professional development. One critique of PBL is that it privileges “backward” thinking (Albanese & Mitchell, 1993; Walker & Leary, 2009). PBL students have been noted as making more, but also more incorrect, initial assumptions (Schmidt et al., 2006). Amateurs left to their own devices may become stuck on irrelevant details or erroneous statements of fact and fail to build appropriate heuristics (Maudsley, 1999). Worse, once bad information is established into an individual’s knowledge network, it can prove hard to dispel or replace (Niri et al., 2010). Appropriate scaffolding and support from faculty can help students make the necessarily connections and build expert knowledge vs. permanently playing the role of inquisitive but confused amateur.

Such transformation in the role of student and teacher should ideally be supported by a shift in institutional culture (Henderson et al., 2011). PBL is a more time-intensive mode of instruction, often requiring considerable investment of faculty and support time (Hung, 2006). If an instructor’s professional advancement is measured through research, not teaching excellence, modes of education where time spent on teaching starts and stops at the lecture hall are considerably more attractive. There are also potentially significant facilities issues – a mode of education structured around small independent group work may require distinctly different physical spaces than the traditional lecture hall (Costa et al., 2007).

2.2.2 Experiential Learning

A related concept to social constructivism, experiential learning is a learner-centered educational approach that builds deep learning through active engagement (Kolb, 1984). Experiential learning aims to design curriculum that develops higher-order skills such as evaluation and creation (Anderson & Krathwohl, 2001). While challenging to develop and
administer, the challenges of a complex world may make such learning essential in some cases. This is especially the case in medical practice, where contingent truth is the norm and creative engagement and critical thinking is increasingly seen as important (del Bueno, 2005). The American Association of Medical Colleges has specifically acknowledged the value of creative reasoning, noting that clinical error often results from invoking closure too early in a diagnostic process (Dyche & Epstein, 2011; Slawson & Shaughnessy, 2005). By encouraging open-ended investigation of complex problems, experiential learning provides valuable training to medical professionals by giving them experience and a level of comfort with complex problem solving.

“Problems, in general, are at the heart of PBL. They function as a content and knowledge organizer, learning environment contextualizer, thinking/reasoning stimulator, and learning motivator. Unquestionably, the design of problems plays a key role in determining the success of PBL courses and curricula.” (Hung, 2006, p. 58)

One approach facilitators take to create an effective experiential learning environment is to structure sufficiently complex problems. Such problems should encourage student engagement and motivation but not be so wicked that efforts to solve the problem are impossibly frustrating and demoralizing or lead to solutions that are superficial in nature (Dolmans et al., 2005).

Hung’s 3C3R model (2006) proposes six considerations for appropriate problem development in PBL; content, context, connection, research, reasoning, and reflection. Care should be taken to ensure the content of problems are relevant to the curriculum and stated at an appropriate scope. Consistent with Vygotsky’s zone of proximal development (Vygotsky, 1978), problems should be challenging enough to encourage further exploration without being too wickedly complex to solve. The context of the problem is also an important consideration. Given the conditions many people enter medical care, imperfect information and a stressful and emotional context are common occurrences. Problems that replicate this context are more likely to prepare future clinicians for effective practice. The notion of connection grounds context and content into an integrated intellectual framework. Problem cases are not intended to be isolated pieces of information but building blocks of a more robust mental model. The construction of these connections should not be assumed, since integrative thinking is rarely stressed in traditional education (Norman & Schmidt, 1992). Problem-based learning approaches demand
active engagement on the part of students to discover and integrate information. Core to this process is *researching*. Students must not only leverage existing literature but ascertain its contextual relevance. Related to this is the *reasoning* process, in which students apply their research towards the goal of deriving an appropriate solution.

The last component, *reflecting*, helps the student integrate the previous five components of content, research, context, reasoning and connection. Reflection engages metacognition about what was learned and what gaps of knowledge may still exist. It is an essential component of double-loop learning (Argyris & Schon, 1992), in which learning not only leads to incremental change but also potentially revolutionary changes in knowledge foundations and structure. While Kolb explicitly noted reflection as a component of experiential learning practice, faculty and students often fail to see the immediate relevance of reflective practice, even to the point of dismissing reflective assignments as a waste of time (Turns et al., 2010). However, reflection on action is an effective defense against creating and repeating mistaken or erroneous assumptions, and addresses PBL concerns about backward learning by encouraging learners to critically engage mistakes and in doing so learn better practices. Reflective learning is also in highlighting emotional learning and empathy with patient concerns, two centrally important skills in medical practice that by definition require patience to develop (Dyche & Epstein, 2011).

### 2.2.3 Information Literacy and Lifelong Learning

Another noted benefit of medical PBL is the development of critical information literacy and lifelong learning strategies. Given the purpose of medical education is quality medical practice, a mode of learning that teaches students how to learn is more relevant than test scores conveniently ignored once a job is secured. The American Association of Medical Colleges concurs, suggesting that development of a culture of independent, self-directed learning within medical education bodes well for future professional development (DeFillippi, 2001). Lifelong learning encourages personal reflective learning that could be applied to other situations (Dolmans et al., 2005; Dunlap, 2005). Graduates from PBL programs have been shown to be more capable and comfortable with the responsibilities of lifelong learning than their traditional education peers (Dochy, Segers, van den Bossche, & Struyven, 2005).
Slawson and Shaughnessy pose an interesting question of whether problem-based learning is mostly an information management problem (Slawson & Shaughnessy, 2005). Of particular concern to the authors was a perceived trend in clinical practice towards using heuristics, guides, and other easily digestible information as bases for complex decisions. Decision makers facing a complex information challenge will often be satisfied with “good enough” information, given time, cognitive and search limitations (Simon, 1997). In complex knowledge domains, it is impossible to collect and verify all possible relevant data. While satisficing information is in part inevitable, Slawson and Shaughnessy do raise interesting questions regarding the quality of information and argue for a curriculum that stresses critical information analysis.

This is particularly important in the context of PBL, where the onus is on the student to compile and manage information resources and critically analyze and integrate new information sources independently to create their own expertise. This is a skill not covered in depth in traditional education, yet is critical for effective lifelong learning. Independent information analysis is a particular challenge in the Internet age, when both professionals and patients having immediate access to a vast information store, much of which may be of dubious quality or veracity. Evaluating an ever-growing and increasingly diverse store of information is not a trivial task to be sure, and with the rise of difficult to authenticate Internet sources and “fake news”, sorting out the defensible from the nonsense can be increasingly challenging.

2.3 Project-Based Learning (PBL*) in Engineering Education

The foundational notions of problem-based learning have expanded beyond medical education into other domains. While the root concerns and challenges of medical PBL can be extrapolated to other fields, it stands to reason that different fields will adapt lessons learned in different ways.

As with medicine, the emergence of PBL in engineering education can be traced to professional and accrediting agency concerns regarding the breadth and practical utility of traditional engineering education (ABET, 2011; CDIO, 2011). PBL in engineering education can also be traced back to an early leading institution: Denmark’s Aalborg University (Kolmos,
However, PBL in engineering has traditionally taken on a slightly different scope, given the focus of the discipline. For the purposes of differentiation from its problem-based roots, I will hereafter refer to project-based learning as PBL*.

### 2.3.1 PBL*: A Long-Term Project Orientation

Kolmos describes engineering PBL* as involving five key differentiating factors from traditional engineering education.

<table>
<thead>
<tr>
<th>Traditional Education</th>
<th>Project-Based Learning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Given a professional problem</td>
<td>1. Identify a professional project based on inclination, interest, experience or curiosity</td>
</tr>
<tr>
<td>2. Accept the problem momentarily</td>
<td>2. Accept it seriously as one’s own project to be analyzed and solved.</td>
</tr>
<tr>
<td>3. Work towards a final examination</td>
<td>3. Work realistically towards resolution of the project.</td>
</tr>
<tr>
<td>4. Leverage existing professional structuring</td>
<td>4. Professional structuring is connected with personal inclination, interest and curiosity. Reflection loop creates integrative knowledge.</td>
</tr>
<tr>
<td>5. Finish with final examination.</td>
<td>5. Finish with ideas of how knowledge may be implemented in practice.</td>
</tr>
</tbody>
</table>

**Table 2: Traditional vs. Project-Based Learning in Engineering Education**  
(adapted from Kolmos, 1996)

According to Kolmos, engineering PBL* efforts require students to formulate goals and objectives, determine project start and end dates, analyze and solve specific problems, report on results, and create appropriate team-building, collaboration and project management tools to manage their own learning processes. While PBL activities in medical education often have ad hoc teams and shorter time frames, PBL* in engineering tends to involve longer-term, creative projects engaged by larger teams with more complex lifecycles and workflows (Bédard et al., 2012). Engineering education has begun developing such student-centered learning projects, particularly around “capstone” projects done at the conclusion of a student’s degree program (Dunlap, 2005) and by supporting extracurricular student clubs and project-based teams. Projects have emerged in a number of applied fields, including computer programming (Ge et al., 2010), environmental science (Nation, 2008), systems engineering (Chujo & Kijima, 2006), mechatronics (Costa et al., 2007) and mechanical engineering (Karri, Bullen & Rossmanek, 2001).
How students maintain motivation over a long-term sustained effort is of interest in this research. PBL* teams are somewhat similar to Stebbins’ notion of serious leisure, where activities are pursued by individuals who engage in voluntary, complex behaviors driven by personal passion (Stebbins, 2007). Such people interact with those of similar passion to create informal communities of practice (Lave & Wenger, 1991), which over time can lead to the formation of an organization to support this shared activity. In doing so, students adopt leadership roles within their communities that are not dissimilar to management positions. All this is done at considerable personal opportunity cost, but the tradeoff between their pursuit and other alternative uses of time and energy is seen as personally fulfilling.

2.3.2 PBL* and External Regulation

Another qualitative difference between PBL and PBL* efforts is the common presence of external participating agents. Many PBL* efforts function within a larger context structured by external requirements (e.g., external client requirements in capstone design projects, the rules and regulations of student design contests, etc.). Externally defined regulations help structure the activity, creating deadlines and requirements under which PBL* students must operate to be successful. Externally imposed regulation acts as a particular constraint to creative discovery. Specific objectives and deadlines create a tension between convergent and divergent thinking (Dym et al., 2005). While convergent thinking is essential to reach an objective, divergent thinking – e.g., tangential experimentation, accepting failures as welcome phenomena, encouraging digressions from main goals - can lead to truly innovative outcomes (Fasko, 2001). PBL* groups have to balance the creative and inquisitive nature of divergent thinking with convergent thinking focused on terms and timelines set by external agents.

Another external force necessary to consider is the school’s larger administration which can impose its own constraints on PBL* group activity. Some schools have been active in encouraging PBL* teams, supporting teams with space and financial resources. For example, Pennsylvania State’s Learning Factory (http://www.lf.psu.edu/) provides both space and support services to project-based learning teams and provides structure to term-long industry-sponsored capstone projects as well as student-led project-based learning teams. McMaster University,
leveraging its own strong history in constructivist learning in medicine, has recently broken ground on its own project team centre (http://www.eng.mcmaster.ca/hatchcentre/).

Such administrative support for PBL* is helpful towards supporting the success for such team efforts (Kumar & Hsiao, 2007). However, the larger administrative context introduces new possibilities for conflict. Financial and space allocations provided by universities to PBL* teams come with strings attached, namely adherence to university rules and standards of behavior and attention to administrative requirements regarding budgeting, recruitment, marketing and branding etc. While a mutually beneficial relationship between a PBL* team and administration is ideal in supporting team success (Kumar & Hsiao, 2007), a problematic relationship can pose serious challenges to the viability of a PBL* team.

2.4 PBL* Teams as Knowing Organizations: Information Behavior and Knowledge Management Concerns

PBL* teams provide an opportunity to engage the passions of individuals by focusing that passion towards the end of achieving collective goals. This balance between individual passion and organizational imperatives creates particular patterns of information behavior and use that are worth further exploration. While “teams” are not normally regarded as organizations, I am using Choo’s conceptualization of the “knowing organization” (Choo, 2006) to describe patterns of information behavior in a collectivity of people bound together by shared purpose and a common enterprise. As PBL* teams sustain themselves over time, they collectively define their information sharing and use, leading to the establishment of knowing organizations with their own particular dynamics.

2.4.1 Information Behavior in the Knowing Organization

Choo frames his understanding of the knowing organization in a pragmatic and constructivist (Talja, Tuominen, & Savolainen, 2005) model of information behavior (Choo, 2006).
Figure 2: Choo’s integrated model of information behavior
(adapted from Choo, 2006)

The model suggests three interconnected concepts of information behavior in the knowing organization – identifying information needs, seeking out and evaluating information, and selecting appropriate information to act on identified needs. The identification of information needs can be a complex challenge. As Dervin’s information gap theory suggests, individuals and organizations possess some awareness of their existing knowledge and a gap between that knowledge base and their intended outcome, leading to the need for a bridge to cross that gap (Dervin, 1992). One then engages in information seeking to bridge the gap with available and appropriate information. Perception of information gaps and the extent and quality of information searching is not done in a vacuum, but rather shaped by the dynamics of information use, which may privilege certain information sources over others or prioritize certain research topics over others that can be avoided or ignored. Information literacy and the
constructive use of information are skills that can be developed, trained and refined and may be valuable to PBL* teams in achieving their outcomes.

In contexts where the intended outcome is unclear or ambiguous, however, it may be difficult to identify and leverage appropriate resources, making it difficult to determine whether a perceived information gap is a simple crack or a vast canyon. Conversely, in situations where no information gap is perceived, individuals may be falsely comforted that they possess the requisite information. In PBL* teams where students are learning on the fly, both confusion about a potential gap or unwarranted confidence in one’s knowledge are common situations.

Based on this foundational understanding of information behavior, Choo notes three arenas of information use in a knowing organization – sense making, knowledge creation and decision making. Sense making, knowledge creation and decision making interact in complex, unpredictable ways influenced by cognitive, situational and affective challenges, leading to particular patterns of information behavior in a given organization (Choo, 2006). PBL* teams certainly face challenges in understanding sensemaking, knowledge creation and retention, and appropriate decision making, and some of these challenges will be discussed in brief below.
2.4.2 Sensemaking in Organizations

Weick (1995, p. 17) defines sensemaking as:

a) founded in identity construction (individuals and organizations will interpret reality based on their existing self-concept);
b) retrospective (such interpretations will be reflective of context and history);
c) driven by enactment (sensemaking is an active attempt to reduce complexity);
d) social (sensemaking is a collaborative and social process influenced by the perceived or actual opinions of others);
e) linked to existing concepts, schemas and heuristics (new information builds upon existing knowledge);
f) ongoing (sensemaking is a continuous and cyclical process);
g) driven by plausibility and sufficiency vs. perfection (satisfactory information will be seen as acceptable and actionable)

Organizational sensemaking is shaped by organizational culture, which shapes individual sensemaking by providing a pattern of shared assumptions, beliefs, stories and unwritten rules to
leverage (Schein, 1992). While organizational culture can be a vague notion, an organization’s past history does help guide the identification of what problems are considered important, what information sources are valid, and the latitude of acceptance of a variety of solutions.

Choo qualifies Weick’s outline of sensemaking noting situational factors that influence sensemaking as a process. Of particular interest here are ill-structured problems bracketed by environmental uncertainty. This can be a routine experience in PBL* teams given researchers are often neophytes, arriving at problems with a weak foundation of knowledge, processes and heuristics. A vaguely defined problem context creates multiple avenues of investigation, many of which may prove to be less than fruitful. This can create multiple opportunities for ineffective sensemaking. Organizational culture and history may provide a fallback position for PBL* teams, but newer teams will not have a solid history to leverage, compounding the problem.

A sensemaking process based on such a flimsy foundation may yield multiple cycles of poor outcomes before solutions approximate a satisfactory outcome. Understandably, such a repeated cycle of trial and error learning can cause significant stress and unease among PBL* students. Kuhlthau’s model of information search processes notes that early stages of exploratory research is vague in nature and can yield affective feelings such as uncertainty, confusion, frustration and doubt (2004). Starting from a limited set of previous experiences and a naïve sense of final outcomes can be challenging, but through engagement participants PBL* teams can develop and refine their knowledge, leading to a more focused search and affective feelings of confidence, clarity and satisfaction (Kuhlthau, 2004). PBL* teams can assist early learners in this process by creating and curating a foundation of organizational knowledge to assist those in the early stages of sensemaking.

2.4.3 Knowledge Creation

Over time, PBL* teams can improve their ability to address their challenges by developing and retaining organizational knowledge. Doing so, however, requires that PBL* teams not only learn from their mistakes but retain that learning and pass it on to future generations of team members. Complicating this effort is the fact PBL* teams experience considerable turnover - due to student graduation, PBL* teams routinely lose highly-skilled
members and leaders. Consistent reinvention of team membership and structure is particularly challenging if the team does not attend to organizational knowledge generation. Identifying and building organizational knowledge capacity is a key concern for teams experiencing such regular yet largely predictable organizational turnover.

Choo outlines three forms of organizational knowledge: tacit, explicit and cultural (Choo, 2006). The distinction between tacit and explicit knowledge emerges from Polanyi’s work on the personal and socially embedded nature of scientific knowledge and departs from the notion that “we know more than we can tell.” (Polanyi, 1958). For Polanyi, all knowledge is in part tacit, including knowledge that can be readily captured, represented and shared (Grant, 2007). It is the result of what Schön referred to as “knowing-in-action”: actions we are often unaware of having learned and can be shared only imperfectly through social interaction (Schon, 1983).

Even assuming that all knowledge has a tacit dimension, Nonaka and Takeuchi do note that some knowledge can be represented in an externalized and sharable form, potentially transferable within an organization. Nonaka and Takeuchi’s SECI (socialization, externalization, combination and internalization) model elegantly outlines the relationship between tacit and explicit knowledge and how each informs the other in the building of organizational knowledge.
In the *socialization* phase of knowledge creation, individuals transfer tacit knowledge to each other through social interaction, demonstration, and apprenticeship. If tacit knowledge is seen as knowing-in-action, socialization is learning through shared action. Where Nonaka and Takeuchi expand from Polanyi is suggesting tacit knowledge can be made explicit and shared among others. *Externalization* involves transferring tacit knowledge to explicit form. This process of externalization is not perfect. It can be difficult to faithfully translate the complexity and depth of embodied tacit knowledge in a disembodied, abstract form. Many of the failures of early knowledge management efforts involve overlooking or ignoring the inherent complexity of capturing and sharing knowledge in a decontextualized and externalized form (Fahey & Prusak,
However, it stands to reason that knowledge can be rendered in objective form and can lead to a sufficient level of intersubjective understanding. Explicit information allows for the exchange and recombination of similar texts, which is the goal of the *combination* stage. In combination, texts are recombined to create higher-order meta-representations. It is at this level that knowledge (and as implied in the above diagram, authorship) becomes collective. To be effective, however, such explicit collaboratively managed texts must be experienced by individuals and reintegrated into their personal knowledge frameworks. This happens in the *internalization* stage, where explicit representations are filtered and adapted until they become part of an individual’s tacit knowledge base. This new tacit knowledge can then be shared with others, starting the SECI cycle anew.

In later iterations of work, Nonaka expanded SECI to represent contextual factors that facilitate or inhibit progress through the SECI cycle. Nonaka called these factors “ba” – a Japanese term loosely translated to place, space or field (Nonaka & Konno, 1998). Nonaka’s ba is similar in kind to Choo’s notion of cultural knowledge. Ba outlines the cultural milieu that supports (or harms) the generation and sharing of organizational knowledge. Awareness and attention to an organization’s ba could provide insight into the diffuse but powerful effect of cultural knowledge. While interesting, Nonaka’s definition of ba is perhaps a bit too metaphysical for managers to internalize into practice. This is unfortunate, because the notions underlying ba can be translated into real-world application if reframed to meet business needs and logic. More applied interpretations of ba can lead to changes in physical space, organizational practice and business strategy (Nomura, 2002), and similar reframing may be helpful to PBL* teams.

**2.4.4 Decision Making**

Organizations do not engage sensemaking and knowledge creation in a vacuum. The information seeking and knowledge creation activities of PBL* teams are shaped by the core mission of the team, and information seeking and knowledge creation efforts are often directed to inform better organizational decision making and performance.

In cases of low procedural and goal uncertainty, organizational decision making can be seen as a rational process, where simple inputs are easily processed by set rules and routines...
leading to outcomes that are precise and predictable. In practice, however, such precision in goal and procedure is rarely the norm in organizations (Simon, 1997). Organizational decision-making often happens in a situational context that is vague or ambiguous, where actors have fragmented knowledge, and where choices range between a number of alternatives with an imprecise understanding of the future consequences of their choice. Simon considers this a state of bounded rationality (Simon, 1997). Bounded rationality stands even after considerable information seeking and knowledge creation activity, which reduces uncertainty but never fully eliminates it. As March and Simon note, organizational decisions are not about perfect decision making, but decisions that are “satisficing” - good enough, given the information at hand (March & Simon, 1993).

Choo highlights four models of decision making based on varying levels of goal and procedural uncertainty: rational, process, political and anarchic (Choo, 2006). In conditions of low goal and procedural uncertainty, decision making approaches full rationality. Process models involve clear goals but multiple possible solutions, each of which can be compared and analyzed logically. In a political decision-making frame, there is general consensus about procedural considerations but a battle among institutional stakeholders eager to advance or defend their own agendas.

In conditions where both goal and procedural uncertainty are high, an anarchic state of decision-making is reached. Problems, solutions and the positions of stakeholders are relatively unclear. In such a state, organizations strain to find an appropriate approach to decision making, and rational models can prove to be unsatisfactory. Cohen, March and Olsen metaphorically describes this state as a “garbage can” where potential problems are deposited and are engaged by participants in an unstructured, organic and emergent process (Cohen, March & Olsen, 1972). In the garbage can model, a variety of ill-structured attempts are made to solve problems in the hopes of finding a satisficing answer. While a potentially chaotic state, it is also a state where play, trial and error experimentation, improvisation, tinkering and divergent thinking occurs (March, 1976). Through this anarchic but emergent and organic process, organizations may discover new innovative solutions to poorly understood problems.
While the garbage can model may sound ineffectual as a decision-making strategy, sometimes a satisficing decision in a context of goal and procedural uncertainty is ideal. In his Cynefin model of knowledge creation, Snowden (2005) notes four environmental contexts—simple, complicated, complex and chaotic. In simple environmental contexts, leveraging best practices and rational decision making processes are a valid approach to informing better decision making. However, in complex or chaotic contexts where truths are contingent, emergent or novel, using best practices may be a horrible decision, as new contexts may demand out of the box thinking (Snowden, 2005).

We can speculate that PBL* team members may be more likely to face less than rational decision contexts due to their relative lack of experience and the constraints imposed by external regulations that mandate various decisions be completed at specific times. While some decisions are relatively simple, many challenges emerge from complex or chaotic states where a garbage can model may be the only approach available. PBL* teams have to be made aware of what problem state they find themselves in and their available options in deriving a satisficing, if perhaps not ideal solution.

Balancing sensemaking, knowledge creation and decision making questions can be a particularly daunting challenge for students on PBL* teams, who arrive at their chosen task with limited professional experience to leverage. Faculty and professional advisors can help teams develop heuristics to better manage these challenges, but too much structure from experts may risk reducing complexity to simple procedural rules, returning the context to a more teacher-centered learning environment (Golding, 2009) where students are relegated to a position of following rules, not actively making their own decisions. As Kuhlthau’s information search process (2004) notes, there is value in progressing through an exploratory and vague state, even if that may be painful and messy in the short term. Providing set answers too early helps skip the formative stage of information search, but may also lead to decontextualized knowledge not adequately internalized, thus creating a weak tacit knowledge foundation for future knowledge creation (Nonaka & Takeuchi, 1995).
3. Cultural Historical Activity Theory (CHAT) as an Integrative Theoretical Approach

As discussed above, PBL* opportunities can create a broad skill base by engaging studies in applied, contextually grounded projects. In doing so, PBL* leverages the constructivist, experiential and collaborative strategies of problem-based learning but extends its scope to longer-term projects requiring significant organizational complexity to accomplish. Through continued activity, PBL* opportunities can develop into stable knowing organizations (Choo, 2006) with a consistent long-term goal orientation and cultural knowledge foundation that help shape approaches to organizational sensemaking, knowledge creation and decision making.

Given the above, a theoretical understanding of the activities of PBL* teams should include both individual agency as well as social and organizational dimensions. Cultural-historical activity theory (CHAT, also referred to as activity theory or AT) has shown promise in information science in addressing these factors and has shown to be an appropriate framework for a range of information behavior research questions (Allen et al., 2011). Despite the name, CHAT is often considered less a formal explanatory theory than a conceptual framework that can lead to the generation of more specific research questions (Kaptelinin & Nardi, 2006). In this section, I will discuss the historical foundations, contemporary uses and foundational concepts of CHAT towards the end of informing research questions relevant to the study of PBL* teams.

3.1 Historical Emergence and Contemporary Relevance of CHAT

As with social constructivism, CHAT traces its roots to the work of Russian psychologist Lev Vygotsky (Engestrom, 1999; Roth & Lee, 2007). For Vygotsky, building knowledge is an active process done by a motivated individual using various mediating instruments to interpret their environment towards the end of realizing their objectives (Vygotsky, 1978). This subject -> tools -> object relationship is still seen as the core activity process (Allen et al., 2011; Wilson, 2009). This process is dialectic and iterative in nature, cycling between internalization of cultural knowledge and externalization through the creation of specific knowledge objects (Avis, 2007; Peim, 2009) in a manner similar to that described by Nonaka and Takeuchi’s SECI model of knowledge generation (Nonaka & Takeuchi, 1995).
The formal inclusion of sociocultural forces in activity theory is largely regarded to be the work of Vygotsky contemporary Leont’ev (Engestrom, 2008; Leont’ev, 1978). Leont’ev also stressed the intentionality of individual agency, but grounded this agency in cultural and historical factors including community influences and power relations. Despite a more ideologically correct grounding of human agency in dialectical materialism and power relations, Vygotsky and Leont’ev’s work was not well received in the Soviet Union under Stalin, leading to their work being repressed until well after their passing (Roth & Lee, 2007). The contemporary resurgence of activity theory is largely traced to Yrjö Engestrom, who reinterpreted Leont’ev’s work on human activity and worked to raise its profile in contemporary Western scholarship (Engestrom, 1999; Meyers, 2007; Roth & Lee, 2007).

The rediscovery of CHAT was aided by an iconic diagram included below:

Figure 5: Engestrom’s representation of cultural-historical activity theory
(adapted from Engestrom, 1987; 1999)

The above diagram visualizes “…the individual practitioner, the colleagues and co-workers of the workplace community, the conceptual and practical tools and the shared objects
as a unified dynamic whole.” (Engestrom, 1991, p. 267). Represented in this form, the CHAT activity triangle has enabled researchers to unpack an otherwise dense theoretical discussion, facilitating a clear way to communicate findings across a variety of knowledge-based domains (Allen et al., 2011). The objectification of CHAT in this form has generated some resistance from those who see Engestrom’s reinterpretation as post-positivist (Peim, 2009). Sannino defends against such critiques, while noting that application of the activity triangle without deference to its dialectical roots may yield conclusions inconsistent with the original intent of CHAT (Sannino, 2011).

CHAT has been used to unpack a range of information behavior problems from human-computer interaction design (Nardi, 1996), library and information systems (Meyers, 2007), organizational learning (Engestrom, 1987; 1999), cultural psychology (Ratner, 1997), and information behavior (Allen et al., 2011; Wilson, 2009). Allen et al. suggest the emergent interest in activity theory in information science dovetails nicely with three emergent intellectual trends in information science – the importance of context in information behavior research, the importance of technology as a mediating tool in information creation and the perceived need for information science to have an applied impact (Allen et al., 2011).

Allen et al. (2011) also note CHAT’s flexibility in understanding activity at multiple levels of analysis as a significant benefit. CHAT is a meso-level conceptual framework that can bridge individual models of information behavior and macro-level social systems theories. Allen et al. (2011) provides a good example of how CHAT can address activity models at the individual and collective level by showing how a particular activity – completing a group school assignment – operates at multiple levels. This model will be expanded upon to describe the particular elements of the CHAT triangle in the following section.
3.2 Exploring The Core Elements of CHAT

Starting from the top triangles in Figure 6, we see Vygotsky’s core construction of activity - a relationship between subjects and their intended objects, mediated by tools (also referred to as technology, instruments or artefacts\(^1\)) that bridge that understanding.

The subject can be either an individual or collective, depending on the level of analysis of the activity. In the right diagram, the subject is a group of students doing a group assignment and striving for an A grade. However, one of their group members, represented by the left diagram, may be satisfied with a C+ and plans to structure their approach to the activity accordingly.

---

\(^1\) Semantic variations in the naming of CHAT elements (especially tools/technology/artefacts), are largely a function of the Russian roots of the theory, with inconsistencies resulting from translation debates (Bakhurst, 2009).
The group outcome is shaped by collective decision making regarding information objects of varying quality and value, and may go above and beyond the call given their intended outcome of an A - but as noted above, the student with the C+ orientation is likely to contribute only what is quick and convenient, leaving the rest of the group carrying most of the load.

Complicating matters are the components Leont’ev explicitly added to ground activity in social and historical foundations. Community includes all others that may be affected by the subject’s desired outcome. At the individual level, community may simply be seen as other students in the group – at the group level of the activity, community may include other groups, TAs, professors, support staff, etc. who may influence the group’s progress.

Norms/Rules (also referred to as praxis in some translations) are both written rules and procedures and unwritten norms that govern interaction. These are necessary to mediate social order and help regulate larger questions of justice, ethics, and morality. At the individual level of this activity, the C+ student rules may consult baseline standards regarding plagiarism, grading policy, and course requirements and tailor their effort accordingly. The group however is striving for higher standards, and will likely begin to feel frustration for taking on extra work and/or correcting the work of the C+ individual, leading potentially to ethical questions of fair grading of group work.

Division of labor acknowledges that subjects require the assistance of others to realize their goals, that other powers exist that can constrain activity, and that power relations are often unequal. At the group level, division of labor may involve appealing the group’s grade to lecturers/TAs so ensure those who contributed fully to the final group project are rewarded while the slacking student does not. Or, it could be that the group reluctantly accepts the fact the C+ student was a free rider and resolve never to work with him again. The C+ student however may not care – their effort may not have been from malice, but rather a situation where their school work conflicted directly with other school, work, and family priorities that they sincerely believed to be more important than the inflated expectations of their group.
As is evident in this simple example above, balancing individual and collective activity models and negotiating tensions among the nodes can yield many different types of tension, which Engestrom (1987, 2008) denotes as contradiction.

### 3.3 Identifying and Negotiating Contradictions

While activity theory can be helpful in explaining forces shaping human activity, the most compelling component of CHAT may be when these forces act in contradiction to each other (Meyers, 2007). The concept of contradiction highlights open challenges that may influence particular activities (Engestrom, 2008). CHAT contradictions are not intended to provide a prescriptive solution nor is it squarely tied to particular literatures in conflict resolution. Rather, CHAT leaves open the notion of contradiction as a negotiation to be considered from multiple perspectives, some of which may be more effective than others. Engestrom’s concept of expansive learning (Engestrom, 1987) through the identification and negotiation of contradiction is similar to the reflective, “double-loop” learning advocated by experiential learning in PBL/PBL* (Argyris & Schon, 1992; Kolb, 1984).

Engestrom highlighted four levels of contradictions present in activity systems:

<table>
<thead>
<tr>
<th>Contradiction</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary</strong></td>
<td>Differences within a given node in an activity system (e.g., competing interpretations of goals by individual subjects)</td>
</tr>
<tr>
<td><strong>Secondary</strong></td>
<td>Differences between two given nodes in an activity system (e.g., interactions among subjects, artefacts and outcome)</td>
</tr>
<tr>
<td><strong>Tertiary</strong></td>
<td>Changes in activities over time (e.g., evolution of an activity such that later versions differ from previous)</td>
</tr>
<tr>
<td><strong>Quaternary</strong></td>
<td>Differences between two competing activities (e.g., two subjects attempting to achieve the same outcome)</td>
</tr>
</tbody>
</table>

*Table 3: Engeström’s outline of contradictions adapted from (Engestrom, 1987; 1999)*

Given CHAT usually becomes clearer through application and example, consider the following examples of activity diagrams from Kane’s analysis of a social software design project (Kane, 2007). The first diagram outlines the activity from a system designer’s perspective:
Figure 7: Social software design from the perspective of a system designer as subject
(adapted from Kane, 2007).

(Not represented in the diagram is the intended outcome of developing a social software platform to enable end-users to create and update websites.) In this activity, the system designer as subject uses programming tools and assorted documentation to enable the creation of social software that affords community participation. She is governed by existing rules and norms on accessibility and usability, including common conventions of user interface design. She may be concerned about questions of ownership of her source code, and is influenced by various communities, including the end-users of her system. Consider, however, how those end-users may envision the same intended outcome:
Figure 8: Social software design from the perspective of end-user as subject

(adapted from Kane, 2007).

The above is provided as an example of a potential quarternary contradiction—the system designer’s point of view may clash with that of the end-user, even as both wish to achieve the same end goal of a social software platform. For example, an end-user may want access to the source code to expand their own creativity; a designer wishing to defend her intellectual property rights may resist this.
There are many other possible contradictions in the above case. Consider the following hypothetical situation. The systems designer, in her research, discovers two contradictory sets of guidelines on designing for accessibility (a primary contradiction within the rules). Which should she follow? The designer may use a variety of technologies (a secondary contradiction between subject, tools and object). Should she program the system in Java? PHP? .NET? Ruby on Rails? Each of those platforms may lead to the same intended outcome. However, platform choices are supported by different user communities (many of which strongly disagree with each other), and may create tensions in division of labor internally (e.g., a developer choosing to code in .NET in a Java-based firm will not be appreciated due to systems integration issues.) Similarly, the software designer may be inheriting code from a previous designer (a tertiary contradiction between a previous activity and a new version). Should she extend the code already provided? Rewrite some parts to her liking? Scrap it all and start from scratch? If she scraps the code entirely, does this create new and unforeseen contradictions to consider again?

None of these contradictions have “right” answers - they are simply points of potential tension that may arise when exploring the underlying social, political and technological complexity of human activity. These contradictions exist in multiple ways at varying levels of analysis. Reflecting back on our previous discussion on decision making, such resolution of contradiction is often a key mission of management and the most appropriate resolution is not clear, obvious or universally correct.

3.4 Investigating Key Contradictions in PBL* Teams: A Consideration of Research Questions

This research effort intends to investigate the information behavior and knowledge management strategies of PBL* teams as they aim to corral motivated students to meet project outcomes in an environment framed by competition rules, administrative requirements and other countervailing pressures. Effective PBL* teams develop into knowing organizations generating and retaining organizational knowledge over time, sharing that knowledge in a high-turnover environment, and using that knowledge to guide better decisions in a complex and competitive environment. In their efforts to realize the team’s objective, PBL* team members and leaders must negotiate a series of contradictions that need to be identified, and resolutions to these
contradictions are often unclear leading to organizational decision making based on bounded rationality and the derivation of satisficing solutions.

3.4.1 Primary Contradictions

PBL* team members are engaged in a sustained effort towards realizing a collective outcome. The nature and intensity of an individual’s motivation may differ among individuals, however. Hobbyist members are likely to have a different level of commitment than those engaging the activity for career-building purposes (Stebbins, 2004). In a PBL* team context, hobbyists and those with potential career aspirations must learn to coexist. Sonnenwald’s notion of contested collaboration (Sonnenwald, 1995) does note that individuals with divergent priorities can learn to collaborate, but this process may lead to a primary-level contradiction among a diverse range of subjects.

**RQ1:** What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations?

3.4.2 Secondary Contradictions

While there are multiple contradictions among elements in CHAT, the core contradiction remains that outlined by Vygotsky - how subjects use various instruments/tools to create particular knowledge objects. Information behavior research suggests this may be influenced by an individual’s perception of information gaps, professional training and the structuring influence of the instruments used in discovery (Talja et al., 2005).

There are many possible paths through the subject->tools>object contradiction. Some paths will lead inefficient methods and ineffective objects that are not seen as professionally valid. These paths may nevertheless be tempting to pick for novice engineers struggling with and/or intimidated by the magnitude of their information gap (Dervin, 1992). However, trial and error experimentation and “reinventing the wheel” may function well as a experiential learning exercise and can be very effective if lessons from such “sketchy” work are internalized to inform later work (Dym et al., 2005).
Such investigation is also a potential point of influence of faculty advisors and more experienced team members “guiding from the side” (King, 1993) to help avoid backward learning in PBL/PBL*, where early learning leads to faulty or shaky foundations for later, even more problematic investigation (Mandin et al., 1997). This process of knowledge generation is represented in the following research question.

**RQ2: How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction?**

Leont’ev expanded Vygotsky’s initial construction of the subject/instruments/object contradiction by grounding it in social context. PBL* teams operate in an environment structured by the rules and deadlines of their given competition. They also operate as units of their school, a relationship that potentially creates contradictions between team practice and an overarching layer of bureaucratic control. Over time, PBL* teams also develop their own unwritten norms and traditions that help govern behavior. Rules (written or unwritten), community concerns and power relations compel teams to make certain organizational decisions, as failure to meet the requirements of some of these forces may compromise a PBL* team’s chance at success.

**RQ3: How do PBL* teams negotiate contradictions between team activity and intended outcomes and school administration and established norms of practice?**

### 3.4.3 Tertiary Contradictions

Ideally, PBL* teams transcend the passion of individual team members and create a knowing organization that sustains knowledge generation over time. Sustaining organizational knowledge is especially important to student PBL* teams, who end up regularly losing highly qualified team members and leaders due to graduation. This may require tapping the experiences of past team members and planning to ensure future team members can pick up the torch when senior members graduate. As Nonaka & Takeuchi note, organizational knowledge retention is not as clear-cut as simply building an explicit knowledge repository – the social processes of internalization and externalization of knowledge are essential (Nonaka & Takeuchi, 1995).
RQ4: How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on their knowledge to future generations?

Accrediting agencies see PBL* opportunities as a means of developing skills relevant to professional employment (ABET, 2011). As PBL* team members negotiate these contradictions, ideally they develop skill sets that allow them to enter their professional career with experience and confidence. While this research question is not intended to be the core of this research effort it is worth asking PBL* team graduates about how – or if - their experience is seen as a future professional asset. This research question will be investigated in a specific context as proposed later in this paper.

3.4.4 Quaternary Contradictions

One potential source of information for PBL* teams are other teams in their competitive series. While the competitive nature of these teams may compel holding some information close to the chest, the educational nature of PBL* competitions encourages a degree of information sharing, and co-presence at competition will inevitably lead to sharing perspectives. Understanding what teams share – and what they do not – becomes an interesting question to investigate. Another source of potential information sharing are other PBL* teams at a given school – while not directly competing with each other in a given competitive series, they may be competing for a school’s limited supply of financial, space and human resources, as well as administrative attention and support. Interteam relations within a school can thus pose a potential quaternary contradiction.

RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private?

3.4.5 Summary of Research Questions

The proposed research questions highlight specific instances of potential contradictions PBL* team members may face in their pursuit of the team’s outcome. There are no evidently correct answers to any of these questions, suggesting the potential for diversity of approaches and concerns among PBL* teams. However, it is also fair to assume some attempts to negotiate contradictions are likely to be more fruitful than others, and that in some contexts, contradictions
may be minimal. The following section proposes an investigation into one particular PBL* competitive context. Before beginning that discussion, a summary of the five proposed RQs is provided below.

<table>
<thead>
<tr>
<th>RQ1: What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations?</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ2: How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction?</td>
</tr>
<tr>
<td>RQ3: How do PBL* teams negotiate contradictions between team activity and intended outcomes and school administration and established norms of practice?</td>
</tr>
<tr>
<td>RQ4: How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on knowledge to future generations?</td>
</tr>
<tr>
<td>RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private?</td>
</tr>
</tbody>
</table>

Table 4: Summary of Research Questions
4. Research Context and Methodology

While there are a range of PBL* opportunities available for engineering students, I will focus on one domain with a long international history - Formula SAE (FSAE) Racing. FSAE is an engineering design competition in which student teams design, manufacture, test and race a small one-seat autocross racecar conforming to rules imposed by the competition organizers, the Society for Automotive Engineers (SAE). The original Formula SAE competition, currently based in Michigan, USA, hosts 120 teams from over 10 countries. Regional competitions have emerged as well - there are now twelve Formula-style competition venues spanning the globe (two in the USA, and one each in Canada, the UK, Germany, Australia, Japan, Italy, Austria, Hungary and Spain (FS World, 2016)), with other informal and emergent competitions taking root in India and China. Given its long history, Formula SAE has also been the subject of academic study in engineering education as a capstone design project or PBL* team effort (e.g., Anderson et al., 2007; Goff & Terpeimy, 2006; Karri, Bullen & Rossmarek, 2001; Saddique et al, 2010; Schuster, Davol & Mello, 2006).

The selection of the FSAE context is partially motivated by personal experience with the event - I served as a participant observer, team member and management consultant to Cornell University’s FSAE team from 2001-2005. I will start this chapter by briefly describing a general lifecycle of FSAE teams based on archived documentation of my involvement and previous discussions with other teams, as well as the published competition rules that give structure and direction to the activity of building such a vehicle. The influence of my experience on the research methods chosen for this study will be discussed later in this chapter.

4.1 FSAE Team Lifecycle

The intended outcome of the activity of FSAE teams is to design, manufacture, test and race a car able to race in competition. The competition itself spans three days and includes "dynamic" racing events and design-oriented "static" events. Dynamic events test the performance of the racecar and the training of its drivers. There are presently four dynamic events that account for 675 of a total 1000 competition points (FSAE Rules, 2016). At 400 points, the endurance event is the most important and with drivers pushing their cars to the
highest level of performance, failures are common. Failure forces the car to be disqualified from
the event thus forfeiting any chance at winning overall.

The competition is not about performance alone, however. The FSAE competition
evaluates engineering design logic through three "static" events. The business presentation event
requires teams to justify a market for their car through a presentation to industry executives. The
cost report details material and process costs to ensure teams operate within a reasonable cost
frame. And teams have to present their design choices and logic to automotive and motorsports
engineering experts, who critique their design in a 30-minute interview. Top teams advance to a
final round of more in-depth adjudication. While worth only 150 points, the design event is a
validation of a team’s engineering skill and winning is seen a valuable prize in itself.

Months of work and thousands of person-hours are required to create a competition-ready
car. While teams can organize their work schedule as they will, most will progress through three
common phases in engineering design: design, manufacturing and refinement (Thompson, 1996). In the design phase, teams envision the constituent parts and systems of their new
vehicle. For new teams, getting through this phase can be a challenge as they have little to no
previous knowledge to leverage. To leverage Dervin’s concept of information gaps (1992), the
new teams face multiple and wide gaps in knowledge, with many information stops and rarely a
clear path to navigate. Even for more established teams with developed organizational
knowledge bases, there are challenges. The design phase may be an evolutionary process based
on years of previous work and experience, but it can also be an opportunity to engage in
experimental work that radically transforms previous work. For both new and experienced
teams, the challenge in the design phase is knowing when to stop. Insufficient closure of the
design cycle can lead to rushed manufacturing and limited testing, whereas premature closure
can lead to lack of in-depth consideration of alternatives and preformed conclusions based on
flimsy evidence (INCOSE, 2016).

In the manufacturing phase, required parts of the car are fabricated or acquired and
assembled into a complete vehicle. How this is done depends on a variety of factors, including
the resources available to a team, time limitations and sponsor assistance. Some parts are best
procured on the market - e.g., the engine is usually purchased as designing and building an engine from scratch is an exceptionally complex endeavor that is rarely attempted. Other parts require specialized technology that FSAE teams may not possess in-house, requiring outsourcing to industry partners. For example, while a steel space-frame chassis can be manufactured relatively easily in-house, the lighter, more integrated composite monocoque requires a high level of materials science knowledge, composite manufacturing experience and specialized technologies like industrial autoclaves and thus may require an industrial partner for assistance. Dependence on external parties can create dependencies and unexpected bottlenecks, and may lead to catastrophic failure. When the car is completed, the process of testing and refinement begins. Time spent on this phase largely depends on the team’s design and manufacturing schedule. Finishing the car one week before competition provides little time to validate results.

While all this technical work is being done, team leaders must also keep the organization operational and financially solvent. Teams often receive financial support from the school, private companies and individual sponsors, requiring the maintenance of relationships with external stakeholders who should be kept satisfied about their participation. Teams must also ensure compliance with the administrative and legal requirements of their school and external regulatory authorities. Team leaders must also ensure activities remain on schedule, identifying and resolving bottlenecks in production, and making tough decisions regarding people and projects that are falling behind or not meeting standards. As leaders are managing their peers, any intervention may cause significant strain in personal relationships.

The work done is largely voluntary. Some teams receive curriculum credit for their work, but the workload is often far more than required in most university courses. Many teams are structured as extracurricular clubs with no formal curriculum reward. In either case, student team members and leaders often find themselves having to balance team duties – which for some can meet or exceed the workload of a full time job - with other scholastic, professional, employment and personal priorities.

Faculty advisors can help student team leaders manage these organizational challenges. The level of engagement of the faculty advisor varies. Eight teams interviewed noted they had
faculty advisors who play an active and valued role in the management of the team. Three noted faculty advisors who might be a bit too active, acting as micro-managers of what should be a student-directed project. And other teams have advisors in name only – individuals who sign administrative forms as required but are otherwise largely absent from team activities. Faculty advisors may also have to mediate relations with the school’s administration, which has its own priorities and values.

4.2 Research Methodology

This study is based on qualitative methods of inquiry. Qualitative inquiry allows the researcher to understand the complexity of a research context through a range of methods and represent that complexity through the creation of robust narratives (Creswell, 1998). Qualitative research is common in achieving a deep understanding of information behavior (Case, 2006) and a good fit for CHAT-based information science research as well (Allen et al., 2011). While the resulting narratives are not generalizable in the same manner as some quantitative research, they provide a deep understanding of a given activity (Yin, 1989), and can influence other contexts through transferability to similar domains (Lincoln & Guba, 1985).

The final selection of research methods used in this study was an iterative process shaped by constraints imposed by the research context and unforeseen sociotechnical developments that required dropping one of the initially proposed major research methods, as will be discussed later. Before looking at research methods used in this study, however, I would like to note how past participant observation research has informed this effort, as well as provide an argument as to why this method was not considered in this research effort.

4.2.1 Integrating Previous Participant Observation Research

In qualitative research, the researchers’ depth of engagement with the community is a key consideration, and can range from non-participation to full membership in the community studied (Alder, 1987). When a researcher plays a passive role, the community being studied is in
theory uninfluenced by the researcher’s presence. However, an external observer is rarely fully benign. Awareness of an observer can alter the dynamics of a culture in unpredictable ways.

To address the unnatural assumption of passive observation, qualitative researchers often negotiate participatory roles in the context of study. Many studies are driven by the researcher’s own personal passion or interest. Such researchers “begin where they are” (J. Lofland & Lofland, 2006) and may already be active in a context of study. They cannot easily withdraw to a passive observation role without directly affecting the group’s activities. Even for researchers not previously participating in their research context, there are benefits to participation. Participation observation may uncover practices otherwise hidden and engender a deeper sense of trust with research subjects (K. M. Dewalt & Dewalt, 2011).

A considerable drawback of participant observation research is the time commitment required. Qualitative research is already a time-consuming endeavor requiring detailed exposure to an activity, detailed field note and media recording, and considerable time spent post-observation reflection and analysis (Creswell, 1998). Committing to participation adds to the complexity of analysis and the time commitment required. Extensive participation in the research context may also lead to excessive influence by those studied on the researcher, which may bias later analysis (Jordan & Yeomans, 1995).

The above considerations are important to consider regarding my previous work with FSAE and its integration in this proposed research project. My time with Cornell’s FSAE team started as a passive role when my research lab was commissioned to identify best practices in team management. My first year viewing the team was a largely ineffective effort. Team members would discuss issues in what might as well have been a foreign language. My presence was treated as a curiosity at best, intrusive and suspicious at worst.

My role shifted to participant observer during the 2000 competition. One of the team leaders, tired of my simply observing work, gave me the task of sanding and painting the car’s firewalls. I found that my willingness to put in work, however basic, helped breach trust barriers. Team members were more eager to share their experiences and I learned a great deal that
evening about the real dynamics of the team and its work. I became inspired to engage the team in a participatory role, and signed up to be a full team member, assuming all responsibilities of the role. After two years as a team member, I was able to understand team practices and dynamics at a far deeper level.

The opportunity cost of this effort is important to note. This effort was not strongly supported by my advisor, who moved on to other research endeavors leaving this project and myself in the process—abandoned, eventually leading to the suspension of this research and my decision to pursue it at this later time. The knowledge I gained about FSAE was acquired at a very steep price. However, I would argue that the depth of knowledge acquired was invaluable in informing this research effort. A generic information studies graduate student would find it very difficult to enter this context without some understanding of its operation. The “foreign language” of the team I initially experienced became familiar, thus allowing me to engage current respondents with a foundation of intersubjective understanding on core concepts.

In restarting this research project at University of Toronto, I briefly considered revisiting a participatory role with the Toronto FSAE team in 2010. I attended team meetings, assisted with public relations efforts, and updated my machining skills. In doing so, I came to the conclusion repeating this participatory role would not be helpful. I learned a great deal about this activity at first because I started from nothing and was desperately trying to figure everything out. In returning to Toronto, I did not feel I was expanding my knowledge in any substantial manner. My role in this context seems to have evolved from eager participant to elder statesman—itself a valuable role that I suggest can best be leveraged by acting as a bridge between multiple teams’ experiences.

As noted by CHAT, there are no right answers to contradictions in activity theory. This suggests that over 500 teams worldwide are experiencing their own challenges and devising their own solutions in this commonly shared activity. My history does put me in a unique position to collect and interpret other FSAE teams’ experiences of CHAT contradictions. Coming from a position of prior experience opened doors to participation that a neophyte observer might not be
able to access, and being able to interpret “shop talk” on the fly allows for a more natural engagement with research participants.

While this does provide possibility for bias, I deliberately excluded Cornell and Toronto’s teams from consideration to avoid any personal attachment to these particular teams and their history. I also deliberately represented interview and survey responses in the respondent’s own words as much as possible in order to preserve their voice. I only included information from previous experience if necessary to contextualize and interpret data points. Changes in the competition since my participation also keeps me somewhat naïve. As I learned through the research process, today’s competitors are operating on challenges that are significantly different than ten years previous, requiring some background research to understand and properly contextualize technical points.

4.2.2 Participant Recruitment and Identification

Two main research instruments were used in this study: a) a written survey derived from research questions directed at teams participating in either the 2014 or 2015 Michigan and Nebraska competitions (see Appendix A) and b) semi-structured oral interviews on-site at these competitions or at invited lab visits, based on the same questions from the survey. In addition, faculty advisor and competition judge perspectives were solicited through contacts at competition, and asked questions in person or by email as outlined in Appendix B. Information from published documents, online content and core competition documents were also analyzed and used to situate and contextualize data points as necessary. Specific details and challenges regarding these specific research instruments will be discussed below in their own sections. Before discussions of specific instruments, an overview of participant recruitment and those who participated is in order.

In 2014 and 2015, 120 teams registered for the Michigan competition, and 80 teams registered for the competition in Nebraska, with some teams attending both competitions (SAE, 2016). These registration lists served as the foundational documents that identified currently participating teams. From this list, I manually visited team websites and social media platforms
to create a master list to contact via email. Emails were sent out to 137 teams in April 2014, with followup emails made in October 2014, January 2015 and May 2015. At followup attempts, research was done to try to find alternative contact information for those teams whose retrieved emails bounced back as no longer active. No further contact information could be found for 24 of the 137 teams and these teams were thus dropped from the survey sample.

In addition, competition interviews were held at the Michigan and Nebraska competitions in 2014 and the 2015 competition in Michigan. One team for whom email could not be found was interviewed at competition. Nine of the 24 were not in attendance at competition despite initially registering, suggesting their teams are semi-operational at best. While it would have been interesting to explore the global Formula Student audience, this was beyond the scope for this particular study and is noted here as potential future research.

Approaching active teams by email and at competition allowed teams the ability to choose how they would engage this research project, and provided a balance of long-form written responses and oral responses given in the context of the activity and in the presence of their vehicle. Each method has its benefits and limitations, which will be discussed by method in the sections below.

In both survey and interview settings, teams self-selected representatives to respond to these questions. Given questions were oriented to those with a high level of systems understanding of the activity, the task usually was routed to senior team members or team leaders. In email communication, the task was usually routed to one specific individual. In three instances, a joint response written by multiple individuals was shared as a single representative document for their team. Similarly, in the competition or lab interview environment, individual members acted as a primary representative for the team, but in eight cases another team member would participate in the conversation. In two instances, this occurred because the initial contact was less experienced and required some assistance to help answer questions. As the goal of both the survey and interviews was a response representative of their team as a whole, joint responses are scored here as a single response.
Participation in this research was voluntary, with respondents able to withdraw consent in whole or in part at any time. With respect to competition interviews, three respondents exited the interview early due to competing demands on their time and did not follow through with requests to complete the discussion, leaving their records partially complete but substantial enough to be considered in this research. Three others did manage to complete questions later by email or Skype chat.

In order to ensure confidentiality of individual responses, responses are coded by number, with responses #1-13 from emailed team questions, #14-32 interviews at teams at competition, and #34-43 from interviews or emailed questions with faculty advisors, judges, and alumni, plus one site visit of a new team not yet ready to enter at either competition. As such there are 33 separate teams represented, plus 10 responses from those playing other roles in this context. The following table summarizes the nature and roles of the respondents in this study.

<table>
<thead>
<tr>
<th>Respondent #</th>
<th># of Individuals</th>
<th>Roles</th>
<th>Medium/Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>Team Members</td>
<td>Email</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>Team Member</td>
<td>Email</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>3 Team Leads, 1 Team Member</td>
<td>Email</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>Team Lead</td>
<td>Email</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Team Lead</td>
<td>Email/Site Visit</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>Team Lead</td>
<td>Email/Site Visit</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>Team Lead</td>
<td>Email/Skype</td>
</tr>
<tr>
<td>13</td>
<td>2</td>
<td>Team Member</td>
<td>Email/Site Visit</td>
</tr>
<tr>
<td>14</td>
<td>2</td>
<td>Junior and Senior Team Member</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>Team Member</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>17</td>
<td>2</td>
<td>Junior Member and Team Lead</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Senior Member and Team Lead</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>19</td>
<td>1</td>
<td>Team Member</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>20</td>
<td>2</td>
<td>Senior Team Members</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>21</td>
<td>2</td>
<td>Senior Team Members</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>22</td>
<td>2</td>
<td>Junior and Senior Team Member</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>23</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>24</td>
<td>2</td>
<td>Senior Team Members</td>
<td>Interview, Michigan/Email</td>
</tr>
<tr>
<td>25</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Michigan/Email</td>
</tr>
<tr>
<td>26</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>27</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>28</td>
<td>1</td>
<td>Senior Team Member</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>29</td>
<td>1</td>
<td>Senior Team Member</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
<td>Team Lead</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>31</td>
<td>2</td>
<td>New Team Representatives</td>
<td>Interview, Nebraska</td>
</tr>
<tr>
<td>32</td>
<td>1</td>
<td>Senior Team Member</td>
<td>Interview, Nebraska/Email</td>
</tr>
<tr>
<td>33</td>
<td>1</td>
<td>Alumni</td>
<td>Interview, Michigan</td>
</tr>
<tr>
<td>34</td>
<td>1</td>
<td>Alumni</td>
<td>Interview, Michigan</td>
</tr>
</tbody>
</table>
One primary outreach method to teams was through a survey consisting of open-ended questions, included here as Appendix A. These questions were formulated by examining potential contradictions that can be inferred from the CHAT activity model, and rewriting these contradictions in language more accessible to this audience. Such customization is necessary to ground what is otherwise dense theory into concrete language relevant to this particular context. This process was informed in part by previous experience with the work cycle of these teams, and validated via discussions with team members participating at the 2013 informal “shootout” competition organized by University of Toronto’s team. The questions were framed in a deliberately open manner to encourage a wide variety of responses based on the respondent’s experience.

These questions were delivered to 137 teams attending the Michigan and Nebraska competitions in 2014 and 2015. While these competitions had representatives from over 10 countries participating, English is lingua franca for the global FSAE circuit and thus most likely have English-speaking participants able to respond to these questions. I did note in the request to participate that non-English responses could be provided, at which point I would have made an effort to translate responses. However, all responses returned were in English, including two from universities where the primary language of instruction was not English.

Contact information for teams and faculty advisors were collected from an environmental scan of team web sites found off competition registration lists (SAE, 2016), with the assistance of Google to find teams that did not provide a link while registering. One
particular challenge was the varying quality of online presences among teams. Approximately half of the teams had a recently updated public website and active social media channels, making finding contact information relatively easy. Other teams, however, had minimal, dated or non-existent web or social media profiles, making online contact with the team difficult. For example, one response came from an alumnus who passed on my request to the currently active team, as well as asking that their name be removed from the team website.

After identification of team contact information, the questions noted in Appendix A were sent out to 137 teams for which an email address or contact form could be found. The first contact was in April 2014, with followup contacts in October 2014, January 2015 and May 2015. At each time, I endeavored to find substitute email contacts for addresses that returned errors, with 24 teams eventually being dropped from the contact list. 13 fully completed surveys were returned, with one of the above respondents preferring to complete their answers over Skype text chat, allowing for more opportunity for further questions. In addition to these 13 respondents, 9 asked me to visit them at competition, leading to six competition interviews. Five teams expressed initial interest only to not return a response in any form. 7 email addresses returned errors and were later dropped from the sample, and use of a trackback service in April 2014 suggested that approximately 40 emails were never opened, suggesting the emails may have been sent to a destination that was no longer active.

Written responses ranged from point form answers to long and detailed responses that proved particularly insightful. The longest response to this set of questions was 11 single-spaced pages – the shortest was two and a half pages of notes that were less robust, but still offered valuable information. Most responses were returned within a week of the call for participation, with one team creating a well formed six-page response in less than four hours. Respondents were primarily team leaders, either answering as individuals on behalf of their team or collaborating with other team members to fill in details on specific questions. Team roles are summarized in Table 4 above.

While securing team contact information, I also attempted to collect contact information for team faculty advisors to answer a smaller set of questions, noted here in Appendix B. Four
teams had both faculty and team member responses, allowing some comparison of opinions between these two roles.

4.2.4 Interviews at Competition and Site Visits

Competition interviews were valuable to engage teams directly in the context of their core activity. I attended both the 2014 and 2015 Michigan competitions as well as the 2014 Nebraska competition. While this led to 19 team responses (#14-32) as well as served as an opportunity to recruit competition judge and faculty advisor respondents, this had to be done judiciously out of respect of the core activity.

Semi-structured interviews of active students were conducted based on the same questions asked by email (Appendix A). As a semi-structured interview, the questions served as a general guide towards discussion as opposed to a list of questions asked verbatim and in order. Order and phrasing of following questions were shaped by respondents’ answers, as answers often covered material relevant to other questions. While there were many possible entry points to this conversation with team members, I started with the first question regarding personal motivation, as it seemed to be an effective icebreaker in the competition setting.

The major challenge of on-site interviews was potential interference with the core activity. Competition is the ultimate objective of a team’s work over a full year. Anything interfering with that objective is likely to be seen as a non-priority task. Flexibility around the requirements of the competition was a necessary constraint on information gathering. For example, early discussion with the eventual winner of the Michigan 2014 competition was ceased within five minutes as the team discovered a technical issue that would have disqualified them from dynamic events. The faculty advisor and team leads jumped into action to resolve the problem, leaving me with little choice but to move on to other schools that were less concerned with immediate challenges. Unfortunately, I was unable to restart the interview with the same individuals, so their input in this research is based solely on published information on the team’s
website, in conjunction with comments made by other interviewed teams regarding this team’s recent success, as will be discussed later in the discussion of RQ4.

Such interruptions proved to be a relatively common occurrence, with two responses taking places over multiple visits to the team’s workspace, and three completed later by respondents via Skype or email, as noted in Table 4. The best place to talk to teams for a longer period seemed to be in lineup for dynamic events or the competition testing area. Less on-car work was being done in these locations and non-driving team members were more available for conversation, as event lineups can be long.

All interviews were recorded by cell phone acting as a digital recorder, tethered to a battery backup. Recording was accompanied by field notes taken on a notepad, which were edited for clarity immediately after an interview and transcribed to electronic form on return from the competition venue in the evening.

Another challenge of competition interviews was the noise of the environment. The recordings vary in quality – see for example this interview with respondent #27, ending with notes from the transcription assistant.

MJ: “One thing I’m interested in is how teams learn what they need to know—pick a system or part you were involved with, how did you learn about what’s required to make that happen?”
#27: “Well, I was involved with suspension design mostly. We mostly started from Milliken and went into various iterations using ADAMS to develop…."
<motor fires up – approx. 5 mins.>

In cases like this, I was forced to depend on my own field notes to recall answers to the questions as posed.

As noted above, recordings were transcribed by myself with the help of a hired assistant. The assistant did have some issues with technical terminology and was instructed to transcribe phonetically if required and note parts that were confusing or unclear with three asterisks (***) and a time count so I could review the material. It was interesting to note than he had some
issues with terms that I had found confusing in my early days of participation. In one instance, the transcriber apologized for writing “A arms” as his best guess as to what was being said – a term that was actually correct. (Also known as control arms or a wishbone, this suspension part is often called A-arms because it looks like a capital A.) His struggle with such terms confirmed my belief that entering this research context with intersubjective understanding was important in interpreting information, as I was able to interpret the data point about A-arms without issue. However, I was able to sympathize with his confusion, as that term had once been a point of confusion.

Another limitation of competition as a research context is potential pressure for respondents to represent their car in a positive light. This is partially influenced by the fact that competition judges are present. Less than elegant details in design and development may not emerge unless they themselves are compelling. For example, respondent #25 noted they had crashed the car two weeks before competition and had to rebuild much of the front end rapidly. They were proud to showcase this because what they did to rebound was a compelling story. However, other teams may prefer to showcase a more linear, iterative and logical path - a path that may or may not be true.

In emails to teams, I identified specific schools where I may be able ask questions in person through visiting their school’s lab space. Budget and time restrictions limited the scope of this outreach to teams within an approximately five-hour drive radius of Toronto. This approach was predicated on the notion that teams might resist a long written answer or being interrupted at competition, but might be more willing to meet in person at their own school on their own schedule.

I was surprised that few teams expressed interest in this option. Only three teams agreed to a visit and these interviews were conducted in a similar manner to competition interviews. On reflection, engaging in an in-person discussion still requires that the team dedicate specific hours to host a visit, so I suspect it might have been easier for some respondents to write a response or determine they were too busy to host a visitor.
Interestingly, the most valuable of the three site visits happened outside my designated five-hour circle, while at an academic conference. The local university is a regular competition contender, so I looked up their contact information and noted that I was in town for a week. They gave me directions to their lab and were very hospitable in showing me their facilities.

With more resources, I would have considered a trip to an international competition, particularly Formula Student Germany. German and Austrian teams have risen to the top at recent competitions worldwide – the top four finishers at Michigan in 2016 were German or Austrian teams. Exploring that environment was out of my financial reach or scope of this project, but is considered in the final chapter as a possible extension of this research.

4.2.5 Supporting Public Documentation

In the initial research proposal for this study, the main research context considered was FSAE.com (http://www.fsae.com), a public international online forum dedicated to discussion about this event. FSAE.com started in 2002 as a student-run forum among teams in the FSAE circuit. FSAE.com discussions cover a range of topics from technical to management concerns. The “Open FSAE Discussion” forum is the most active, with over 7000 topics that remain archived. As regular FSAE design judge Claude Rouelle noted:

“FSAE.com forum is THE #1 resource to use if you want to find information and ask question about ANY FSAE or FS event, team organization, budget, car design, testing etc.” (Rouelle, 2012)

Given this, the choice of this forum seemed promising. My initial plan was to engage FSAE.com members in semi-structured discussions started by a series of cultural probes (Gaver et al., 1999) mapped to proposed research questions.

In practice, this proved less fruitful than hoped. Shortly after Rouelle’s post, FSAE.com begin to fall into decline, with traffic decreasing to the point that the 2017 Michigan competition thread only had 4 responses, down from multiple pages of content in its prime. In discussions with current participants, it would seem the reason for this decline is a shift in media choice (the
The forum did still prove useful in two ways, however. “Sticky” posts on the forum highlight some of the more informative discussions, and four respondents noted that these specific resources were consulted. The older nature of the population also allowed for identification of alumni, competition judges and faculty advisors for solicitation.

Competition rules and results were also consulted as primary documents (FSAE Results, 2016; FSAE Rules, 2016). Competition rules were consulted to determine the structuring factors of competition and to support arguments as to why some technical challenges were central concerns to the team. Attending competition is the ultimate objective of respondents, and the rulebook defines, often in minute detail, what the rules of that competition will be.

Results were used as a check on certain observations, to classify teams by history or record of success, and to follow up to see if noted examples were indeed successful in practice. Any individual competition score is an imperfect measure of organizational performance, as even established teams with a consistent record of success can be beset by unforeseen events or inclement weather. However, over years it is clear some teams are more successful than others, and a review of team scores over time helped identify teams that are perennial contenders and those who are struggling, as well as teams with a long history and those new to the environment. Results helped classify potential competition interviewees as well. I hoped to include a few less developed teams in the sample as these teams likely would have particular challenges negotiating CHAT contradictions, and scanning results helped identify newer teams.

When scanning public team profiles for contact information, I also joined any available public Facebook and Twitter feed to follow the public relations outreach of teams. This helps reacquaint myself with the general work cycle of this series, as teams would regularly post updates on their progress through design, manufacturing, testing and competition preparation. Potentially valuable pieces were archived as corroborating public documentation, although these sources were not systematically scanned or coded for content.
4.3 Data Analysis And Research Ethics Considerations

The data collected is qualitative in nature, with data being text in original form (e.g., email or Skype/Messenger chat) or converted into text (e.g., transcripts of interviews and on-site visits). This data was stored in a secure folder and backed up routinely as each new record was added to the collection. As noted earlier, transcription was largely done by myself with the assistance of a hired helper, who was trained to code pieces of the audio files that could not be faithfully transcribed with three asterisks for later review. Interviews recorded in real-time were transcribed in full to facilitate coding and analysis. This is an arduous and time-consuming process, but the act of revisiting and transcribing is itself a valuable analytical process (Bennington et al., 1999). Given this I was sure to engage that process for most interviews – even the 7 records sent for transcription by the hired assistant were reviewed for accuracy and verification of technical jargon and in so doing reintroduced me to the content.

The 42 responses noted in Table 4 were analyzed in four iterative cycles of open coding (Corbin & Strauss, 1990). The first cycle of open coding worked on categorizing emailed survey responses. The five research questions derived from CHAT contradictions were set as the high level organizational schema for all data. Given survey questions were directly informed by those research questions, there was generally little ambiguity in the classification of survey data in those categories. Once this data was classified, a second pass through the data was made to identify observations that may also have relevance to other categories, and those observations were replicated and moved to those locations as well.

The second cycle of open coding added interview data from student and recent alumni respondents into the above categorized survey data. While interviews were structured around the same questions as above, the semi-structured nature of the interview process allowed for respondents to explore issues that might span multiple research questions simultaneously, making classification of data points slightly more complex. On the first pass information was classified according to research questions. As done above in the first cycle, another pass through the data set was made to identify points that could be relevant to multiple categories. At this
point of the process, enough data was appropriately categorized to allow for sub-categories to emerge as potentially relevant observations, so early headings on potential subcategories were added to identify common themes and observations.

In the third cycle of open coding, information from competition judge and faculty advisor interviews and surveys was added to the data set. This information was solicited using questions in Appendix B, which were also derived from CHAT contradictions that formed the core five research questions. However, given the role of these respondents within the CHAT activity model was different, many data points served to qualify and contextualize data points provided by student respondents. After initial open coding of this material, a second pass focused on axial coding (Corbin & Strauss, 1990) to highlight contradictions and commonalities between observations coming from considering various functional roles in this activity. Axial coding also helped identity relations among sub-categories that emerged from continued iterative classification of the student interview and survey data set.

A fourth cycle of open coding integrated public documentation such as competition rules, past competition results, collected online content, and other related public documentation such as noted publications. This led to further identification of common themes and refinement of sub-categories within research questions, bridging related observations and contextualizing the reasoning behind and effectiveness of stated observations.

The complete data set was thus compiled through four cycles, each adding information of increasing detail. After information was added to the record in each cycle, iterative cycles of review and reclassification of data helped create subcategories of observations and highlighted interconnections, common observations and potential contradictions and challenges among varying perspectives.

At the conclusion of these four cycles of iterative classification of information resources, axial coding was used to identify examples of specific CHAT contradictions. The overarching classification scheme centered on research questions that themselves were derived from CHAT contradictions. Axial coding helped identify particularly strong examples in the collected data as
well as identify examples that bridged multiple contradiction types. These specific data points were replicated and moved to other categories as required. Notes on specific CHAT contradictions were tagged by red banners for easy retrieval and consideration in the writing process.

Classification, sorting and analysis was done using the cloud-based card sorting tool Trello, which is primarily used as a collaborative outlining and project management tool in IT projects. This tool suited the overall classification structure based on core research questions well. Trello organizes material through project boards that contain individual information cards which can contain text, quotations, digital media and other information pieces. These cards can be aggregated into specific categories, and allows like cards to combined and moved around with ease. Search tools allow for easy discovery and retrieval of specific card information. As Trello is a project management tool designed for mobile use, it integrates well with other mobile communication and productivity tools such as Slack, which enabled communication with the transcribing assistant when specific transcriptions required clarification. Management of cards was also easily done on mobile and laptop devices, which allowed for use of multiple screens to assist in data categorization and analysis. Trello boards can also serve as a “to-do” list, which was very useful in writing the dissertation. Points that had been written up could be checked off, tracking progress in the draft writing process.

One limitation of Trello is that card categories cannot be disaggregated into multiple sub-levels automatically. As this was necessary in specific cases, separate heading cards labeled in green were created to visually denote content sub-categories. This allowed for specific sub-headings to stand out in visual display. Overall, Trello as a tool for data analysis did an effective and efficient job of replicating a manual index-card based model of data analysis, and did so with a more accessible user experience and price point than other online tools such as Dedoose or commonly used desktop platforms such as nVivo, both of which were initially tested on early data points. A screenshot of the Trello deck can be found in Appendix D.

To trace data points back to respondents in a secure manner, each information piece was tagged at the end with a specific respondent number in brackets. This ensured personal data on
sources was available for later reference if required but allowed that personal information to stored off the cloud-based Trello platform. Personal information regarding respondents was stored in a secured Excel spreadsheet offline.

With respect to research ethics, this project was reviewed by University of Toronto’s research ethics board as as minimal risk. The research record is comprised of individual responses either through written responses to questions or by interviews on-site at competition and lab spaces. Respondents were given the opportunity to review and agree to the consent form noted in Appendix C. Respondent names were never transcribed into the research record in Trello, which only included numerical references, cross-referenced to a spreadsheet.

I initially suspected there would be some information that will be offered as confidential. Given the public nature of interviews, it is generally unlikely that respondents would share information that could be harmful to their reputation in that domain. Similarly, peer respect suggests that written responses would not volunteer personally damaging gossip or unwarranted personal attacks. In only three records were personal names used in a way that led me to believe secondary verification on consent were required. In those cases, I was careful to anonymize personal names and checked again to see if the story was acceptable to tell. Overall, I do not foresee any particular issues regarding any personal damage coming from the specific observations and stories shared by respondents.
5. Results and Discussion

As noted earlier, the core research questions of this dissertation focus on specific points of contradiction in the cultural-historical activity theory model that teams face as they build and refine their knowing organizations. These contradictions are potential points of negotiation and challenge that FSAE teams are likely to face as they work towards their end outcome of building and fielding a competition-ready race car. While competition deadlines and rules set the parameters of competition, there remain many possible ways FSAE teams and their leaders can choose to address these contradictions. There are often no “right” answers to these challenges – but there are solutions that seem to work better than others, and other solutions that team members themselves acknowledge are less than optimal. As expected, there was considerable variety in approaches noted over survey and interview responses. In this section, I identify and explore specific points of contradiction that became evident through the data analysis process across the five major research questions posited earlier in Chapter 3.

For each research question, the research question is introduced in its original form, followed by a summary of answers given to specific related questions posed in the research process. These questions ground CHAT contradictions in challenges and wording more familiar to this specific audience.

Where possible, verbatim quotations were used to have respondents speak in their own voice regarding their experience of CHAT contradictions. Respondent numbers are used to keep replies anonymous and confidential to protect the identities of respondents. These numbers correlate to a master list of respondents compiled during the data analysis process. When necessary, some general team-level information may be disclosed to provide context (e.g., a Canadian team with over 10 years of experience and a solid history of performance in competition; or, a community college team starting off and only entering competition for the first time.) Otherwise, respondent information are limited to their numerical reference to protect confidentiality and limit any bias attached to specific schools in the readers’ mind.
5.1 Research Question 1: Balancing Individual Differences

RQ1: What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations?

Fielding an FSAE car is not an individual activity. Even if it was possible to have one person do all the work required to design and build a car, by competition rules, one must have at least six team members on site to compete in all events, based on a rule largely designed to avoid having one or two “ringer” drivers do all the driving (FSAE Rules, 2016). Given that, FSAE teams have to compile a number of active members and keep them engaged and active in the team’s work cycle.

This can be challenging, especially for student-led teams where student team leaders are charged with running an organization of significant size and complexity for the first time. Sonnenwald (1995) notes that there are multiple and possibly contesting reasons that individuals may have for engaging in a collaborative activity. The potential for a CHAT contradiction at the primary level at the node of the subject is very plausible.

Teams have to contend with the fact that individuals arrive to the team with their own individual priorities, and work to channel these individual energies towards a collective outcome. While some students join a team largely aligned with the team’s intended outcome, others may prove to have their own interests which may be quite divergent. As noted earlier by Allen et al. (2011), individuals can have distinctly different motivations that may vary considerably from the collective activity.

As suggested in Karau and Williams’ (2001) Collective Effort Model of individual motivation in group activities, “individuals will be willing to exert effort on a collective task only to the degree that they expect their efforts to be instrumental in obtaining outcomes that they value personally.” (p. 119) Failure to channel individual motivation could lead individual team members to withdraw, or work towards their own unique objects/outcomes, which may or may not be reconcilable with the collective goal.
Understanding this dynamic requires an understanding of why people join these teams and what team leaders can do to mitigate differences among individual priorities to create a collective outcome. Individual subjects may vary in the degree and direction of their motivation compared to the team’s intended collective outcome, and it falls on student teams leaders who often have not led an organization of such complexity to corral these different and often contradictory motivations.

5.1.1 Motivating Factors for Joining FSAE Teams

The amount of work done by a FSAE team member is extraordinary, with 17 respondents estimating workload at over 20 hours a week and five respondents reporting over 40 hours as week. This activity can consume time that might otherwise be spent on other personal, professional and academic goals. Why one would choose to dedicate such time and energy towards this activity thus becomes a question of interest. To uncover this, I asked people of their motivation for joining their team. Their responses were coded according to theme on Trello leading to the following observations.

5.1.1.1 Social Bonding

10 respondents noted some facet of social bonding for their team participation.

“The amount of time you spend with people here – it’s really kind of like a fraternity for car geeks.” [#17]

The “fraternity” metaphor was also directly mentioned by respondents 21 and 24. Respondents 5 and 20 noted a similar metaphor to varsity sport teams, with #20 noting he chose FSAE over his varsity sport because “there wasn’t enough time to do both, and I enjoyed working with this group a lot more.” [#20] Like fraternities and sporting teams, the collaborative activity of building a car provides a sense of social belonging through allegiance to a common outcome, and helps build social relationships that themselves can be a driving motivation for engagement (Baumeister & Leary, 1995).
This sense of belonging and social interaction can help some team members compensate for a lack of bonding in other domains. For example, respondent #30 noted he was driven to join after his second year for the following reason:

“I was going to school, going to my classes most of the time, going home, playing video games after homework. I kinda felt like a bit of a loser really – school was feeling like a chore and I was getting a bit burnt [*bummed? – audio difficulty] out. When I joined the team in junior year, all of a sudden I had these new friends. I’d have people to play video games with that I actually knew, although less time to do it. I’d have people to grab notes off and study with who I actually knew and liked. People started phoning me – usually about car team shit, but at least it was something. My first year, I only had a couple of friends in dorm. I’m not a big drinker or partier, so frat life never appealed to me. I kinda felt out of place. Now I don’t.” [#30]

Notable in the above quotation is how this can further the social connections of those not naturally oriented to traditional “party” scenes in some schools. By joining the team, #30 gained access to a social network that seems to fit his internal motivation and social preferences.

Other team members joined not to find new friends but to keep in contact with old ones. Respondent #29 noted that he joined because his roommate was on the team, and convinced him to give it a try.

“He was never home – that kind of makes you curious. Now I know why. A couple of weeks ago, we talked about just giving up the house and living on campus. There’s a shower in the building. We have a meal plan. We could probably pull it off.” [#29]

In a similar vein, Respondent #30 continued his above statement thusly:

“…my best friend from first year started volunteering in second year. Every time I’d try to hang out with him, he was busy – so one time I figured I’d drop by to figure out what the big deal was. He put me to work taking notes during dyno testing. For some reason, I just kept coming by after that, and now we’re co-leaders of the team. If I found someone else to hang out with that night, I probably wouldn’t be here.” [#30]

And sometimes there are ulterior motives at play, as Respondent #19 suggested.
“Not going to lie - I had my eyes on a cute guy in my economics class. Talked to him after the final exam for a bit and he said he had to run off to the lab. I kinda faked interest about that, he invited me over to see what he was doing, and yeah, I’m doing the team’s PR work and website and dating the engine team lead. Somehow we manage not to argue about team things when we’re alone, but we’re not alone much. But it’s been a fun couple of years – the last two years wouldn’t have been the same without him. And I know so much about cars now that my uncle’s even impressed – got into an argument with him last Christmas about engine tuning and schooled him good.” [#19].

Whatever the motivation for people to seek social connection, it seems from respondents that participation in FSAE teams can foster a sense of identity and belonging and in cases like #30 be a relatively transformative event in their lives. Given the workload required to design and develop these cars, it does help if those engaged are enjoying the company of their colleagues, and it appears from respondents that in the most part, they do. Collective work towards a given activity can create shared interests, orientation and community, and such community is valuable in the organizational sensemaking process, which is inherently social and grounded in identity construction (Weick, 1979).

This sense of group identity is reinforced through a variety of means. For example, most teams have custom branded clothing that serves as a de facto uniform at competition – it is common to be able to visually identify various team members by their team shirt. This can also reinforce identity around campus - as #20 suggested:

“I wore my team shirt proudly last year after the school made a good PR push when we finished [in the top ten]. Suddenly people knew what I was doing and respected that. Not quite the attention our football jocks get, but hey, I’ll take it.” [#20].

This feeling of pride in belonging to something larger than one’s self is consistent with social identity theory (Tajfel & Turner, 1986), which notes that group successes can help form positive self-identity. Wearing the team shirt around campus allowed #20 to share a success valued by the larger academic community, and from further discussion with him it was clear this pride helped justify the many hours of effort he invested in the team’s work.

5.1.1.2 Sense Of Accomplishment
As #20’s example above suggests, FSAE teams not only provide an opportunity to build social relationships, they do so in a context for people to collaborate around a common goal. The core activity of building something of perceived value can itself be a driving force to join a team. Given a lot of the responses were in the competition environment, it is not surprising that 8 responses were coded as related to the sense of pride around the final product.

Respondent #18 noted that he had previously been a member of an extracurricular engineering club based on his national origin, but was not satisfied with the experience.

“Well, the [redacted] club was just that – people talked a lot, we had a couple of social events, but there really wasn’t much beyond that. It was nice to talk to people, but I’m second-generation [redacted] – I’m not homesick, many of them were. I still go to their events when I can – my language is pretty bad, they find that funny, and I do help them on papers and stuff because I did alright in English class and yeah, they didn’t. But I just didn’t feel like I was doing anything interesting with them. Now [with FSAE] I do.” [18]

This particular quotation suggests that for any given individual, some goals might have more intrinsic value than others. While goals can coexist, some will be perceived to be more relevant, and may structure effort and motivation accordingly. While others may have enjoyed Respondent #18’ role as expert in a club structured around common heritage, he found that experience to be wanting and was happy to find something more personally engaging. As suggested by Goethals and Darley (1987), such inter-group comparisons can be common in helping shape one’s individual motivations. By orienting his efforts towards a different activity, he was able to find a collective goal that furthered his personal interests and gave him more satisfaction.

Other respondents were clearly proud of the work they accomplished, especially at competition when the outcome of the activity is sharable to all. One respondent gave me an extensive walkthrough of his work on the suspension geometry of their car.

“I spent most of the month playing with the model, tweaking various setups, getting people to machine new spacers, rockers, and A-arms to get the suspension points right, trying some different damping solutions, trying them out on the car in practice at any opportunity we could. I was frustrated that we just weren’t hitting the sweet spot even
with all the iterations. The simulation is one thing, and important especially for the design presentations, but it has to work on the car and with the drivers – and when things are balanced, you just know. When [driver] drove a few skidpad and autocross runs the other day, he laid down the fastest time we’ve posted to date…he knew it was dialed even before he saw the times. And I was pumped watching it go – it just was glued to the ground, all the time. After a month of work and running out of time, god it was good to see that. Was really proud of what we finally pulled off – now just hope it works here.” [#27]

It was evident from his tone that this respondent was enthused about his effort. There is a sense of hitting a “eureka moment” here. After weeks of hard work to drill down on a complex problem, achieving a workable solution can be a source of visceral joy. A less complex problem solved with less effort would likely not have been relayed with such pride of accomplishment. Given that the team did do well at competition, finishing in the top 10, this sense of accomplishment is probably only reinforced now.

5.1.1.3 “Because Racecar”: Intrinsic Interest in Racing

In engaging any complex, long-term activity, it helps to be interested in the activity itself. Some PBL* projects are going to be more attractive to particular individuals than others, and in schools where there are multiple PBL* efforts, teams compete for the attention and motivation of participants, so appeal to innate motivation in the activity becomes an important consideration.

Seven respondents noted a level of attachment to automotive racing as a sport as a reason for them joining the team. One student team member specifically noted that he applied to his school because of its FSAE team:

“I actually applied to University of [X] because of their car team program – I saw their car out on a visit and was blown away that I could actually do that in school. I did some research on the race, applied only to schools with quality teams and signed up with our team first week.” [#18]

As will be discussed later in discussion of RQ3, universities often use team projects as recruiting tools for visiting high school students, so it was not surprising to learn his research was a factor in his application and decision making process.
Others expressed a more general interest in automotive racing as a sport. Respondents noted they were spectators and fans of NASCAR, Formula, IndyCar, rally racing and the amateur Formula Ford series, which is most similar to the FSAE car in design. Three respondents noted that the team would make an effort to attend local races as a team bonding experience.

Participation in street racing and car customization was also a major point of intrinsic motivation. One respondent shared “I got involved in this because I wanted to customize my own ride better. I’ve spent more time and energy on the racecar. Hopefully this summer I can find some time to fix my own.” [#10] Another noted his long-standing participation in racing go-karts and motocross:

“I’ve been driving since I was 6… go-karts and then dirt bikes. I’m an adrenaline junkie I guess. This just seems like the next step – I’d love to drive further, make some money to get a really nice potentially competitive ride and know how to keep it going. One of our sponsors does amateur Ferrari racing. That would be sweet. Probably too late to go professional, and I’m not that great anyway - good enough to drive for us, but there’s better even here for sure. It’s just fun – and these cars are so fun. Always a letdown when I get behind my 2001 Civic. That’s all I have the cash for now.” [#16]

There is a significant difference between driving an FSAE car and a standard vehicle. Given these cars’ horsepower to weight ratio, FSAE cars boast longitudinal and lateral acceleration statistics that the most expensive road legal vehicles cannot match. For some team members, driving the FSAE car is a key perk of team participation, and one that is quite accessible for most. The design rationale behind the competition is to design for the average amateur racer, so competition rules mandate that the car accommodate up to a 95th percentile sized male (FSAE Rules, 2016). This prevents teams from designing around the smallest driver - advisable for reasons of basic physics, but structuring design around a 5th percentile female driver would risk excluding many from driving, and the adrenaline rush that comes from driving these cars, which in turn could demotivate a good subset of the team.

It should be noted here that racing as an activity is not hospitable to everyone. It is a loud and dirty environment – one regularly comes in contact with oils, fuels and chemicals, many
being toxic and requiring special safety equipment, and the operation of these vehicles often
drowns out ordinary conversations. This attracts some but may repel others. Racing’s historical
cultural norms involve a high degree of machismo and may not be particularly inclusive of
various groups (Collins, 2013; Giang, 2015). Some prospective team members may find such
machismo to be a potentially toxic environment.

For others, though, this is an engaging and even all-absorbing activity. The “because
racecar” meme was referenced on team websites (e.g., GFR, 2016) and social media as well as
being the theme of one team’s t-shirt at the 2015 Michigan competition. Its roots come from a
Craigslist ad where a car for sale was described as “completely stripped inside because race car”
(Know Your Meme, 2012). For normal consumers, such a warning would lead to no sale, but for
racecar enthusiasts, the phrase “because racecar” is symbolic of the many sacrifices made
towards the eventual goal of racing and competition. For some the act of racing alone is reason
enough to sign up to an FSAE team.

5.1.1.4 Extrinsic Motivation

As with many academic extracurricular activities, joining a team may be seen by team
members as a means of enhancing a professional resumé and making connections relevant to
their later careers. Experience with PBL* teams covers many of the technical and professional
skill requirements stressed as important by industry (ABET, 2011; CDIO, 2011). What is more,
many of the competition judges are employed in the automotive and aerospace industry and as
respondent #40 shared, they are often charged with identifying excellent students for recruiting
purposes.

Given the potential value of FSAE experience to a student’s professional development
and career prospects, it was a bit surprising to discover only five student respondents note that
building resume experience or enhancing their career options was a personal motivation to
participate with the team. This may be a result of not wishing to be seen as using the team for
their own personal advancement. An aversion to selfish motivation was highlighted in one story
of personnel conflict from respondent #8.
“We had two mutual friends start the year that really didn’t work out. One freely admitted she was doing it to pad her resume – her friend probably was too, but he was also totally incompetent and lazy. We had to basically fire him, she left a bit after because she was swamped with many other similar clubs she was doing and was probably bitter we fired her friend. But this isn’t a social club. If all you want is a line on your resume, go do something else, it’s easier. If you aren’t willing to learn what to do and work hard to do it, we really don’t have time for you. Go away, you’re wasting our time and yours.” [#8]

The above quotation suggests that these highly collaborative teams are not the place for individuals only in it for themselves. Using the team experience to further one’s individual fortunes can easily be framed as a subject diverting away from the collective activity and creating a primary contradiction at the subject node of the CHAT framework. When specific individuals are perceived as engaging in social loafing (Karau & Williams, 2001), this has the potential to create tension and the collective group may sanction those who are perceived as not fully contributing to the collective outcome at hand. While team participation arguably does make for excellent resume material for employers, the collective nature of this activity and the necessity to work together as a team to meet the eventual outcome likely softens the edges of those with a more ego-centric motivation.

A team member who puts the team’s obligations below their own personal advancement is not likely to be appreciated. A story about a team leader was shared by a colleague at one competition:

“We’ve done OK I guess, but this competition’s really showing how much of a jackass [looking around to see if he’s around...] X is. He’s running around telling everyone what to do, very dictator like…and it’s just worse here. I was in design with him - when it came time to talk about the [redacted] system he literally pushed me aside and took over. I busted my ass on that system for weeks. But yeah, he just jumps in, even in areas he knows fuck all about, and starts saying how “I did X and Y”. Great. He’s already told me he’s trying to get a job out of this competition, but hey, aren’t we all? Plus, he didn’t do it right. I got my bit in when he tripped up on a couple of questions and had to rescue him – the judge saw through his bullshit, had a chance to talk to him after, he didn’t like his attitude either. It’ll be much better next year when he’s gone.” [#32]
One of the challenges student teams face is that they are run by student leaders. For some, this is the first opportunity they have had to manage an organization of this size and complexity. By not valuing the input of the content expert in this case and by stealing the spotlight for his own personal gain, this team leader both sabotaged his own personal goals as well as the collective mission of the team, causing significant tension in the process.

As Allen et al. (2011) notes, CHAT activity models can be mapped at individual and collective levels. Individuals may have a number of intrinsic and extrinsic reasons to participate in an FSAE team. What matters most to the team is ensuring individual motivations are channeled in an appropriate collective direction. Those who joined their team out of intrinsic interest in racing or are motivated from a sense of accomplishment in the activity are probably not difficult to orient towards the collective goal of building the racecar.

Other individual motivations may be more complicated to channel into an acceptable collective direction. While social bonding is important, FSAE teams are not social clubs such as the international student association noted by #18. The core activity of an FSAE team is to design, build and test a functional racecar. That certainly has a social dimension, but a team solely motivated by hanging out with friends may find it problematic to muster the focus and effort to accomplish its goal. Respondent #43 expressed concern that his new team may not survive the year given that many key members treat the team as a social club. Due to competing academic, professional and personal demands, members often cannot dedicate focused work to the task at hand. While they may have fun with the car on occasional weekends, #43 lamented that the result of this occasional attention is that their first car still requires considerable work to reliably enter competition.

Perhaps more complicated are those who join a team for extrinsic motivations such as building experience for a resume or for professional networking. As suggested by #8 above, those who are simply collecting experiences for a resumé are probably not a good fit in a high intensity focused work team aimed on a collective outcome. And as noted by #32 above, excessive focus on individual goals may jeopardize the collective outcome and create tension
and animosity among teammates. Resolving such contradictions at the subject level is thus important in focusing team attention on a coherent collective outcome.

5.1.2 Resolving Contradictions At the Individual Level

As Sonnenwald (1995) notes, teams can be grounds for contested collaboration, wherein a variety of individual motivations seek common purpose to transcend individual difference to achieve a common goal. As suggested by CHAT, an individual’s activity orientation ideally should mesh with the collective outcome, but there are many possible outcomes for an individual subject’s motivation. Team leadership has to work to channel individual motivations towards a collective outcome, since as noted in #32’s response above, a team of individuals selfishly pursuing their own individual goals is not likely to result in a functioning vehicle.

There was comparatively less information provided by respondents on points of interpersonal conflict. This may have to do with keeping up appearances – team members may be reluctant to write down grievances in an email easily traced to their name, even under promises of confidentiality. What is more, as is evident in #32’s quotation above, questions asked at competition may be in earshot of the person in question. Plus, teams in the competition setting have likely already progressed through Tuckman and Jensen’s (1977) early stages of team formation of forming, storming and norming, and are squarely concentrated on performing. In this context, previous interpersonal conflicts might not be front of mind as they have already been resolved as pressing issues. The value of longitudinal research to better capture early stages of contradiction will be discussed later as a potential extension of this study. However, even with these considerations, a few points of interpersonal conflict and how they were handled were noted by respondents.

5.1.2.1 Individual conflicts on technical matters

Those noted interpersonal conflicts were largely tied in part to technical matters. While it would be nice if optimal solutions to all technical problems were derived through objective and predictable means, this is not always possible or plausible, especially in decision-making
contexts not structured by rational decision making models (Choo, 2006). For example, one team noted an ongoing internal team discussion around development of a full vs. partial aerodynamics package for their car.

“As with many teams, we’ve moved to having a wing, but this year we were going back and forth between having a single rear wing, which we had some development and testing data on from last year, and a full aero package with front wing, underbody, vortex channels etc. I was insistent on the full aero package – pushing it from early design, hard, noting that other teams are doing it just fine. The other leaders saw this to be a bit too much of a project to take on in nine months. We ended up sticking with rear wing only for now, and I was definitely pissed off for a good month. We would have benefitted from a full package – it’s doable, but it agreed it would have required a huge change. We just don’t have the time and resources to ramp it up that quick I guess. I got a lot of the preliminary research done for next year and will be training people to keep an eye out for full aero packages at Lincoln this year. Still would have been nice to pull it off – hope to help next year’s team doing that even though I’ll be gone.” [#14]

In the above reflection, team leadership as a whole decided that the full aero package was not yet ready for implementation, and that the intended collective outcome would have to trump respondent #14’s enthusiasm for a different direction. When one team member invests considerable time and intellectual effort on a problem only to have their solution rejected, it is easy to see how questions of design and systems integration can become personal. The cancellation of the aero research effort was a challenge the respondent had to work through, and that clearly still carried lingering personal feelings of disappointment and frustration.

The above example showcases the importance of systems engineering in framing technical challenges (INCOSE, 2016). While teams often organize around specific functional subsystems, eventually their parts must work as part of a larger whole. This is especially the case with a full aerodynamics package, which would have indirect and direct effects on nearly all other subsystems and require a lot of testing and verification to prove its benefit. Without a collective design philosophy that is clear to all team members and a design process that encourages early resolution of potential system conflicts, it is easy for renegade designers to diverge and create systems that do not fit the whole.
Poorly handed, such disagreements about system integration can devolve into deeper divisions, as noted here by #34.

“Well, a couple of years ago we did have one issue with our engine team, kind of screwed us really. We didn’t have a proper leader for engine development – more two co-leaders. Sometime around January, there was a disagreement on the direction of engine tuning – one wanting something a lot more complex. Both started working on their own engine development separately, uncoordinated. By April it was bad - different fuel maps, different settings, not talking to each other and only arguing when they did. Leaders finally intervened to pick the simpler model given time constraints – and the guy who spent weeks on the more ambitious model threw a chair across the room, disappeared for two weeks, and finally quitting. Great help, yeah. We barely had a tested system on the car, probably didn’t matter a huge deal given we failed out of endurance, but we could have done better.” [34]

In this particular case, differences in technical direction that could have been resolved earlier devolved into mistrust and personal animosity. By not addressing the primary CHAT contradiction between subjects early, a primary CHAT contradiction between individuals metastasized into a quaternary contradiction between two wholly separate outcomes - something far more catastrophic to the team’s intended overall outcome. Given the rules of the competition required a solution, team leadership had to intervene to select one solution over the other. Failure to address this conflict early resulted in losing a team member, sacrificing testing time of the chosen solution, and compromising the performance at competition. Negotiating this personality conflict earlier could have avoided the bifurcation of the activity and controlled the interpersonal challenges facing these two individuals, potentially saving face and retaining the loyalty of the ambitious if ultimately unsuccessful team member. Given the circumstances of #34’s story, it is feasible to suggest that the work done on the more complicated engine package left with him, and he would be less than eager to help the team out in future years.

5.1.2.2 Reconciling diversity in individual contribution

As suggested earlier by respondent #16, people being perceived as “lazy” is a common point of contention, raised separately by five other respondents. With five team members reporting that they spend the equivalent of a full time job on car team work, those who do not put in the same effort are potentially targets for animosity and marginalization.
However, it is also important to consider work-life-school balance. A team alumnus noted:

“Unlike many team members, I somehow managed to have a girlfriend. It wasn’t easy – thankfully she was crazy deep into her own research efforts in biology so our schedules were both stupid, but there were a few days I just wanted to take off and spend some time with her. Most people understood, but there was always a couple you got the impression were looking down on you in some way. Thankfully didn’t care much – I did my best effort, the team experience was amazing for the most part and two years later, we’re still together, and at the end of the day that’s more important.” [#42]

While hard working team members are required to sustain a team’s progress, it is important to recognize the whole lives of those engaged in the effort. School, personal, family and other commitments exist outside the lab, and these commitments can be more personally relevant and important. In high-performance team contexts it is easy for some members to lose themselves in the activity and ignore other pressing concerns, creating tensions in work-life balance that can lead to long-term psychological and physical health issues (Guest, 2002).

That noted, there does need to be a core group to lead the team, and enough people who are willing to make the team a priority in their life. In one lab site visit to a new and struggling team, a team leader shared this observation:

“Our team is a bit different – the school is largely mature students. I’m probably the youngest kid here – and I’m 22. People have jobs, girlfriends, wives, kids…lots of distractions from this kind of work. I appreciate that – I work part time 20 hours to help pay for school myself. But I talk to other teams who have full time students with more time to dedicate to this, have to admit they have a huge advantage. We end up kinda like a social club – we play around with the car on weekends and some nights, but even on a two year schedule that’s hardly enough to build a full car. We need more people with more schedule flexibility or this probably breaks up…” [#43]

It is possible to staff a team with team members with a number of other competing work and life priorities, but this would raise coordination and integration challenges. Given a number of student members have limited experience with team leadership to start, coordinating a team filled with part-time members who can only contribute small pieces becomes a potentially
daunting challenge. Those with less time and energy to commit may still provide some benefit towards the team’s intended collective outcome, but are far less likely to do so if they feel their contribution is dismissed as lazy, or if the organization as a whole does not have the resources or capacity to coordinate and integrate their potential contributions.

Other team members might support the eventual outcome but based on different personal motivations. For example, while respondent #19 noted she joined the team partially due to romantic interest in one of the team leads, she also brought public relations and web development expertise. Her dedication to non-engineering related tasks was a positive and appreciated contribution to the team’s overall intended collective outcome, but one that would not be necessarily treated as valuable if the team’s culture dismissed such non-engineering tasks as unimportant.

Her experience speaks to the benefits of cultural diversity in organizations and the challenges of appropriately managing that diversity. As Cox and Blake (1991) note, a heterogeneous organization that values individual difference and diverse viewpoints, promotes cultural inclusiveness, and strives for work/life balance can maximize the potential contribution of people from many walks of life, and enhance the quality and diversity of inputs in information seeking, knowledge creation and decision making by fostering creativity and mitigating the potential for groupthink in more homogeneous work groups.

However, unwritten rules and norms of an organization can create an environment that might complicate participation by some groups. As Cox and Blake note, “…consider a scenario where a prominent value in the organization culture is ‘aggressiveness’. Such a value might place certain groups at a disadvantage if the norms of their secondary or alternative culture discouraged this behavior.” (Cox & Blake, 1991, p. 49).

This may especially be relevant to racing culture, which as previously noted carries historical baggage such as a culture of machismo, where women are still represented in promotional material as sexualized objects and homosexuality can be cast as weak or wrong (e.g., as overhead on site, it is still common in the competition venue to hear “gay” being used as a
pejorative term to describe objects or events unrelated to anyone’s sexuality.) Traditional racing culture has many unwritten norms that can frustrate the participation of a more diverse population and thus restrict the talents they can contribute to the intended collective outcome.

I would suggest that things have changed since my involvement with the FSAE series more than ten years ago. With respect to ethnic and national background, the international reach of FSAE has attracted a number of non-north American teams to Michigan and Nebraska, and the efforts required to make an international visit are commonly noted in competition announcements and awards. Diversity in North American schools is also being reflected in the FSAE teams – in competition visits, I noted two Canadian teams were staffed and led mostly by East and South Asian team members, reflecting the nature of the engineering student population in those schools. Racing culture has also shifted from a perceived white historical foundation - movies such as the Fast and Furious series highlight a very diverse cast of characters, and Asian car manufacturers have encouraged a community of “ricer” street racing that attracts a multicultural range of participants. All this helps FSAE to become just a bit more representative of the global community.

With respect to gender and sexuality, there has also been progress, however slow. Respondent #19 confirmed my observation that it is still common to see “the well-dressed female” being the representative of the team at the business marketing presentation – she noted that she felt strangely out of place on that day in particular, being overdressed for the venue. Given this event is not highly regarded in the competition as a whole and what teams assume are the preferences of what is often an all-male judging panel, attractive women are often slated for this role, which arguably ghettoizes female participation.

And while the population of recent competitions is still predominately male by visual inspection, nearly half of my survey respondents were female. This suggests that female team members are charged with being the public face of the organization, a non-technical role that may be perceived by some as less critically important to the core activity. However, respondent #19 made a very strong argument that her colleagues were appreciative of the work she contributed to the team’s overall operations.
In a discussion with one female technical team leader on Skype chat, I decided to dig in a bit deeper on her experience:

#12: Hope this answers your questions! Let me know if I can get you anymore info
MJ: Thanks, very helpful – just one more thing if I can – what’s the gender breakdown of the team? Assuming you’re a woman by your name, we always had some difficulty getting more women involved.
#12: Actually, not that bad –we’re about 1/3 girls, which isn’t too bad given the ME dept is I think a bit less
MJ: That is pretty high for car team. Any issues there?
#12: Was expecting more really - get more sexist bullshit in class than here. Here, the guys have come to terms that I know what I’m doing – after nearly 3 years you build some respect. I came out last year and introduced my girlfriend to the team and even that wasn’t an issue. The school wouldn’t look kindly on them if they tried of course….
MJ: Wow. Good to hear.
#12: Certainly not perfect yet – I’ve talked to a couple of other girls on other teams where there’s more issues, but they’re smaller kinda backwater schools, probably just the culture there in general. We’re in a pretty diverse city in a pretty liberal state, not much tolerance for bigots here, especially on campus

It was refreshing to hear that #12 could act as a technical team lead while in an out lesbian relationship. Being in a progressive university in a progressive community certainly helps, but I suspect there are other factors at play. As the old guard of racing culture dies off, the millennial generation taking its place is arguably more accepting of individual difference. There is evidence that this may extend to other technical domains – for example, DIY maker communities are trying to break the stereotype of being a male geek activity by actively recruiting female and minority members and making their spaces zero tolerance for hateful language and actions².

Technical team leaders like #12 can set a tone and example for others, showing other young women that they could participate in such a project if they so choose, despite a still lingering macho cultural history. #12 does not make racing and/or engineering culture non-sexist or non-homophobic overnight, but her leadership does lead FSAE norms in the right

---

² For example, while Toronto makerspace site3 does specialize in fire and pyrotechnics, arguably a stereotypically masculine interest, they also hold women and LGBTQ sessions to attract a more diverse clientele, and operate under a zero tolerance harassment and discrimination policy. (http://www.site3.ca)
direction. It is arguable that strong female and minority leaders can create a positive and welcome tertiary contradiction by modifying team norms over time through their example and leadership. This in turn should make it easier for those that follow in their steps – in #12’s case, it is feasible to suggest future female and/or LGBT technical team leaders would likely have to fight fewer and less entrenched biases and stereotypical expectations, making their own evolution to team leadership smoother. People like #12 are also likely to play valuable mentorship roles, especially if team leadership values active alumni participation and encourages people like #12 to advise future leaders. The value of alumni participation will be discussed later in section 5.4.

5.1.3 Summary for RQ1

RQ1: What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations?

Participation in FSAE teams is not a small commitment, with 17 respondents noting spending more than 20 hours a week, with 5 noting over hours of work on the car. This is work done alongside any other academic, employment and personal obligations. As Karau and Williams’ Collective Effort Model (2001) suggests, “…individuals will be willing to exert effort on a collective task only to the degree that they expect their efforts to be instrumental in obtaining outcomes that they value personally.” (p. 119). Given participation is a voluntary activity, team management does have to take into consideration individual motivations and align those motivations with the intended collective outcome of the team.

Respondents pointed to a range of individual motivations, including social bonding, a sense of accomplishment, intrinsic interest in the activity, and external rewards. Some of these motivations are mutually reinforcing. Social bonding helps to build a collective identity, which in turn supports the creation of an intended collective outcome that helps structure future organizational sense making, knowledge creation and decision making.

Maintaining the right mix of individual energies and refocusing them on the collective outcome can be a challenge. Individual team members have to refocus on a collective outcome
that may not be a perfect fit with their individual motivation, and team leaders and team culture ideally structures the collective outcome to be as inclusive of as many individual motivations as possible. This may be complicated by those who are more motivated by extrinsic or selfish goals such as resume building or building personal network connections at the expense of their team, which is arguably why this was not strongly noted as a primary motivation.

If the team’s goal is to do well at competition, and a given design threatens that goal, appeal to technical foundations may help to mitigate interpersonal conflicts by focusing attention on outcomes larger than individual interests. In more complex decisions, goal or procedural uncertainty might require less rational or procedural decisions to be made, which risks alienating individuals who have made strong personal investments to rejected decisions.

A culture of mutual respect of individual difference helps mitigate these concerns. While some team members might have different motivations, histories or backgrounds, they can nevertheless still contribute to an overall intended collective outcome, and a diversity of experience is important in developing new innovation (Roberts, 2006; von Krough et al, 2000).

Given the historical dominant culture of racing has not been particularly inclusive, building on organizational cultural diversity can be a challenge. However, changes in demographics create the possibility of a more heterogeneous organization comprised of a variety of individuals contributing what they can. However, this may require more attention to team management practices that embrace and help balance such diversity and balance workload fairly so everyone can contribute what they can, which could prove to be a significant managerial challenge for student leaders often learning to lead their teams on the job.
5.2  Research Question 2: Negotiating Contradictions in the Core Activity

RQ2: How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction?

As discussed in Chapter 3, the foundation of CHAT derived initially by Vygotsky (1978) is the core activity, located at the top end of the CHAT pyramid – subjects using particular tools/instruments to derive specific objects that ideally match their ideal outcome. In engaging any activity, there are many potential paths through this connection. There are no right or wrong paths to take – however, some paths will lead to objects that better reflect the intended outcome, whereas others are likely to generate poorer results.

In the context of FSAE teams, there are a range of tools and instruments available to discover information that can inform design and development. Frequently, results from multiple paths have to be reconciled and balanced. Often there is no evident “right” manner in which to do this, but rather resolutions that March and Simon would call “satisficing” given the resources and time available (March and Simon, 1993).

Given FSAE teams are comprised of student members and leaders who are still learning the tools of their trade, the heuristics of professional practice may not be readily available or fully understood. As a result, it is likely less efficient paths and less than correct information will influence the process. The role of the faculty advisor and technical staff can be invaluable in helping teams through their challenges. What role they play and how that role is perceived by team members is also of interest here in this research question.

5.2.1  Negotiating Multiple Potential Pathways of Investigation
The core activity of student engineers in this context is to discover information relevant to the design of their assigned part or system and use appropriate tools and methods to realize, refine and ratify that design.

To discover the many possible paths through this core activity, respondents were asked to share their discovery processes regarding a single subsystem of the car they had personally worked on. As expected, there were multiple instruments and tools noted by respondents. The following table summarizes just some instruments/tools used in researching and realizing their system. It should also be noted that because this question was asked during competition in interviews, respondents may have been primed to report on instruments and tools that represented their final product in the best possible light. While it could be suggested that this environment might minimize report of less professional methods of investigation, a range of formal and informal methods were nevertheless mentioned.

<table>
<thead>
<tr>
<th>Tools Used in Design Phase</th>
<th>Respondents</th>
<th>Tools Used in Manufacturing/Testing Phase</th>
<th>Respondents</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAE Research Papers/Dissertations</td>
<td>1, 4, 6, 9, 11, 17, 19</td>
<td>Formal Testing Methods</td>
<td>1, 3, 5, 6, 8, 9, 11, 12, 15, 16, 19, 21, 24, 25, 28</td>
</tr>
<tr>
<td>Course Textbooks and Core Readings</td>
<td>1, 2, 3, 4, 5, 10, 11, 13, 14, 21, 23, 25, 27</td>
<td>CAD Design</td>
<td>3, 4, 6, 7, 12, 15, 18, 25</td>
</tr>
<tr>
<td>Competition Rules</td>
<td>2, 3, 5, 9, 11, 13, 14, 18, 19, 21, 22, 23, 27, 29, 32</td>
<td>Simulation software</td>
<td>2, 4, 12, 21, 27</td>
</tr>
<tr>
<td>Industry White Papers/Popular Press</td>
<td>2, 3, 4, 9, 11, 13, 15, 17, 21, 27</td>
<td>On Car Data Acquisition/Sensor Data</td>
<td>2, 5, 7, 10, 13, 15, 17</td>
</tr>
<tr>
<td>Internal Team Reports</td>
<td>1, 3, 4, 7, 9, 11, 14, 17, 19, 21, 24, 25, 29</td>
<td>Informal Testing</td>
<td>2, 4, 5, 6, 7, 11, 14</td>
</tr>
<tr>
<td>Online Forums/DIY/YouTube</td>
<td>4, 6, 7, 9, 11, 12, 14, 15, 16, 17, 18, 19, 21, 25, 27, 29</td>
<td>CNC Machining</td>
<td>3, 6, 11, 13, 14, 17, 19, 21, 23</td>
</tr>
<tr>
<td>Team Image Collections</td>
<td>3, 4, 9, 13, 17, 19, 21, 24</td>
<td>Manual Machining/Construction</td>
<td>3, 5, 12, 15, 17, 20, 22, 25, 26</td>
</tr>
<tr>
<td>Alumni/Current Member Consultation/</td>
<td>2, 3, 4, 5, 6, 9, 10, 11, 12, 14, 18, 19, 23, 25, 26, 27, 28</td>
<td>Exchanging Testing Data with Other Teams</td>
<td>1, 5, 7, 14, 16, 19</td>
</tr>
<tr>
<td>Trial and Error</td>
<td>1, 3, 4, 6, 7, 9, 11, 13, 15, 18, 19, 20, 21, 25, 27, 29, 32</td>
<td>Driver Feedback</td>
<td>1, 2, 4, 6, 9, 12, 14, 19, 26, 29</td>
</tr>
<tr>
<td>Observing Past/Other Cars</td>
<td>3, 4, 9, 11, 15, 17</td>
<td>Early prototypes/mockups</td>
<td>5, 8, 11, 13, 15, 23</td>
</tr>
</tbody>
</table>
Table 6: Noted tools and instruments in design, development and testing

This list represents a considerable range of means of investigation, from formal to informal and from tacit to explicit, some of which may be more effective and efficient than others. This creates multiple potential pathways through the core activity, with multiple potential options in instruments/tools leading an even wider set of potential possible objects. As noted in CHAT discussion of the core activity, choices among various available instruments/tools has direct effect on potential outcomes. Given that, insights from interviews and surveys on specific tools and instruments follow.

5.2.1.1 Explicit and Authoritative Sources of Information

Ideally the design of a part would be founded on vetted sources of information. While there are a few published academic reports relevant to the FSAE project, they do require some tailoring for this context. However, there have been a few SAE papers written specifically on FSAE car design, particularly around chassis, suspension, and aerodynamic design, and these are seen as valuable sources. Course textbooks were also seen as a supporting resource, although as noted by respondent #1 saying “textbooks or lack thereof”, the connections between course texts and this specific activity may not always be evident.

There are a few special-purpose books that are noted as regular reads. For example, Milliken and Millken’s Race Car Vehicle Dynamics was noted as a foundational read for chassis and suspension design. The Millikens have been active supporters of the FSAE Tire Testing consortium, discussed later in discussion of RQ5 as a long-standing example of interteam collaboration. And Carroll Smith’s books are still considered “bibles” - referred to directly as such by three respondents. Carroll Smith served as the original chief design judge of the FSAE competition, a role he played until his death in 2003. His books (Engineer to Win, Tune to Win, Drive to Win, Prepare to Win, and the Nuts, Bolts, Fasteners and Plumbing Handbook) are written for an amateur racing enthusiast audience and are a very accessible read covering many principles of mechanical engineering, materials science, and vehicle design, testing and
maintenance. These books are not without fault - Smith’s writing is colloquial, and includes liberal use of sexist connotations that were probably more acceptable when first written but increasingly ring false with readers today. As female technical team lead #12 noted, however, these books remain an excellent primer for foundational concepts, even though she cringed at the traditional role of women in Smith’s universe.

Arguably the most important published document to consult in design and manufacturing is the formal rule set of the competition. In four interviews, a printed copy of the rules was in view for ready consultation as required. The 177-page rule book (FSAE Rules, 2016) provides core structure to the activity and sets out specific technical requirements. Safety is a primary objective of the formal rules – many of the rules ensure the competition venue and testing environment is safe for drivers and spectators alike. For example, chassis rules ensure the driver is secured in a roll cage in the event of rollover, emergency shut-off switches are accessible, the driver is able to exit the vehicle in 5 seconds or less, and that appropriate safety gear is worn. Restrictions on engine displacement and an air intake restrictor ensure that student-designed cars are not overpowered, and help maintain a level playing field. Other more complex systems also have their own specific rules – e.g., electronic throttle control systems are only allowed provided the electronic system and its code are approved in advance by technical judges. These rules are enforced by preliminary technical inspection, post-race inspections after endurance, and potential spot checks in the competition environment. Teams must pass brake, tilt and noise tests in order to run in dynamic events, and attempts to circumvent the rules at any time can lead to penalties or disqualification.

Having an active faculty advisor is important in shaping interpretation and implementation of rules. As rules evolve over time, active faculty advisors know who to lobby for particular changes. Given advisors are designated as the formal contact for any rule challenges at competition, teams who arrive without an advisor may be at a disadvantage regarding any secondary CHAT contradiction between the team’s vehicle and competition rules as interpreted by technical and design judges. While there can be debate around the interpretation of the rules, teams strive to understand the formal document and live within it to the best of their ability. Unsurprisingly, no team admitted to any deliberate attempt to circumvent rules, although
as will be noted later in the section on sketchy designs, some teams had to revamp designs on the fly at competition to conform to the rules.

5.2.1.2 Leveraging Internal Knowledge Artifacts

While FSAE teams would likely prefer to frame their research and development around vetted published research, much of the information discovery process leverages less formal and internally generated information sources in practice. These can include internal team reports, consultations with previous and current team members, image and video content taken at previous competitions, and various DIY online content, which may be of questionable quality.

Past cars and team members were commonly noted as information sources. For example, Respondent #3 noted how an in-house online forum stores team reports for later reference and also provides a channel to contact current and past authors to engage in conversation over stored reports. Using such an internal repository makes intuitive sense - internal team reports and alumni networks are likely to provide the most immediately relevant information to new generations of team members, and chart out a quicker and clearer path to bridge information gaps new members may experience (Dervin, 1992). Such a system is possible in teams where there is a strong organizational commitment to retain information and maintain social connections with alumni, such as shown by #3, whose case will be covered in more detail in the discussion of RQ4.

Given the near ubiquity of smart phones and wireless connectivity, in situ photography and video are increasingly common information resources leveraged in design. Most team members now have the ability to take digital photographs and videos on site on their phone, and to publish those photos to team databases in real time. As respondent #4 noted, these image libraries can be especially helpful for visual thinkers, who can easily process the relevance of a single image quicker than reading a full technical report. Photography of competing cars is thus common and generally not seen as problematic – although as will be discussed in RQ5 there is a particular etiquette involved in this practice.
However, as #17 noted, many of these images may become meaningless without context or relevant metadata:

“We have a collection of images on our server from competition photos – but they’re a bit all over the place. A photo might not say much – a photo of a brake system doesn’t tell you which brake system it might be, and no one seems to write down notes about that, especially competition photos. It’s easy to forget whose car was photographed – we try to tell our photo teams to take photos in an order with the car # and inspection stickers so we can at least trace them to specific cars/years, but that’s only followed sometimes. And some photos are more nice photos vs. detailed technical photos where you get a sense of scale and proportion. Trying to get an attractive angle kills the value of the shot – weird perspective or lighting might make for something nice to look at but you can’t filter that out. At the end of the day, you still need to know what you’re looking at to learn much from photos, even of your own car.” [17]

Acting on a tip that someone had taken pictures of a specific design he wished to emulate, #17 went to the team folder of photographs. He had to go through each photo individually to find the right ones, after sifting through hundreds of unrelated photographs. Their “database” is simply a file folder of photos, containing no annotations or metadata. This examples speaks to the potential value of having delegated custodians of such an information repository who could be charged with filling in contextual information and metadata to assist with more precise and efficient information retrieval. Without someone on the team playing such a role, respondent #17 found the search process through the folder cumbersome and frustrating.

Online sources are increasingly a common resource for design challenges. While at times imperfect, there are valuable sources of information that can be found in a Google search. For example, while most current team members have not been active on the FSAE.com online forum, key discussions are public and discoverable through internet search, and three teams noted they had found material of relevance to their design and development on the forum.

Also noted as a source are tutorials emerging from amateur DIY/maker communities. For example, respondent #16 noted an online forum around their specific engine block was essential in troubleshooting engine issues and sourcing parts for rebuilds. By tapping the shared knowledge of public communities, #16 was able to find information and connections unlikely to be found in any formal published source. The maker culture shares a similar ethos of open
collaboration towards solving complex problems (Tierney, 2015). Through various blogs, videos and forums, communities of practice span organizational boundaries to form around shared concerns (Wenger, 1998), and these communities can be invaluable in informing and validating various design questions.

The quality of the instructions in online tutorials can vary however. #18 noted he looked online for information on installing data analysis sensors and hooking them up to their particular data acquisition platform.

“I did finally find a tutorial that was helpfulish, but about 1/3 of the material I had to ignore as it was not relevant to our car at all – that part involved some creative problem-solving to come up with something that would fit our needs. And the video was hard to follow – about an hour too long, a British guy who just kept going off on other stories and kept telling jokes that really were kinda annoying after a while. Was nearly screaming at him to get to the point at times – I could do that video in 10 minutes without the bullshit. Might do it if I get the time…” [#18]

Maker/DIY tutorial and videos are amateurs helping amateurs – which means project quality, sound/video/lighting quality and veracity of information are not necessarily going to be professional grade. They may serve as a foundation for investigation and experimentation, but do require some tailoring and trial and error experimentation to adapt to this particular context.

As Slawson and Shaunessey (2005) note, critical information literacy is a key factor in effective PBL, as students are required to critically evaluate the veracity and utility of the information they find. A Google search can yield information from the profound to the practical to the absurd. As Choo notes, the epistemology of internet sources can lead to “…an age of information abundance and information dubiety, [where] there is a heightened need to calibrate information and knowledge behavior according to the norms of epistemic responsibility and epistemic conscientiousness.” (Choo, 2015, p. 170). Critical awareness and judgements of source credibility can be the difference between choosing an effective research path through the core activity, and one that will never yield an object compatible with the team’s desired outcome because the instruments/tools are compromised, dubious or simply wrong.
5.2.1.3 Trial and Error Experimentation and Tinkering

The sheer volume of investigation paths may itself become a challenge. As Dervin and Frenette (2001) note, there is often a considerable information gap between a perceived problem situation and intended outcomes. Approaching this gap can be a source of considerable questioning, experimentation, doubt and confusion, with many false starts and dead ends. Dervin outlines various “situation stops” (1992) that can halt information seeking wholesale, including decision stops where multiple paths ahead exist, barrier stops where specific paths seem to be blocked, spin and wash out stops where paths seem to end or disappear, and problematic stops where it feels the path is not leading anywhere. In such an environment of false starts and incomplete paths, team members will often experiment with whatever is available to attempt to resolve their knowledge gap.

Reverse engineering past systems can provide significant insight into past work. Six respondents noted dissecting previous parts and systems as a source of information. This is possible since according to competition rules, cars cannot be re-run in future competitions. Past cars are thus free to be dissected, with their component parts recycled. This can help future generations, especially when part designs are relatively static and the likely outcome for this year’s design is similar to previous work.

That noted, it is also helpful for a team to keep previous cars active for on-car testing and driver training. #26 noted they had over ten years of cars stored, at various levels of completeness, while #12 noted in her comments a testing session involving three cars running simultaneously. This living archive can come with a high cost, however – storing 10+ cars requires extensive storage facilities many teams may not possess. As such, even established teams will destroy or find a new home for their past cars - #15 noted they have given cars to corporate sponsors, and #21 noting that alumni have adopted previous cars, but a number of established teams would just as soon recycle core parts and materials for future builds.

Newer teams without such a history of established work may find bridging their knowledge gaps to be quite a struggle. New teams such as respondent #43’s who do not have
historical knowledge or previous cars to leverage may find themselves confused and frustrated until they mature and build up an internal knowledge base and foundational cultural knowledge (Choo, 2006) that can guide research and development decisions. As design judge respondent #41 noted, first year teams should strive to get the basics done, noting that teams who finish all events at competition should see that as a successful outcome.

Respondent #31 was not part of a participating team, but was at competition to learn more about the design challenges they were likely to face as they launched the following year. Given the volume of information available at competition and the number of teams willing to talk about their final designed product, #31’s strategy was quite effective. As will be discussed in RQ5, experienced teams are happy to help out new teams with a learning curve they know to be steep.

Even more seasoned teams will balance scientific testing with trial and error experimentation, however. As respondent #3 noted “…we go out, test it, look at the data, analyze it, hold it, love it, and post it on the forum or write a technical paper...” [#3]. In this case, a more formal written report of design exists – but it is built on a foundation of experiential learning, iterative cycles of improvement and even such imprecise factors as “love”.

Similarly, respondent #29 suggested that designing the driver bay was as much a process of collecting qualitative driver feedback as any scientific approach.

“For a couple of weeks I would go out with the car testing various inserts to get drivers securely in the seat and coming up with options to make our main drivers feel right – you design for Percy (N.B. the name of the prototypical 95% percentile male noted in the rules) but none of our drivers are that size – so Percy has to fit, but the real drivers have to be comfortable too. That was some measurements but really just a lot of tailoring the fit to make it work.” [#29]

As design judge #40 noted, judges do encourage a degree of grounded qualitative understanding alongside formal testing data. While formal methods of testing are preferred, core design assumptions are often based on iterative testing and refinement, such as that noted by
respondent #18 repurposing the DIY tutorial earlier. It is only later that the final result will be formally documented.

From the perspective of building organizational knowledge, such tinkering plays a role in developing deep personal understanding of systems and their various possible configurations. In Nonaka & Takeuchi’s (1995) SECI model, tinkering can be seen a key part of internalization, where available explicit knowledge is transformed and made a part of an individual’s tacit knowledge. Trial and error experimentation allows an individual team member to repurpose knowledge in an intrinsically personal manner, creating a strong foundation for socialization as the SECI knowledge creation cycle begins anew. While this may seem inefficient compared to reading a published report, when it is done to further the development of grounded tacit knowledge, time spent on internalization can be seen as quite valuable. This is especially the case for new engineers, who may not possess the tacit knowledge to deeply understand a written report. By learning by doing something experts may have done many times, they make information personal in a way a formal report would have difficulty conveying.

5.2.1.4 Reconciling and Evaluating Core Activity Decisions

While trial and error experimentation and tinkering is important, formal engineering analysis based on professionally sanctioned methods resulting in quantitative data does matter. Much testing can be done in-house with technologies that most engineering schools possess, with teams noting track simulation software, chassis and engine dynamometer testing, thermodynamic models, suspension analysis modellings, structural equivalency data models and finite element analysis testing among others as instruments and tools to generate data presented to judges.

More complex testing efforts may require larger industrial support, however. While tire data is widely understood by chassis designers as the foundation of suspension design (Milliken & Milliken, 1995), reliable data on tires can be hard to come by as formal tire testing is complex, expensive, and leads to unsellable product (Kasprzak & Gentz, 2006). This makes tire testing cost-prohibitive to manufacturers and teams alike. To respond to this challenge, teams have collaborated with Milliken Research Associates to collect and share tire data for teams willing to spend $500 for access to testing data (MRA, 2016). This consortium has expanded from a
handful of teams to over 450 paid participants, including all teams surveyed and interviewed here. The tire testing consortium gives access to core data from which teams can create scientifically justifiable models of their suspension design, and is an example of how teams strategically collaborate as will be discussed more in Section 5.5.

With so many possible paths to retrieve and validate information, another problem emerges – what sources to trust. Respondent #2 noted, “it’s a hard balance to strike, we often have to go with our best guess given the information available”. [#2]. Respondent #4 noted that they are suspicious of Internet search results, often using them only to expand upon existing relevant information. Triangulation of information sources was also noted by respondent #8:

“In any complex system you’re going to have a lot of ideas and concepts that might not match. But if you find the books are suggesting one thing, your testing seems to back it up, it feels right on the car, other teams are doing it, and everything you find in Google seems to agree, well then it’s a pretty safe bet.” [#8]

In the event data points from various instruments/tools are in contradiction, teams must decide what sources are trustworthy and how to reconcile any discordant information. As Weick (1995) notes, such sense making is a function of three processes: enactment, selection and retention. In *enacting*, individuals attend to the raw data they experience and through engagement with it begin to imbue it with potential and possible meaning, although this data remains equivocal. Through *selection*, individuals refine data, privileging interpretations consistent with their past understandings, and evaluating and discarding information that is incongruent. In *retention*, equivocal decisions are made regarding truth claims which can then be subjected to further interpretation.

Many systems on a FSAE car can be validated through formal testing and are thus are best understood through a rational model of decision making (Cyert & March, 1992) where information is readily attainable through a structured scientific research process, leading to relatively unambiguous decision options. However, given resources and time constraints, at times teams will have to arrive at a sufficiently satisfactory decision in absence of a more perfect solution (Simon, 1997).
The role of the competition design judge adds some complexity to this research, development and testing process. The competition design judges are the ultimate evaluator of design quality in this particular context, with their judgements leading to team scores in the design component of the competition (FSAE Rules, 2016). Their relationship to the core activity of a team is a secondary level CHAT contradiction between the team’s core activity and division of labor, as judges can play an authoritative but also a formative role in guiding the design process as will be discussed below.

Competition judges are volunteers recruited from industry sponsors, the amateur and professional racing community, and FSAE alumni. The design event is a two-stage affair. In the preliminary stage, all teams enter a preliminary round of 30 minutes of questioning. Each team is assigned a particular queue and time to attend with their car. Design judges arrive at their queue having read the team’s design report, submitted weeks before the competition begins. While queue designation is not outlined in the rules, design judge #41 confirmed that top-tier teams are usually distributed evenly to avoid some queues being too weak or overly strong. Judges provide an evaluation on a general rubric found in the rules (FSAE Rules, 2016), and top teams are selected for the final round of design.

In the final stage, top teams answer more in-depth questions over three hours with the core judging team, including the chief design judge who makes the final public presentation of results. At this stage, a team’s mastery of core concepts is really put to the test, with judges asking in-depth questions on specific design challenges and decisions. Teams often arrive at both stages with well-designed poster boards, computer tablets, and binders of testing data ready to showcase relevant data if asked.

The challenge some teams may face is that there are not unambiguously right or wrong answers to consider, and as such judges may have their own preferences and perspectives that may influence their judgement. Respondent #16 noted that:
“I really, really hope we don’t have [judge X] this time. He was almost hostile to the lack of sophistication of our aero package – we laid out our best argument but you got an impression that we were wrong in his mind out of the gate. You don’t want to think that’s what kept you out of final design, but at the end of the day you’ll never know – and it doesn’t help when you spend most of the 30 minutes arguing about what’s pretty unresolved in the paddock area. Many teams do what we do – some do full package, some don’t run anything at all, and they all do pretty well anyway. X is just in the full aero camp or nothing, we’re in the middle on that, and if had another judge that wouldn’t be an issue. Just what it is.” [#16]

Random assignment of judges in preliminary design makes it impossible to shop arguments around to an accommodating audience. Teams may get stuck in the lineup of a judge who, by virtue of their history, expertise or personal bias, may not be predisposed to the car. Teams therefore have to learn to be flexible in their argumentation and learn how to parry challenges from judges that may not be inclined to support their choices. (As it turns out, #16 avoided X and still did not make final design, so their suspicion of bias may have been moot.)

As design judges often return for multiple years, some established teams noted that they tried to do their homework on past judges. #17 noted: “We had [judge Y] last year – he was tough but fair, but really ripped our system apart. We weren’t ready for that line of attack – now we are. Hope to see him again.” [#17]. Respondent #22 noted that she consulted with two generations of past design leaders for advice – including two phone calls after finding out the team made final design. “I wanted to make sure I wouldn’t set off any tripwires unnecessarily – judges are human, we all have our set opinions, and the more you can learn about their positions, the better.” [#22].

Scanning the public comments of design judges might also be helpful to prepare for design questioning. In one of the few recently active FSAE.com threads, regular design judge Claude Rouelle noted pointedly that “FSAE is Not a Kit Car Competition”, touching off an interesting dialogue among (mostly alumni) participants on the right balance between teams’ integrating off the shelf components vs. building parts themselves³. While questions raised in this thread are not easily resolved, a team that had read this thread before talking to Mr. Rouelle would be far better prepared to handle his questions on this and similar matters.

Respondent #28 offered another simple insight on potential perils in the team – judge relationship:

“Don’t piss off the design judge. We had a team leader who got in screaming match in preliminary design four years ago. We obviously didn’t do well – but he’s a regular and you have to figure he’ll remember us. And he does – made a snide comment to us about our team and the fight last year. Our chassis lead apologized and made his case and smoothed things over some – but he clearly remembered us, and not well.” [#28]

A design judge concurs and notes they do try to keep on the right side of objectivity.

“We’re actually eager to help and provide very detailed feedback. And we do listen to their presentations and try to understand their design from their fundamental principles – if it’s internally consistent and overall solid, great. Even if I might do something different, if you can explain why you did what you did, acknowledge there’s other options and can argue for your choice, super. If it’s contradictory, not supported by data, poorly presented or you really should’ve known better, we’ll let you know that too, but constructively I hope – I’m not trying to fight people here.” [#41]

Particularly in the rushed preliminary design phase, time for detailed engagement with design judges is limited. Given that context it is important for teams to constructively guide the process. The same design judge offered this advice:

“You have 30 minutes and a bunch of judges looking to ask their own questions. Don't just stand there waiting for questions, and don’t waste your time on a list of crap every car has and no one cares about. Show off the big efforts you did. Have the core people behind that system ready to launch minute one. Don't expect we’ll find your secretly brilliant work. We might not. Lead with the awesome and explain that cleanly and clearly, with data ready to go in a clear accessible format. We might have other questions beyond that, but the more you lead the conversation and keep it on the things you want to talk about, the more favorable an impression you’ll make, every time.” [#41]

The better judges take the time the next day to provide more insight and analysis – teams can request such time by appointment, and some judges are eager to follow up with those in their queue to extend the conversation. Respondent #30 noted:

“Last year we were a first year car – guess what our car weighed? 650 (N.B. the elite
And it showed. The design judges took it easy on us being noobs and all but let us know we’re going on a diet. And the next day one of the chassis judges pulled three of us aside to give us advice on what to do next time – a good hour of awesome help. This year we’re 540 – still too big, we still have work to do all over the place – but without his advice we’d be far behind where we are now.” [#30]

Given the complex nature of engineering design decisions and the inherent subjectivity of both team members and judges, pure objective evaluation is impossible. However, judges who operate in good faith will attempt to make judgments clear. It can be concluded from the above responses that both team members and competition judges try to keep the secondary CHAT contradiction between team objects and division of labor positive and constructive, but given the stakes at hand, it is not surprising to see some tension in that domain. Teams preparing to defend against multiple judges and judges endeavoring to be supportive and constructive in their role can help mitigate conflicts in this domain.

5.2.2 Creativity at the Edges: The Benefits and Drawbacks of Being “Sketchy”

In engineering design, there are plenty of opportunities for less than perfect solutions to emerge, designed out of necessity or selected due to lack of clear alternative options. While full adoption of a garbage can model of decision making (Cohen, March & Olsen, 1972) may not be advisable in every circumstance, circumstances may dictate that FSAE teams have to go forward with a partially formed, least-worst alternative, given more satisficing options may not be available.

Such solutions are often described in this culture as “sketchy”. Sketchiness is often seen as a point of concern in formal engineering design. Systems engineering tools and technologies are based on rational processes to identify and eliminate poorly designed parts and systems (INCOSE, 2017). Ideally, it would be best that trial and error experimentation and play concluded in a more rationally defined and defended part.
That noted, formal engineering processes disguise that many ideas are developed on the back of napkins, from idle chats at a party, or in a eureka moment in the shower. Sketches, quick jotted notes, and rudimentary prototypes are where design efforts begin (IDEO, 2015). It is where crazy ideas can be explored with little consequence and from where better ideas slowly emerge. You ideally do not conclude investigation with a sketchy solution, but it is likely where you start, and encouraging that kind of creativity, imagination and play is one of the reasons starting with a garbage can model of decision making (Cohen, March and Olsen, 1972) can be very effective in leading to innovative and novel solutions.

As noted in the earlier section, FSAE teams are staffed by students who are just learning their craft, and as a result may embark on long, frustrating, partial and incomplete paths of information discovery through the core activity. As a result, it can be argued that sketchiness may be more prevalent in FSAE teams. Student inexperience means they are more likely to start research in the early stages of Kuhlthau’s information search process model, where exploratory behavior, vaguely defined problems and an environment of uncertainty characterized by confusion, anxiety and doubt is the norm (Kuhlthau, 2004). Ideally working through this vague and frustrating problem space leads to more robust and effective solutions downstream.

Respondents were asked to identify their sketchy projects and what they might have learned from the design process that might inform further design. The results are shared below.

5.2.2.1 Semi-Functional Sketchiness

Sketchy solutions often emerge from necessity – a team is faced with a series of bad options, there is no obviously valid solution, requisite resources to do the job right are not available, time is running out, but something needs to be done all the same. In the FSAE context, this can be a rather common problem. Team members are not yet professional engineers, their labor is voluntary, core competition deadlines are set by rules and are inflexible, and organizational resources are limited. Given this, corners may be cut and satisficing decisions (Simon, 1997) may be made more out of necessity and less by choice. Despite potential
pressures to only represent the positive side of their design efforts, respondents did share examples of efforts that were less than ideal.

Respondent #1 noted that the body was one of their last minute projects that finalized at competition itself, delaying their ability to pass technical inspection early. Respondent #19 showed me their nose cone, which failed the rule concerning the radius of front protruding parts, and required the quick duct taping of a rubber insulation hose to pass technical inspection. Especially for teams running a steel space frame chassis, the body is a non-functional aesthetic shell. Both #1 and #19 claimed that their teams would learn from their lack of preparation in the future, but given the body is a low-priority part, it is easy to understand why allocation of limited human resources might flow to more essential components first.

The noise test can be a common cause of last minute problem solving. Competition rules require internal combustion cars to run under 100 decibels at idle and at under 110 decibels up to a defined engine piston speed (FSAE Rules, 2016). Teams who have not tested muffled sound output may find themselves creating new exhaust solutions on the fly at competition, because noise is a mandatory pass/fail test before any dynamic event can be entered. Six teams expressed frustration with passing the noise test. All but one managed to pass it eventually, but required last minute changes at competition to do so.

Respondent #22 suspected they might fail the noise test, and arrived with a plan B ready to mount, which they eventually had to use. If allowed, teams would prefer to run lighter exhaust systems with a lower center of gravity to maximize power output and optimize handling, even if this means testing the limits of the noise test. Larger mufflers like those #22 bolted on last minute come with overall weight gain and higher center of gravity, both negatively influencing performance. However, this is still preferable to disqualification.

Other sketchy solutions may be more problematic in overall systems design, raising possibilities of potential failure. For example, respondent #32’s car had an external oil reservoir mounted on the back of the car. I asked why they chose to mount this part there and their answer suggested it was a matter of fitting it somewhere at the last moment. After discussion, we
mutually agreed the location was not ideal – in the event of a rear-end collision, the oil reservoir would act as a crush zone, disabling the car, dumping oil on the track and thus jeopardizing the runs of following cars. Their solution was not illegal per se, but was by their own admission less than ideal and worthy of reconsideration. Given technical judges are allowed to be subjective on specific items, I suspect they looked the other way regarding this relatively new team’s work.

Even more established teams can make oversights in design that require last minute adjustment. Respondent #3, a perennially strong contender as verified through review of past results, noted that their fuel tank in the previous year did not fully fit into the roll cage. Left unaddressed, this would have created a secondary CHAT contradiction with competition rules and likely not passed technical inspection, because safety considerations involving flammables are treated seriously by technical judges, for the protection of all involved. Respondent #3’s solution was to cut off a protruding corner and reweld the tank. The new tank passed technical inspection, but it was an inelegant solution that judges noted as evidence of poor design choices. Designing for appropriate packaging of the tank was a team priority for the following year.

Some sketchy solutions do become reason for disqualification. Respondent #5 shared this sketchy solution resulting from a late minute engine swap.

A makeshift “diaper” was made to catch leaking oil from our engine. We threw a rod about 2 weeks before FSAEM and had to put in the dyno engine that did not have the same customizations that the main engine did so it leaked. They did not work and we got DQed from endurance because we leaked oil. This year we will have an oil pan. [#5]

In this case, there was not enough time to customize and test the backup engine appropriately to standard. The endurance event is a significant challenge that usually tests the limits of a car’s design. The team hoped the diaper solution would act as a last-minute solution to their problem, but in stressful conditions it failed and disqualified what was historically a very competitive team out of contention.

Given such sketchy solutions noted above can disqualify a team from passing technical inspection or lead to its failure in dynamic events, last minute sketchy decisions ideally spur
organizational learning as teams look to learn from mistakes, poor planning, or design oversights. Consider the generalized tertiary CHAT contradiction in Figure 9 below.

![Figure 9: Generalized Model of a Tertiary Contradiction, Moving from “Sketchy” to Rational Decision Making Over Design Cycles](image)

In any given year, a team might find itself struggling to finalize a given part. As noted above, this can be due to a range of factors, be it lack of knowledge, poor time management, insufficient resources, lack of community support, simple oversight, bad luck, or other unforeseen or unplanned circumstances. However, given competition deadlines, they may be forced to compete with their best available solution, leading to a sketchy object and imperfect outcome, as shown in the left diagram. As the team closes down that year’s work, they may choose to reconstitute the design team, learn from past mistakes, secure additional resources, and otherwise address the challenges the earlier design team faced. Leveraging lessons learned from that past experience, future teams may be able to bring the design challenge into a more bounded rationality state and create a preferable outcome – although this new design team will still have the constraints of competition rules and time pressures to contend with.

Ideally, teams such as #5 above see this as a learning opportunity, identify the root of their particular problem, and develop solutions to resolve that problem. In the above model, this
may involve changing design team members, acquiring necessary technological and financial resources, lining up assistance from the community – whatever the cause of the earlier problem, the team looks for alternative solutions that better contribute to the overall outcome. Done appropriately, this moves what was previously a problematic and sketchy design process towards a more boundedly rational and defensible decision-making process.

Continued enactment of sketchy solutions may also lead to changes in rules over time, especially if safety concerns are identified. In reviewing current rules before attending Michigan in 2014, one noted addition was formal design specifications and testing procedures for a front impact attenuator. In these vehicles, the driver’s feet rest inches away from the front edge of the vehicle. In the event of a front-end collision, serious driver injury would be likely if loads were not absorbed by a functional front-facing crushable zone first.

Design judge #41, who is also a long-standing member of the rules committee, noted that these requirements were added to the rules due to concern that teams were not taking this safety threat seriously and consistently arrived with poor designs, poorly tested. As noted in the “kit car” FSAE.com discussion thread noted earlier, one team outlined how they tested their impact attenuators by dropping 200kg of weight from a considerable height using a homemade testing apparatus. While creative, this is not a robust testing regimen or particularly safe practice. According to #41, design decisions such as this convinced the rules committee to define requirements more precisely and mandate use of professionally acceptable testing regimens.

Such rule changes may put a strain on the resources of a given team, however. Respondent #25 noted in discussion that they had to outsource their testing as their school did not have the appropriate testing facilities. This cost the team time, money and frustration. Given that frustration, it is understandable why some teams may feel inclined to buy a unit that meets specifications, as these products are now common in the market as noted in the thread above. However, that does make this safety system a “kit car” piece that students poorly understand, as design judge Rouelle notes in the above thread (2016).

The lived effect of this new rule requiring the formal testing of a front impact attenuator (FIA) creates a series of potential contradictions, summarized below in Figure 10.

![Figure 10: Potential contradictions in choosing to purchase a front impact attenuator](image)

As noted above, there are good reasons why a team might choose to purchase an FIA versus design and test one themselves. As noted above in Figure 10, formal design and testing requirements now outlined in the rules require student teams to have access to industry standard testing apparatus that some teams may not have access to. This new rule may spawn a commercial market for off-the-shelf options that arrive with required testing data and are rules-compliant out of the box. This is not without precedent - other safety equipment such as seatbelts, helmets and racing suits are habitually purchased by teams, as all must have specific industry certifications that are beyond the resource capabilities of most FSAE teams to meet in-house. However, the effect of such rules changes move the FIA from the domain of engineering
design and development to “kit car” parts that are simply purchased and bolted on. While necessary to conform to safety rules, such parts do not develop engineering design or manufacturing skills, which is privileged in the design event at competition. If further refinements to competition rules sway the most optimal solution away from engineering design and development, FSAE risks losing the spirit of one of the core learning outcomes of the competition.

While meeting the letter of the new regulations, purchasing pre-made parts may alienate some design judges who prefer a good-faith effort to do in-house design. However, teams facing contradictions between their activity, competition rules and technical resources provided by their school might see no alternative but to go with a purchased product. This may especially be the case give the alternative is to spend significant time and money to meet this regulation’s standards, as respondent #25 noted. As teams do not have an unlimited supply of either time or money, in-house design and testing may divert key human, financial and time resources away from more pressing concerns, potentially jeopardizing other more essential components in the process. By setting very high testing standards in the rules, the rules committee reduces the scope of experimentation in the design phase and may thus steer teams towards purchased units that easily meet core standards, as is already done with other safety equipment such as helmets or seat harnesses which, given mandated safety standards checks, are not designed in-house.

5.2.2.2 Sketchiness and Spontaneous Creativity

While the above are sketchy solutions that potentially negatively impact performance, I also found examples of sketchy efforts that emerge out of tinkering, experimentation and trial and error work. Respondent #3 shares this story:

"We’d been working on composites in our back room and caught glimpse of a stereo there we’d never noticed before. Being both naturally curious people, we looked right at each other and agreed we had to see if the stereo would work. [X] logged into his Spotify account as I wired the stereo, and we started blasting music and dancing ridiculously, and embarrassingly getting walked in on by another team mate. We have yet to live down this night." [#3]
Access to tools and materials might also lead to side projects for personal interest, as shown here by respondent #6 and #21.

“We had some left over carbon fiber so we decided that it was necessary to make some flat plates so we could cut out some bottle openers. Our university just purchased a 5 axis CNC waterjet so we experimented with having our school mascot cut out on our sprockets.” [#6].

“My first welding projects were actually small sculptures – when I had some down time I just went in to see what I could make with the scraps around the lab. Some of it turned out pretty OK actually – I make a couple of things for birthday and Christmas gifts now and people really like it, just a personal touch I guess. But in doing that I was able to learn how to do smaller and more complex welds between different thicknesses of material, which comes in handy.” [#21]

While these side projects are tangential to the core activity, they show a curiosity about instruments and tools in the general environment, and how through experimentation and play with these tools can be used to create new objects. Particularly with the waterjet and the welding projects of #6 and #21, such tangential work can be an opportunity to explore an unfamiliar tool without the immediate pressure of having to develop something functional. These examples are framed by Choo’s (2006) information search behavior model below.
Figure 11: Spontaneous Creativity as Framed By Choo’s (2006) Information Seeking Behaviour Model

Spontaneous creativity can be an effective way for student team members to develop and refine their knowledge through play, trial and error, and creative engagement with the tools and materials that surround them. The above are examples of divergent thinking and tinkering (Dym et al., 1995; Fasko, 2001) in PBL* that helps build and refine a foundation of tacit knowledge. In doing so, these respondents develop skills that may eventually be of use to the team – indeed, #21 was one of the lead welders on their car, suggesting refinement of skills through building small sculptures can lead to skills directly relevant to later work more central to the team’s core activity. Such learning however may be complicated if students have too profound a cognitive gap to overcome, if there is little quality information available to bridge that gap, or if rules and norms of the environment frown on such creative engagement.
This noted, it is arguable some spontaneously creative projects are a bit less productive. Respondent #23 notes:

“We were bored one Friday night and decided to build a compressed air potato gun from some stuff around the lab – we launched a few potatoes at the wall of the lab, splat splat splat. Then launched a few at the football field trying to clear the bleachers. Was fun until the campus police dropped by on reports of explosions. They don’t like us much.” [#23]

Another told a story of a prank on a colleague that also ended with a police interaction.

“One kid on the team has this beat up car – among other things the panels hiding the wires up to the steering column and dashboard fell off so it’s all pretty exposed. We borrowed his car to make a run for some lab supplies and my friend Googled the specs for the wiring. We fixed it so the left turn signal would blink right and right, left, but the dashboard would still look the same. He drove around three days blinking wrong until the cops pulled him over for a look. Came into the lab wondering how the hell his car could be screwing up that badly and I couldn’t stop laughing. We fixed it that night. We’re banned from using his car now.” [#31]

Both these examples show that creative energy and experimentation can have a messier and more problematic side. Such side projects may lead to a secondary CHAT contradiction between the tangential activity and rules and norms of the school and its larger community. When police become involved, this may also trigger contradictions in division of labor and could lead to serious consequences for individual team members and the team as a whole. As will be later discussed in RQ3, it may be tempting for some community members to exert control and rein in such tangential and problematic behavior.

These concerns noted, excessive constraints on tinkering, experimentation and play may frustrate and slow down the informal tacit learning of team members described in Figure 13 above. When asked about what sketchy projects their team may have done at 3am, respondent #7 simply noted there were none – team members did not have access to campus facilities after 9pm, as their administration refused access to even basic laboratory facilities without trained supervision.
While such regulation likely reduces the school’s liability and mitigates the number and severity of pranks such as those done by #23 and #31 above, such regulations also means less access to core facilities than other less stringently supervised teams. No other interviewed/questioned suggested any ban on 3am activity, sketchy or otherwise – given this, #7 is operating at a significant disadvantage, forced to do a similar workload within a restricted range of hours. Given this, #7 also may have less opportunity to engage in more tangential, playful, spontaneous and fun projects, which while arguably creating a safer environment could frustrate individual and organizational learning that comes from spontaneous sketchy activity.

5.2.3 Leveraging Expertise: The Role of Faculty Advisors and Technical Staff

A potentially valuable stakeholder in helping teams arrive at rational engineering decisions is the team faculty advisor. He or she can play a strong mentorship role, help guide exploration in a complex problem space, and help avoid developing bad habits through backward learning (Mandin et al, 1997). Whether all this happens depends on the effort the advisor, which can be highly variable in practice as will be discussed below.

As per competition rules, every team must have an advisor, and that advisor is the point person for any official communication regarding rule interpretations or results (FSAE Rules, 2016). However, it is clear from on-site observation and discussion that some teams do not have any active faculty support at competition. Respondent #28 could not even name their advisor, but did not seem too concerned: “It’s more a club at our school, so we do our thing. The machining guys at the lab are more helpful – I believe there’s a professor who handles some admin things, but haven’t seen him around at all.” [#28].

While I suspect the team has fun “doing its thing”, an amateur approach to an increasingly competitive event is not likely to yield extraordinary results – in #28’s case, their competition scores over the years have been mediocre at best. Without expert input to help students negotiate tough problems, it becomes that much more challenging to develop a professionally valid design.
Team members with less engaged faculty advisement usually expressed some concern over their situation as a result. Respondent #1 noted they see their advisor “a couple of times a semester” and that they were generally fine with that contact but “more time would be helpful.” Respondent #27 noted they were considering getting a new advisor, as their current one was often too busy with his research to really get involved. #21 noted that their main advisor was often too busy to really pay attention but “other faculty have helped out time to time with specific questions, and the tech staff are really helpful, including serving as our team representative here.” [#21]

A potential substitute for the role of advisor is technical staff, noted by eight teams as a valuable resource. Technical staff are often on hand to ensure safe operation of manufacturing facilities, and are usually eager to share their specialized knowledge with students eager to learn. #34 was particularly enthused about their school’s lab manager:

“[X] at our machine shop is a god. I’ve learned so much about machining and how to design for manufacturability from him – stuff I wouldn’t get out of regular courses. Spending weekends and early mornings in the lab with him you pick up so many things, and he really cares about people – he kept the lab open extra hours in our manufacturing push totally volunteering his time and we really wouldn’t have the car we have without that. He’s also funny as hell – I sometimes just drop by to hang out, and I’ve gone to grab a beer with him after shift a couple of times. He even came to competition last year with his family. Just an awesome supporter of us. We’d be pretty screwed if he left.” [#34]

Not all schools have that kind of hands-on support though – #30 noted that their expert machinists were recently laid off and the student lab now has more of a safety monitor than an expert in the room.

“It makes a huge difference both in expertise and attitude – the safety monitor isn’t much older than us, and it really just nitpicking on safety issues vs. being of any real help. The guys who ran the expert shop were crusty old farts, but they knew their stuff – they were helpful if you got on their good side. That’s gone now – two of them retired and the other two were let go. Kinda sucks.” [#30]

On further discussion, #30 assigned blame for this particular case to changes in manufacturing technology. The machinists’ primary responsibility was to support faculty
research, but computer-aided manufacturing now makes it simple to outsource such projects to remote CNC machine or 3D printing facilities.

While some teams lamented their lack of faculty advisement, a few teams noted excessive participation, from their own advisor or others. Some advisors allegedly overplay their role. One team leader noted:

“Our advisor is a great guy, but can really be a pain in the ass at competition – tends to micromanage things, inserts himself in tuning and car preparation… he means well of course, but we have to tell him to back off sometimes. He takes it well, but he does get close to making it look like he calls all the shots, which is dangerous.” [#16]

In this case, this is perhaps just competition jitters - there is a lot of pressure to ensure last-minute decisions are done right. But another alleged a school in their area has an advisor who did even more:

“It’s kind of an open secret that [X] does a lot of the core design work at [team A]. Students do a lot of the grunt work, but most of the main design parameters are set in advance at the top. I’d hate to work in that environment – and some of their team members off the record do, at least that’s what they tell us when he’s not around. I almost went to [school] too – glad I didn’t, I know from meeting X a couple of times we wouldn’t get along.” [#22]

As per competition rules, faculty advisors can only act in an advisory capacity, but are not allowed to design or manufacture particular parts or make non-critical design decisions (FSAE Rules, 2016). Apart from being a violation of the rules, the case noted by #22 is a problematic learning experience, if complex decisions are indeed made without much student involvement.

Referring back to Golding’s continuum of constructivist learning (1999), an excessively teacher-directed activity robs students of the agency to make their own decisions. Such an approach would not be particularly effective in this competition – in design judging, only students are allowed to speak, and faculty interference would be obvious, unwelcome and potentially penalized. Students have to learn how to defend their designs, which is hard to do without the deep tacit knowledge that comes from designing and realizing a system yourself.
The team questioned by #22 usually presents a solid car, but design scores have recently reflected a poor defense of the work, validating #22’s concerns.

As noted earlier by Golding, neither extreme indifference nor extreme over-engagement are ideal states for constructivist learning, suggesting a more proper middle ground is more beneficial. This was noted by both students and faculty advisors alike in their responses.

Respondent #2 noted that their advisor was “a huge help” on logistics and a keen sounding board early in the design process. “He attends all the design reviews and asks many of the questions we expect the competition judges to fire at us – not only does that clean up many potential design flaws, we can go to competition pretty prepared to answer some tough questions.” [#2]. Respondent #3 had a similar experience, noting their advisor acted as a resource vs. “the one in charge”, and “aims to guide us to the right answer and lets us explore your own ideas instead of simply stating ‘this is how you do it, end of story.’” [#3]

Through engaging as a sympathetic source of critique and advice, these faculty advisors improved the quality of design and helped these respondents develop the skills required to rationalize and defend those choices in front of judges, making them well-prepared for the design event at competition.

Faculty advisor respondents concurred with this approach, although it should be noted that advisors who responded were more likely active in their role. As respondent #38 noted, “I would only intervene if safety or budget were at risk. They are empowered to fail.”

Another expanded on their role on how he would handle a flawed design idea:

“I strictly follow the rule that advisors can have no design input; but I interpret that to permit me to ask good questions. In a situation such as this I would require the team leader to walk through the design process that led to the proposal; this rarely fails to either prove that the proposal was flawed… or they were on to something new which would be of value to pursue.” [#37]
By playing a consultative role, both these advisors empower their students to make their own decisions, within reasonable boundaries of safety and budget. In acknowledging that students are primarily charged with leading the design process and making key decisions, these advisors put themselves squarely in an advisory capacity, withdrawing from any undue interference in non-critical decisions. By setting high standards and helping students rise to meet them, students generally make the effort – and if they do not, students are empowered to fail, leaving responsibility for that failure in the students’ hands.

Faculty advisors can also help mediate relations in a team where student team leaders are learning the finer details of personnel management. One faculty advisor noted that he occasionally had to intervene to tone down the enthusiasm of a former team leader:

“He was very intense and driven, and that can rub people the wrong way, especially if expressed in anger. I was able to give him some advice on how you get more flies with honey than vinegar and to give him some personal stories of how being a hothead got me in trouble at that age…he and I are pretty similar people but some lessons you only learn with time and experience. He’s always going to be edgy but he slowly learned to tone it down some and listen a bit more.” [#35]

It is easy to see how a student-run project might grind to a halt on personality or leadership conflicts, especially as some student team leaders are often managing a team of considerable size and complexity for the first time. An active faculty advisor can be a source of wisdom on how to handle challenges, both technical and social, before they get out of control.

From the above, we can envision a picture of a more effective faculty advisor, described in Figure 12 below.
In the above figure, a strong supportive role between engaged faculty advisors and student engineers (represented by the dashed line) can change the dynamics of the activity considerably. An experienced advisor can play a valuable role in mediating the core activity by highlighting more efficient information discovery routes and serving as a source of friendly critique regarding design options. They may also help identify supporting community members and help mitigate any contradictions regarding institutional rules and professional norms, as will be discussed further in the following research question.

What was interesting to note is that for three teams, their faculty advisor had their own experiences of being a team member. Given the FSAE series has been around over 35 years now, it was not surprising to learn that that some alumni made the jump to academe, where they may

Figure 12: CHAT roles when subjects have an engaged faculty advisor
be tempted to take on an advisory role. Respondent #3 credits how their new faculty advisor has adapted to the role - he was a former team member and was inspired by the style of their recently retired faculty advisor. “It helps to have someone who knows the workload and design cycle first hand – he knows what we’re capable of having done it himself 10-15 years ago.” [#3]

The faculty advisor is also often the team’s voice on issues related to the school’s administration, which is a focus of RQ3.

5.2.4 Summary for RQ2

**RQ2:** How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction in a productive direction?

As suggested by CHAT, there were multiple potential paths through the core activity model, represented in CHAT as connections between subject -> instruments/tools -> object. Table 6 notes just some information channels that were consulted by respondents in the course of research and testing of specific parts. The challenge of any team is to leverage the most valuable sources of information available to arrive at a satisficing decision (March & Simon, 1993) given time and resource constraints.

Published works remains a key authoritative source, but requires significant effort in combination with other tools to negotiate into a functional satisficing solution. Internal data such as team reports, photo/video libraries and design preparation documents help validate knowledge and provides data in a form most acceptable to design judges. And there is a significant history of informal testing and experimentation, with team members reverse engineering their own vehicles, considering what is valuable and what is not from online DIY tutorials, and testing various components in an informal trial and error manner.

The competition judge acts as the ultimate arbiter of a team’s design and development work. Established teams try to operate in a strategic manner to cater to their requirements early
in the design process. Judges generally respond in kind by offering individual feedback beyond the design judging process and attempting to make what could be a more adversarial process more transparent, educational and cooperative. While there is still opportunity for disagreement in the heat of competition, teams value the expertise and judgment of the majority of design judges.

The backstory of designs may be hidden from a judge’s view as there may be pressure to represent the final product as emerging from a more scientific process. On investigation, however, there is a significant amount of “sketchiness” and informal experimentation in the background. Experimentation through play and discovery on tangential projects can be a valuable route in building a foundation of tacit knowledge. It is also the case that some teams are forced to settle with less than ideal outcomes given lack of time, materials or human resources. Teams might not be proud of last-minute solutions at competition. However, these semi-functional sketchy solutions can become launching points for more in-depth research and more sophisticated designs.

Expert opinion and advice may help teams reduce the complexity of design choices and provide a sounding board for critical formative assessment of work. Faculty advisors and technical staff can play a valuable role in shaping a team’s direction through technical consultation and asking tough questions early in the design process. However, some faculty advisors do not put in significant time or effort, and while not allowed, in a small number of cases some faculty advisors overstep boundaries set by the competition to prevent over-engagement. As Golding (1999) noted, there are a range of roles in problem-based learning for faculty in PBL, from detailed faculty structuring of the problem and available solutions to largely abandoning students to their own devices. FSAE advisors and their teams seem to be trying to find the optimal balance for their given team in any given year. Both advisors and teams seem to agree that a measured advisory role is the ideal, allowing students to take responsibility for their successes and failures in the competition setting.
5.3 Research Question 3: Negotiating the Concerns of the Larger Community

RQ3: How do PBL* teams negotiate contradictions between team activity and intended outcomes and school administration and established norms of practice?

The core activity represented by the subject->tools->object relationship does not occur in a vacuum. Leont’ev’s main contribution to CHAT was grounding activity into social and cultural context through introducing the nodes of community, rules and and norms, and division of labor (Engestrom, 1999).

For FSAE teams, the larger context most immediate to their activity is their academic institution, which has its own rules, norms and intended collective outcomes. When team and administration objectives match, there is ample opportunity for a symbiotic and fruitful relationship. When team activities contravene school rules or cause tension with the larger community, student teams might discover that larger institutional powers have the upper hand in this contradiction. While school administrations can be important sources of financial, administrative, technical and space resources for FSAE teams, teams that operate at odds with their administration can find all these resources in jeopardy. As such, the potential contradiction between the team’s activity and priorities and requirements of the school is an important question to attend to, as are other relations such as that between a team and the larger community, such as industrial sponsors.

5.3.1 Benefits of Team-Administration Cooperation

There are good reasons for FSAE teams to want to have a mutually supportive relationship with their administration. One is simply existential - FSAE is an educational event, and independent non-collegiate teams are prohibited by rules (FSAE Rules, 2016). Beyond simply acknowledging the team’s existence, however, the academic community can provide other benefits to team members as they engage their core activity.
A major operational concern for FSAE teams is financial resources. While some teams are not keen on publishing budget information, others did share precise contribution levels. For example, respondent #9 noted a very strong annual contribution of $60,000 from their school, while #17 and #25 both shared a $20,000 figure from the administration. Respondent #32 was lobbying the student association to install a student activity fee to raise approximately $15,000 a year for team activities, to complement similar monies from the school. Faculty advisor #37 said the student association already provided $25,000 in funding, with additional resources available from the department as needed, while advisor #39 noted an annual school contribution of $10,000. At the other end of the spectrum, student #43 suggested they were struggling with trying to leverage an initial $5000 grant into a larger operation. As will be discussed later, many teams supplement financial contributions from the school with external fundraising from friends, family, alumni, and industry partners. This increasingly includes online crowdfunding, as evident with respondent #29’s team posting a fundraising campaign to their Facebook feed.

More resources means more ability to experiment with different materials, better access to tools and testing technologies, the ability to maintain multiple engine packages, test on more tire combinations, and attend more events. For example, going abroad to competitions in Europe or Asia requires a significant cash outlay to ship the car and cover travel costs for team members, with respondent #22 estimating their European travel costs to be in the US$25,000 range for a bare-bones team. This may be more than than entire budget for lesser-funded teams. While funding is no guarantee of success, teams with considerable funding can engage in more varied, complex and expensive efforts that lesser funded might not be able to consider.

Where a school can really make a material difference to an FSAE team is providing space and administrative and technological support. This also varies widely by institution. Schools who are committed to PBL teams are starting to build dedicated facilities to support these teams. For example, McMaster University, with a strong history of PBL in medical education, is currently building a special purpose facility to house their engineering teams, centralizing technical and administrative support and facilities so teams can share these resources.5

5 Information on the new facility can be found at : http://www.eng.mcmaster.ca/hatchcentre/ (N.B. McMaster no longer has an internal combustion FSAE team, so is not included in this respondent pool.)
Faculty advisor #35 shared this description of facilities support:

“Our team occupies prime space in our [X] Facility. This arrangement has good synergy because most of the TA positions are staffed by SAE team members. The various departments at [school] provide about $50K per year with the remainder provided by industrial sponsors.” [#35]

Advisor #37 shared more details of their special purpose facility.

“For space, the team has space within what is called the [X], a 24,000 ft² space dedicated to the support of our student engineering competition teams. Each team within this space (there are currently 7 hosted) has office space, dedicated build and storage space, and access to the common machine tools. X is open 24/7. It has machine tooling available 24/7, up through 3-axis CNC mill. The school staffs a ½ time machinist/staff support person dedicated to the infrastructure support of the X and its teams.” [#37]

**Figure 13:** CHAT relationship where special purpose team facilities are built
Not surprisingly, both these teams are perennially strong contenders in the competition, having finished in the top ten multiple times. Schools that make such investments in facilities tend to also be very supportive of the teams themselves. As Figure 13 above illustrates, when a school invests in special purpose fabrication facilities, office space, financial assistance and technical staff to support FSAE team activity, they can provide a context in which many core challenges are supported, helping teams focus on their core activity without being diverted or distracted by external challenges. A strong basis of school support can also lead to synergistic goals and objectives between an FSAE team and their administration, encouraging students to participate in recruitment and promotion of the school’s programs while using that support to leverage buy-in to administrative concerns such as health, safety and professional responsibility issues. While such investments in FSAE team activities do not necessarily buy success, teams with this level of support have far fewer challenges to navigate.

All this noted, such a level of support is not always as robust. Most teams surveyed or interviewed did not note having full buildings dedicated to project team activity. #43 not only struggles with limited financial support, but a working space that doubles as a loading dock, requiring team members to move the car to their office space when team members are not present. More common would be the experience of respondent #27, who stated they have “about 800 sq. ft. of dedicated space, but down two alleys – it’s actually kind of scary to get there” [#27] as well as a shared machining lab and small team office. School teams do however have access to fabrication facilities tailored to their needs by virtue of regulatory necessity. This is not an activity you can support in a standard classroom – fabrication facilities have very specific electrical, venting, and health and safety concerns that must meet regional and national health and safety standards, and school administrators are understandably quite risk adverse on these matters. Two faculty advisors noted safety as one of the few instances in which they would interfere with team decisions.

Another way a school can support a team’s activity is through curriculum integration in the form of course credit for team design work. Some teams are “clubs” – an extracurricular activity supported by the school but not otherwise integrated into curriculum. While one might
think club teams are not likely to be successful, this is not necessarily the case – respondent #3 noted his team does not receive course credit, but is nevertheless one of the perennial contenders in Michigan (FSAE Results, 2016).

Some engineering schools have a capstone design project course in the final year of their academic program, and team design projects can usually qualify for inclusion. Three respondents (#16, 21, and 23) noted they were presently getting course credit through a capstone course. It can also be the basis of graduate research - #15 shared that she was doing her applied master’s project course through FSAE.

“Actually it’s been a great year – I did some design work with [school X] two years and now I’m here at [Y] helping out at a higher level. Easier the second time for sure – this whole event was pretty overwhelming the first time, now I know what to expect. And hey I get credit this time – the aero package is basically my M.Eng project.” [#15]

Outside of formal capstone courses, respondent #8 explained that “we do offer an engineering elective for FSAE participation provided certain prerequisites are met (you must have been on the team for at least a year and are currently holding a prominent design role).” [#8]

Even in cases where course credit is granted, team participation is largely extracurricular. With some team members noting full-time job level workloads, work done often greatly exceeds what is normally done for similar credit hours. However, schools that offer capstone design or elective credit are acknowledging that such project work has value and relevance to the curriculum. This can help defend the project within the context of the academic community, allowing faculty to see this as part of the educational experience versus a club distracting students from their day-to-day academic work. Offering course credit can thus help mitigate any contradictions between the core activity of the team and the larger academic community.

While FSAE teams do benefit from the support of their school, the relationship is often mutually beneficial. Schools often solicit the participation of their teams in recruiting. As noted earlier in RQ1, these teams can be a draw for students to consider attending the school or consider engineering as a major. Six teams explicitly noted they were happy to participate at
recruiting events. Respondent #2 considered it a way of keeping administrators onside, fair payback for the resources the school invested into to the team and a potential long term recruiting tool for the team. Respondent #23 remembered seeing the car in his visits to campuses:

“I saw the car when I visited senior year and talked to the guys at the tent for an hour. They really sold me on coming to [X] and when I showed up two years ago, they remembered talking to me and everything. It was nice to not be a total stranger in that first week and everyone was really helpful in getting through the first year, which can be kinda overwhelming for some kids.” [#23]

As noted in Section 5.1, project teams like FSAE can give students a place for social bonding and can help build a sense of community. Such a support network can also help younger team members cope with the stresses of a new environment and a challenging workload, which are common drivers of early attrition in STEM fields (Seymour & Hewitt, 1997).

The car can also be effective in reaching out to alumni for fundraising. Respondents often noted that the team would participate in alumni homecoming and special events, and that these relationships were often mutually beneficial. Respondent #11 was the point person for internal and external relations for their team, and noted that they spent a lot of time working with “the Foundation”, the unit which handles charitable donations and handles external relations and marketing. #20 is a non-engineering student in a business development role with the team and pointed out a few sponsor decals on the car:

“These two are previous team alumni who have been giving back for the last few years. This one I met at homecoming showing off the car to alumni – he wished there had been such a team when he was at [X] 25 years ago and was really keen to help out. He even drops by with his family time to time. Great guy. And this one saw the car at a university open house and volunteered some carbon fiber and use of their autoclave, which has been very handy. Any little bit helps, and we love all our sponsors.” [#20]

FSAE teams may also help a school with the accreditation process. As noted in Chapter 1, accrediting agencies like ABET are stressing that engineering education offer opportunities for applied learning of professional skills like effective communication, teamwork, and project management (ABET, 2011). Project teams are a convenient way to showcase curriculum
commitment to these goals. Respondent #30 talks about when his team was asked to help out on that directly:

“Our school went through its external review process last year, and the Dean was keen on us being involved to check off a lot of the ABET requirements. I had a couple of meetings with them and the next you know I’m writing up that section of the review document as an independent study course, and showing the external reviewers around the lab. The Dean’s office was pretty happy with what we did – ended up getting another 5K out of them this year and I know who to talk to now to get things through the red tape – and also learned a bit more how the system works. Win-win for all of us.” [30]

5.3.2 Noted Contradictions With School Administration

While it is better when the team’s intended collective objective matches that of the larger administration, this is not always the case. An FSAE team is squarely focused on the core activity of building a racecar. School administration may have different core activities, such as allocating budget and space, maintaining bureaucratic procedures, and protecting the health and safety of students, among others. When team and administration goals differ, there is opportunity for contradiction between the team’s core activity and both division of labor and rules, given the FSAE team is dependent on and thus largely beholden to the requirements of administration.

As noted earlier, financial resources can be a point of contention. While teams do raise funds and get in-kind donations from industry and their own alumni, stable annual funding proves a secure foundation from which to build. As noted earlier, while some teams have reasonable base funding, others like respondent #43 are struggling with less. The stability of that funding can be a question as well - #24 noted that while they get $15-20,000 a year from the school, they have to apply for that every year, and there is no guarantee that it will be approved or at what level. Respondent #1 noted the earlier years of their team had similarly tenuous funding but as the team grew, the administration become more amendable to supporting them, eventually agreeing on stable annual funding.
A common complaint emerged around budget and finance procedures, noted by nine respondents overall. School administrations have their own procedures to track spending and to ensure only authorized individuals can make large purchases. It is likely that students are not well versed in bureaucratic procedure, and may find these procedures to be barriers to their core activity of building the car. Respondent #9 shared this experience:

“Our biggest conflict with University regulations comes with purchasing. An easy example is when we needed to purchase a new engine: We wanted to buy a CBR500R engine and had $4,500 to do so. We were not allowed to buy an entire bike and pull it apart for the engine and relevant electronics (despite the fact that it fit within our budget) because the University was uncomfortable with our team owning a motorcycle. We ultimately paid $4,000 for the company to pull the engine and electronics for us, which means we over-paid. This year, when we wanted to buy a new engine, one of our team members purchased one out-of-pocket on Ebay and then went for reimbursement to avoid the hassle. The school didn't like it, but it's easier to beg forgiveness then ask permission in cases like this.

We're also not allowed to pay X State Tax, which is frustrating when we have to go into stores like Autozone or Home Depot. This means we eat 10% of our purchases, since we can't get reimbursed for it, and tax-free forms are a pain in the butt.” [9]

This example intersects a number of issues. In bureaucratic settings, larger purchases often have to go through a formal procurement process, involving purchase orders, invoices, and delays in payment and receiving the actual purchase. Student team members are not likely accustomed to such controls, and are forced to learn proper procedure all the while debating their utility to their core activity. Given the contradiction between the team’s urgency behind this purchase and a slow bureaucratic system, students might feel compelled to bend the rules in their favor as done above, which may create grievances down the road.

Risk and inventory management procedures are also not well suited for the intended purchase above. Large capital purchases are usually cataloged for asset protection purposes, and in the case of a vehicle would require information about approved drivers, insurance, and security and safety regulations regarding school fleet vehicles. A school would likely have liability concerns about a student group owning and operating a motorcycle. Of course this was not the team’s intent, but I suspect in this case the school had no procedure in place to buy and destroy a vehicle, as this is not normally why a school would acquire a motorcycle. Unable to
find a solution to this contradiction, the team ended up having to outsource a job they could have handled themselves, and abandoned procurement policies in later purchases, thus potentially escalating tension with administrators.

This frustration extends down to even minor purchases – for small purchases as noted above, it may be easier to just ignore the rules and pay a tax that will not be reimbursed. This comes at a direct cost to students and again could serve as a point of contention with administration if internal procedures are openly flaunted.

Accessing team money controlled by the university bureaucracy can also be hard, as #30 suggested.

“We used to have a university procurement card – that helped a lot on online purchases, store runs, anything under $500. We were always careful to track purchases and ensure we never overran our budget – but others weren’t as careful I guess since our faculty’s new financial officer comes in and suddenly half the cards are cancelled. Now only one the admin staff and our faculty advisor can buy things for us. All store runs we have to go through petty cash or wait weeks for a check, all online purchases we have to track down two people and interfere with their regular jobs. It blows.” [#30]

In this case, a new regime of centralizing purchasing control in fewer hands was implemented at the expense of local efficiencies in team purchasing, with much work transferred to someone who may not be as responsive as hoped. Respondent #9 shared a similar situation, noting that at key times of their work cycle, “purchasing becomes a full time job”.

As a result, some teams have opted out of their school’s finance system. #20 notes:

“We have our own bank account and Visa debit card now. Whenever possible we use it because going to [admin staff X] is never, ever fun. She doesn’t like us and any time we’re forced to deal with her is just a huge pain in the ass. I’m not going to see her over $20 of crap at Pep Boys, no way. Easier just to swallow the hit and move on with life. So, any alumni donations we try to get sent to us directly, and we collect our own team lab fee and put it in our account. We only deal with X for things we can’t directly afford or to access the money the school gives us.” [#20]
This solution does allow for petty cash and small purchases to be controlled by the team and provides a level of flexibility that centralized systems controlled by university bureaucrats might not allow. However, as noted by #20, this might also create opportunities for contradiction with administrative rules and procedures. They were appropriately concerned that the administrator in question would discover their deceit. However, given the flexibility such accounts afford teams not accustomed to bureaucratic procedure and given that two other respondents noted similar slush funds, it is reasonable to suggest that #20’s team is not unique in arriving at such a solution.

Some concern over allocation of university resources were also shared. As noted later in section 5.5, FSAE teams are not the only PBL* teams in any given school, which means there can be direct competition from other teams for limited resources. Competition can also happen between teams and other interests in the college whose position may give them preferred access to key spaces. According to #17:

“This year was kind of frustrating – our office space was taken over by graduate TAs over the summer, and there was an attempt to carve off a section of our manufacturing space to install testing equipment for a completely unrelated material science research project. We managed to negotiate keeping our manufacturing space, which is already small. But all our office stuff is in a room about 1/3 the size – we can have four people in there, maybe. This really hurt us as it was a cool place to just hang out, read up on books, whatever. Our advisor’s trying to line up more space for us, but it’s tight until the [X] building is finished.” [#17]

The above suggests that student teams can end up on the losing end of a quaternary contradiction between team needs and other competing activities and may find themselves forced to make do with what is allotted to them. As noted earlier, special-purpose buildings to support collaborative teams help mitigate such challenges by reducing competing concerns eligible like TA offices who might stake a claim. This is also a situation where having an active and engaged faculty advisor can make a different in defending space allocation, although in this case the advisor’s involvement seemed to have limited impact.

The benefits of specialized buildings also brings up questions of larger budget priorities of a school’s administration. On many campuses in the United States, there is substantial
investment in non-academic facilities such as athletic facilities to support what are *de facto* professional sporting teams. This is not lost on some FSAE teams, as respondent #4 suggests:

“It is in our opinion that the design teams are like the engineering varsity sports teams, though the actual varsity sports teams are catered to significantly more… I spoke with teams from Germany as an example, where they do not have a varsity football team, so they have everyone join and get excited about their team.” [#4]

The above case reflects an inequality of resources, especially in the United States. Varsity sporting teams on many American campuses have access to specialized training and development facilities, a number of paid staff supporting their activity, significant budgets for attending regional and national events, and in #4’s case are regularly featured on national broadcasts. FSAE teams play a similar role in recruiting new students, advancing the school’s brand, and attracting alumni support, but in many schools are not supported nearly to the same extent. In places like Germany where school is more focused on academic achievement versus being a *de facto* minor league for professional sports, perhaps this dynamic is more balanced.

Given its role in governing the school community, another point of contradiction with school administration can materialize on legal concerns. For example, university facilities are governed by national occupational health and safety laws. Failure to provide training or to keep facilities in safe condition can lead to significant fines and closure of facilities. The university is also accountable to the larger community for maintaining order on campus. For example, universities often ban the consumption of intoxicating substances on campus – and that danger becomes more severe in environments where power tools are involved. Complicating matters is that racing is an inherently dangerous activity. As per competition rules, team members and spectators sign a lengthy waiver at competition reminding everyone of the dangers at hand and absolving SAE from any liability (FSAE Rules, 2016). Add to this that students given their age may have a poor sense of their own mortality, and you have a potentially dangerous confluence of factors at hand.

This understandably leads to restrictions on what a car team can legally do. Some schools set very strict rules on access to machine shops, opening facilities and labs only when
technical staff are there to support them. On asking about sketchy late night projects, respondent #7 replied, “Our university restricts access to the machine shops (and our work area) after 9PM, so we haven’t had the opportunity to play around at 3AM.” [#7]. While this helps ensure a safer work environment, such a restriction puts this team’s work flow in a significant bind.

Technical staff and faculty make spot inspections to ensure compliance – for example, faculty advisor #40 notes: “I catch people working by themselves or without eye protection etc. Usually, I just make them comply and they do. When I get pushback, I remove their shop privileges for 1-2 weeks.” [#40]. Given there are serious legal and health implications at play, lack of compliance is usually treated seriously, and sometimes the only solution is exercising the full legal force of the regulations. Respondent #18 noted that the team had been suspended from their lab after repeated requests to keep it clean and follow government-mandated checks had been put off:

“One day no one’s access cards worked. We had to agree to do a full cleanup under supervision and only got our cards reactivated when the school’s safety inspector checked our work and did a review of protocol at a mandatory team meeting. We’re a bit more careful now – we try to clean up after ourselves and check the major things that the inspector mentioned, many of which made some sense when you think of it. Really no fault but our own there, so we try to be more aware of the rules now.” [#18]

He continued to note that the inspector did a good job tying regulations to things that could actually harm them in the space they were working, acting out some of the consequences to humorous effect.

Violations of laws and internal regulations can be treated harshly. Respondent #29 noted that a semi-official frosh party which team members actively participated in was shut down after concerns about underage drinking and hazing accelerated into two allegations of sexual assault. While he lamented the loss of the party, he agreed that it had gone too far and saw the wisdom of the administration’s decision in suspending this tradition.

Given the potential seriousness of contradictions between division of labor and the team’s core activity, teams are often in no position to bargain on such matters, and generally attempt to
live within the rules as prescribed. A team’s core activity does depend on institutional approval, and if that is withdrawn, their activity would cease. While often administrative rules have merit, one should take care not to overregulate such contexts. As noted earlier in Section 5.2, creativity is often messy and may grow from tangential projects and spontaneous creativity. Life and death rules are important – and codes of social conduct are no less important, because for those unfairly subjected to abuse or discrimination, it can be a life or death matter.

However, messages of health, safety, legal and ethical requirements are probably better received if team buy-in is secured. This might best be done by taking care to align administrative rules and regulations with the core activity of the team by engaging in constructive dialogue on why specific activities are not acceptable. The more a team’s core activity aligns with the priorities of administration, the more likely it is that the team will self-regulate on key matters of common concern. By virtue of division of labour, a school’s administration has the power to mandate adherence to rules and regulations and sanction those who transgress, and in serious cases exercising this power is right and necessary. The more a team sees the administration’s intended outcomes as compatible with their own, however, the fewer opportunities there will be for hard contradictions between competing worldviews.

5.3.3 External and Public Relations

While a FSAE team’s immediate community in the CHAT model would be its hosting school, the team also has reason to interact with non-school community partners. This can at times involve public relations and community service work. For example, respondent #11 mentioned participating in a STEM outreach program at a local grade school, and respondent #28 noted that the team occasionally participates in a local parade. Local racing events are also a means of community outreach - #22 said that the car usually runs in local Sports Car Club of America autocross races, which are designed for street cars but are ideal courses for the FSAE vehicle.

Given the financial requirements of FSAE teams, a major focus of public relations work is to attract and retain sponsors who can provide financial, material and in-kind support.
Industry sponsors can be an invaluable source of resources and knowledge, and keeping them engaged and happy helps sustain the team as a knowing organization over the long-term.

Most FSAE cars will acknowledge their sponsors through decals on the car, the size and position of which are often tied to donation levels. This is very much in keeping with racing culture at amateur and professional levels – corporate sponsorship is a tolerated part of the culture, with corporate logos of sponsors liberally covering cars and drivers. Sponsors are also acknowledged on team websites, social media, team newsletters and other public events.

The work to maintain such relationships is work that can be a means for non-engineering students interested in participation with the team to contribute. Respondent #19 (previously noted as having joined the team out of romantic interest in one of the engineers) gravitated to the business development role, becoming the custodian of a very well developed online presence.

“I had to learn a lot of marketing and web development stuff – I’d dabbled a bit but having a real goal helps. And it’s amazing how many of the guys have no idea what they’re doing on the Internet. You’d think a guy who can program the ECU would be able to do some basic HTML. He can, he just really, really sucks at it. We have some very smart guys who are completely clueless on what I do, but they at least appreciate someone’s doing it.” [#19]

This suggests that being good at one technology does not necessarily extend naturally to others. Some people may arrive to the team context with a passion for and interest in design, writing and content strategy. Having taught digital marketing for over a decade, my experience with #19’s team website and email newsletters suggests she has strong skills in all the above domains. In a complex team environment, there are many possible ways to make a contribution, and assigning external relations and marketing tasks to those more inclined to build and develop external relationships just makes sense.

Indeed, not having an online presence can be a competitive disadvantage. As noted in the methodology chapter, nearly half of 137 identified teams were difficult to find online, having old, limited or no web presences. This can be a serious oversight with respect to sponsor outreach. A clear, contemporary web presence can be invaluable in providing a passive marketing channel
that allows sponsors to come to you on their own time. As noted earlier in the methodology chapter, nearly 50 teams seemed to be unreachable through their public online presence, either returning bounced emails or not showing any indication of a live person on the other end attending to the message. These teams would very likely benefit from someone like #19 who can curate an effective online presence and engage public relations work. If instead of being a researcher I was looking to provide money or goods in kind, I would likely have moved on after not receiving any response to my query.

Individuals charged with representing the team in public may also have to work with school administration on formal public relations and sponsor relations work. As #11 shared:

“The Foundation requires that we get all external communication approved by them before sending out. This includes newsletters, sponsorship packets, and thank yous. They also require that we report all charitable donations that our organization receives, both monetary and gift in kind donations. It’s been a little difficult to get all team members to get on board with this and get the required forms turned in in a timely manner, however, we are slowly making progress.” [#11]

Acknowledging the contributions of sponsors is important, but in school contexts such as the above this might require additional collaboration with school bureaucracy, adding a layer of complexity. As with maintaining an online presence, this is an important piece of contemporary marketing and public relations and requires specialized attention to manage and fulfill well. Sponsors enjoy knowing they are making a difference and often enjoy receiving updates on team progress, but such updates take time and energy to manage.

Beyond formal thank you notes and newsletters, some teams opt for a more personal approach. Respondent #24 notes their team does sponsor tours, visiting the offices and factories of industrial sponsors with the car.

“Sponsor days can be a lot of fun – we bring the car out to them, guys on the floor take a break to come see it, sit in there, take pictures….we often get a tour of their facilities, which gives us some ideas on what other things may be possible with the right resources and tools. Usually that’s why I go with the business team on these – they know their stuff at a general level but there are some questions they probably couldn’t handle, and
some things I see that wouldn’t register with them. Plus it’s a day out of the lab, off
campus and sometimes out of the city – we’ll do anything within a couple of hours drive.
It can be a nice break.” [#24]

The above statement shows how the personal touch can not only help build sponsor
loyalty, but also act as a learning experience. Seeing professional grade manufacturing facilities
first hand can inspire engineers with possibilities on future design and manufacturing, and some
of these possibilities may not be immediately evident or obvious to a non-technical team member.

#26 takes a different take on sponsor outreach – inviting sponsors to the competition in
Michigan. This is doable in this case as the school and its sponsors are in the general
eastern/central Michigan area. However, this has its own organizational challenges given the
dynamics of the competition area:

“We invite many of our local sponsors to show up actually – the best way to show off the
car is in motion. We particularly invite them to show up to endurance, get a BBQ going
for some food in the parking lot, and an opportunity to see the car in action. We email
them the night before to let them know what run we’re in and do the BBQ around the
break time. Unless the car’s needing last minute work most of the leaders are available to
talk, and we can take kids over to sit in the car and all that.” [#26]

Whether through thankful messages or hamburgers, retaining sponsors is a smart move
for any team, as it sustains technical and financial support, helps build a long-term relationship,
and reduces the need for business development team members to solicit new sponsors.

5.3.4 Summary of RQ3

RQ3: How do PBL* teams negotiate contradictions between team activity and
intended outcomes and school administration and established norms of practice?

The core activity of building and testing a competition ready racecar does not happen in
a vacuum. Every team must have backing from an academic institution, which means fruitful
and productive relations with school administration becomes a priority concern. While faculty
advisors can play a valuable liaison role in this regard, in schools with weaker advisement team
leadership is often charged with building and sustaining a positive relationship with school administration, which has its own core activities to address.

Financial and administrative support was a common concern for respondents, with significant variety in school support. Schools that value the PBL* experience are increasingly dedicating resources to FSAE and similar engineering project teams, providing special-purpose facilities, capital for startup teams, annual sponsorship from department and student union funds, access to tools and technologies, and hiring dedicated technical and administrative staff. Teams are usually happy to repay this generosity by being ambassadors at recruiting, homecoming and other special events. While such a broad level of support is not necessary for success, it removes many barriers faced by teams whose schools are not as supportive.

Not all teams have such strong bonds with their administration however. Some teams do have complaints of lack of financial support, limited space, access restrictions to key technologies, and navigating what can be a confusing set of bureaucratic rules and regulations. Given school administrators and legal authorities have more formal power underlying their roles, such contradictions can jeopardize the viability of the team. While there are notable concerns, most teams seem to have struck a reasonable balance with school administrators, couching the nature of their activity within the rules and priorities of their supporting institution. However, there remains some envy of other groups – especially varsity sporting teams in some schools – who receive more support for what is arguably a truly more extracurricular activity.

Beyond relations with their school administration, teams may also engage in outreach with the larger community. This can happen in public events as well as more direct and private relationships such as with industry sponsors. Teams engage in a variety of outreach efforts to keep sponsors who contribute financial and material resources happy and informed of the team’s progress as the organization evolves. Strong relationships with community members are essential to top up what can be limited resources from the host school, and such sponsors can also provide in-kind assistance in technology and training as well as internship and employment opportunities.
5.4 Research Question 4: Sustaining the Organization Over Time

RQ4: How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on knowledge to future generations?

As noted earlier in section 5.3.2 by respondent #4, FSAE teams likely do not have the same budget as varsity sports teams. However, they do share one common challenge: maintaining a sustained organization in an environment of high annual turnover of its most skilled members. As with student athletes, student engineers eventually graduate, and those graduates are usually the most experienced and knowledgeable members of the team. It is very common for all FSAE team leaders to be in their graduating year, leading to a full organizational renewal at the top every year. What is more, it is never guaranteed all returning members will choose to return, potentially creating other organizational holes. High organizational turnover of skilled team members and leaders is thus a considerable and annual process that FSAE teams have to negotiate.

![Diagram](image)

**Figure 14: Changes in activity over time**

In the hypothetical example depicted in Figure 14 above, a 2016 team of 15 people loses 6 key members (represented as black dots) to graduation, and two others are unsure if want to return. 2017 starts with less than half the previous team returning. Replacement team members
(as represented by lighter shaded dots) do not have the same breadth or depth of experience as the graduating members they replace. The 2017 team is beginning its work from a relatively weak position, and will have to leverage the information artifacts and social relationships that remain. If the members noted by question marks are leaving due to bad personal experiences, it is unlikely they will be of much help in resolving this contradiction of two activities evolving over time.

One might expect as a result that teams would be keenly aware of such a potential situation, but a number of teams seem to struggle with this issue. Respondent #1, as a member of a relatively new team, expressed concern that knowledge transfer is a challenge to address but that the team hasn’t spent much attention to the issue due to lack of time. #4 admitted that “we’re not as good at documenting progress as we should be” and that “in years where a lot of senior members left, there has been a slower year following.” [#4]. Other teams seem less than concerned however – as faculty advisor #40 answered the question about recruiting new members to replace graduating leaders simply like this:

“It just happens.” [#40]

While honest, an “it happens” attitude leaves a lot to chance. It is also not a particularly strong strategy – respondent #40’s team has been a regular participant at Michigan for over a decade, but has yet to crack the top 25 and routinely places in the lower half of the competition (FSAE Results, 2016). “It” does not seem to be happening very well. Other teams have identified more proactive strategies for their chronic annual renewal challenge.

Before investigating respondent’s observations on this research question, it should be noted that this represents individual reflections on the organizational learning and development process of their team, and thus does not necessarily engage questions of the efficacy of specific learning processes in any one team in depth. The challenges of a survey-level study of multiple teams vs. in-depth investigation of any one team’s learning will be discussed later in Chapter 6.
5.4.1 Building and Leveraging A Team Information Repository

As noted earlier in section 5.1.2, internal reports were cited as one of many information resources leveraged by teams in their research and development. Such reports can be a key factor in building and retaining organizational knowledge over time. It is tempting for some to suggest that all team knowledge can be so codified and stored. Early research into knowledge management systems focused on information systems design, often dismissing sociocultural context of information use. Early models focused storing, indexing, accessing, disseminating and interacting with information resources (e.g., Milton, Shadbolt, Cottom & Hammersly, 1999; Preece et al., 2001) to create a body of persistent, relevant and explicit information that can be extracted, stored, and retrieved accurately and rapidly by all on a just-in-time basis (van Heijst, van der Spek & Kruizinga, 1997). However, such models of knowledge management often neglected the importance of tacit knowledge and social constructivism in the generation and retention of organizational knowledge.

In Nonaka & Takeuchi’s SECI model of knowledge creation (1995), internal reports play a role in the combination stage, where people engage explicit resources and recombine them with other explicit resources to create new knowledge artifacts. An inventory of reports serves as a cyber/systemizing ba (Nonaka & Konno, 1998). These reports can certainly enable knowledge creation and sharing, but it does require that the explicit information is relevant and accessible, and that those reading reports possess the requisite tacit knowledge to faithfully interpret the material and make it their own internalized knowledge. Confusing reports provided to neophytes struggling with core concepts will not transfer knowledge between generations effectively.

This does not mean developing an explicit knowledge repository and data is a waste of time or effort. Thirteen teams explicitly noted that past team information should be protected and accessible for future recall – including the “it happens” team who stores this information on shared hard drives [#40]. Respondent #7 explained how they involve their team database in the design process.

“We also have an ever-growing database of reference material on anything from suspension dynamics to engine parts to race car driving. This allows students to refer
back to info that people found useful in the past. We also keep extensive documentation of our design cycle, so students can see the design justification made on a previous design. “[#7]

Having a database of readings peers have found useful gives students a great starting point from which to begin any investigation, and provides a quick and relatively unambiguous path through early stages of Kuhlthau’s (2004) information search process. While there are compilations of literature available such as “sticky” posts on FSAE.com⁶, having a list vetted by team members likely means someone in the organization has personally used that material, thus adding social support for building required tacit knowledge around the topic. Having the design rationale and resources of previous designs archived for retrieval also helps future years in determining what was done and why.

One notable technological change is the ubiquity of internet access in key lab and competition locations, particularly through smart phones and tablets, and the availability of productivity apps that leverage cloud storage in these and other locations. The current generation is very connected, both to themselves and to the teams’ core data. Respondent #14, 17, 21 and 24 all noted using Google Docs or Microsoft OneDrive for storing team data, allowing the data to be retrieved at will from multiple locations on multiple personal devices.

“Putting everything online really helped things – I could call up past work on my phone in the lab, add results from testing on the fly and have it ready on a tablet for competition judges as well. We started loading up everything to Google Docs two years ago so we have more and more material from past years available now – I think about five years of stuff is up there now. Definitely a lot easier than reading through past printed papers and easier to find things than on our lab computers. It doesn’t work for everything though – no way to get simulation data on there yet I don’t think – but works well for reports and spreadsheets.” [#17]

This solution only works well for American teams in Michigan and Nebraska however – respondent #21 noted that given their Canadian data plans, they were cut off from their cloud-based storage unless they found a wi-fi hotspot, which is somewhat spotty in the middle of the competition venue, or if they paid for international roaming packages, which can be expensive:

“We’re a lot more tied to the cloud than we realized – it’s been frustrating to not have 24/7 access to data. One team member took it all offline yesterday at the hotel so we at least have everything on a laptop in the truck, but that’s not easily retrieved everywhere. And while a few of us bought a data plan before getting here we’re already over - a few of us are going have a shock on our bills when we get back.” [#21]

To help accommodate international teams, a couple of teams opened up their mobile data plans to act as a wi-fi hotspot, writing their public hotspot information on the walls of their truck and thus allowing access to email, text messaging and access to online data stores. As will be discussed later in RQ5, this is emblematic of the kinds of cooperation that happens even in the heat of competitive events.

One team that has focused on mobile information storage and retrieval is Global Formula Racing (GFR). GFR is a unique team in that it is a joint effort between two schools – Oregon State University, and DHBW Ravensburg in Germany (GFR, 2016a). Team members in both locations work on designing and testing the same inventory of core parts, leading to cars that can be built in both locations, although Oregon State specializes in the internal combustion series in North America and DHBW Ravensburg building an electric drive car in Germany.

This joint effort is facilitated by an internet-based information store both teams can access and add to in real time. With the teams being nine time zones apart, reverting to a quick informal chat about confusing or missing details is not an easily available option, although the team does engage in real-time chats through Skype (GFR, 2016b).

While I was only able to view this system and unfortunately was unable to reconnect with initially interviewed subjects, it is arguable that their system has paid dividends. GFR has been a consistent top-tier competitor since its inception, with its internal combustion car winning Michigan five times and three times in Germany in the 2010s, and the Ravensburg electric car doing very well in the electric circuit in Europe (FSAE Results, 2016). Further investigation of both the technical and organizational practices that have led to this particular team’s consistent success in the modern era is something worthy for further discussion, as will be discussed in the concluding chapter.
Respondent #21 did specifically suggest they were inspired by GFR’s structured approach to creating a robust, cloud-based data store, but also noted replicating it will take effort beyond negotiating cross-border data plan issues. Resource limitations play a role as well – while cloud-based data stores are relatively cheap, a robust network of tools and adequate storage still requires some cash outlay and would also require near-ubiquitous availability of smart phones or tablets to access and contribute to the archive – although increasingly that is a reality among the millennial generation.

One central challenge for teams to replicate this model would be the quality of team reports themselves. As #17 previously noted regarding the team’s collection of random digital photographs, sometimes what is available is an unorganized mess, missing the required metadata to be searchable and identifiable to specific cars and years. While #29 noted that team reports and past data were used in design, he didn’t find internal reports particularly useful. “There were a couple of things written by past team members but they were impossible to follow – I got more by just phoning them up and getting them to explain what they meant.” [#29]. Similarly, #14 noted that past notes on engine tuning were “garbage – half the data was missing, the rest of it was just crap. I hope I can do a better job this year, definitely going to be a summer project.” [#14].

This speaks to one problem tied to the work cycle of FSAE teams – between design, manufacturing, and testing, there is often not enough time devoted to documentation and reflection on what has been done. While Nonaka and Konno talk about an exercising “ba” to support internalization (Nonaka & Konno, 1998), the work cycle of student teams does not provide much time or space to attend to this valuable part of the SECI knowledge creation cycle. The Michigan and Nebraska competitions happen at or after the end of most North American schools’ academic year. At the end of competition, many team members are exhausted – and then they have to prepare for summer jobs, graduation, moving home or to first career jobs, and other major life events. Even if one agrees that quality documentation is a good idea, there is very little time or energy remaining at the end of the FSAE team work cycle to do so. For teams not structured as an academic course with mandatory requirements for report writing, it is even less likely that quality documentation will happen. Teams that stress the importance of quality
documentation and endeavor to find the space, time and reward structure to make it a reality are arguably more prepared to ensure knowledge capture by closing the SECI cycle.

There is also arguably a skills mismatch at play in some cases. Extending from what respondent #19 noted about web design and marketing skills, being a good engineer does not necessarily make you a good technical writer or information scientist. Without someone charged with vetting and editing team work or ensuring the team’s data store is logically structured with appropriate metadata, it is easy to end up in a situation like respondent #17 noted earlier, drowning in a folder of photographs that may not be relevant. Making documentation a team priority often means allocating skilled human resources to attend that priority, and not all teams have the requisite human resources to make that happen.

All of these barriers to appropriate documentation does not necessarily mean past work is lost on graduation, however. Just as there are many possible ways that team members search for information for design, so are there many ways to retain and integrate the experiences of past team members, with direct contact with alumni being a commonly cited one.

5.4.2 Integrating Alumni Experience Through Continued Engagement

One way to ensure knowledge does not walk out the door on graduation is to keep in touch with alumni as they move on into the next chapter in their lives. As Tsoukas (2003) notes, tacit knowledge is built through engagement with practical problems with the guidance of experts, so having subject matter experts remaining engaged after graduation increases the likelihood that tacit knowledge will be instilled in the upcoming generation. Unlike other organizations where attrition might be due to layoffs, termination or insolvency, team alumni generally have positive feelings towards the team they left, and are usually happy to continue to be involved as sponsors and advisors if invited to do so. Seventeen respondents noted some form of leveraging of team alumni connections in sustaining and building organizational knowledge.
Respondent #3 noted the existence of an internal team forum that not only served as a data store for team documents, but also a social space involving team alumni in the discussion. This has the benefit of overlaying a document library with direct conversation with authors, which enables sharing of information not otherwise included in documentation. This data store also includes the emails and phone numbers of alumni who are willing to be further consulted after graduation. This system helps bring what otherwise might be a passive repository of information to life, integrating continued social contact with authors who are willing to mentor new students on the research and development work they completed. Considering Nonaka and Konno’s concept of *ba* (1988), this hybrid database/social engagement system extends a cyber/systemizing *ba* into one that also serves as an interacting *ba*, and thus supports both the externalization and combination phases of Nonaka and Takeuchi’s (1995) SECI model.

Other teams try to involve alumni in a more structured manner, especially around the design process. Respondent #17 and 23 noted that the team invites alumni to attend design reviews either in person or via web conferencing. They publish presentations to alumni so that those who cannot make presentations can offer their feedback on their own schedules. This helps alumni share their history of design and development of specific parts, extending the design lifecycle beyond the time any specific team member may be involved. It also has the added benefit of having a number of experienced eyes vet design concepts. On teams with less than active faculty advisors, an active team alumni group may substitute as the experts in the room, even if they are no longer able to work on the car directly. (The same rules that restrict faculty and staff from a direct role in design and development also apply to alumni.)

Capturing the input of alumni can also happen at competition itself, particularly at the Michigan location. A number of graduates end up working in the automotive industry or at related equipment manufacturers. Even with large structural changes in the industry shifting labor to other locations, there still are a number of alumni employed in the Michigan area, and alumni are encouraged to attend competition and share their input in person.

It is possible that strategies of continued contact with specific alumni may eventually time out – as #4 suggests “after 5 or so years off the team, most people lose touch or are out of
the loop too long to have extremely constructive input.” [#4]. After years in their profession (or whatever other careers alumni pursue) their first-hand knowledge of FSAE design processes fades. In addition, every year competition rules are updated, based on input from competition judges and the student community, meaning past knowledge of design may not be as relevant to current rules.

5.4.3 Recruiting and Mentoring Future Team Members and Leaders

A commonly reported means of information transfer among generations of team members is the establishment of mentorship relationships, noted explicitly by 10 teams in this sample. This focuses on tacit knowledge sharing among team members and leverages the socialization and externalization components of Nonaka and Takeuchi’s SECI model (1995). Informal mentoring encourages socialization through informal chat, while more formal mentoring relationships may focus on specific deliverables and reporting relationships, making it more part of the externalization process. In either case, the goal is to ensure senior members of the team share their expertise through social contact and hands-on work. This method has the added benefit of not having any financial cost or requiring IT expertise. It does require time, but it can be done within the work environment, situating organizational learning squarely in the context of the activity itself.

Mentoring can be done at various levels of formalization. Respondent #5 noted simply, “We make a point to teach others before we graduate. It’s a team expectation and members get yelled at if they aren’t teaching.” [#5]. While admirable to note, this approach seems a bit blunt and unstructured. There are more structured and formal methods used that are probably more efficient and focused. Respondent #7 shared this perspective:

“A lot of my time this year will be sitting with the new recruits to quickly bring them up to speed with the team and general suspension design. I have also given all the new members senior mentors. Hopefully this will allow for a better knowledge transfer to the freshman. We are also looking at ways where the new members can sit, watch and ask questions while the senior members design parts, so they can see more complicated design process. My hope from this is that this will show the new members how to make good design decisions, and get a general idea of how more complicated parts are
designed. Technical knowledge can always be learned, but this design mentality can only be gained from experience.” [#7]

This more structured approach targets new members and formally links them to more senior mentors, who are encouraged to guide their mentee through the design process. It also stresses the social and experiential nature of design thinking. Technical knowledge is relatively easy to learn through published resources, but the process of piecing together all the components in a coherent whole is not something one can easily look up in a textbook. Having junior members shadow more senior members gives less experienced members access to the design process without overwhelming them with the pressures of developing something out of the gate. Such structured mentoring relationships were noted by respondents 17, 19, and 23 as well, and I suspect are quite common across teams.

A more subtle form of mentoring can happen by creating functional teams where junior members are assigned to multiple design projects led by senior leaders. Respondent #8 describes their organization thusly:

“One way we attempt to minimize the impact of losing experience team members is to allow younger students to hold understudy positions. We organize the team such that there are team leaders and then multiple sub-design/understudy within each system of the car. This not only allows more participation due to the increased positions available but it also forces the experienced and inexperienced members to work together and ultimately prepare them for when graduation comes along.” [#8]

In this organizational model, junior members are given a lesser role on any given design project, but in doing that limited role they bear witness to the more complete process of design. In doing so, they hopefully learn more about how such systems integrate into a coherent whole, and can make their own decisions on what projects are more relevant and interesting to them. While most teams did not speak in detail on their team structure, team websites suggest teams choose to organize into functional subteams. Structuring early exposure to subteams allows senior members to mentor new members in the context of practice of their activity, thus sharing tacit knowledge gained on the job. This can be seen as an example of Lave and Wegner’s (1991) notion of legitimate peripheral participation, in which peripheral activity can be seen as a valuable learning channel for less skilled members.
With respect to identifying and recruiting new team members, there are multiple possible strategies. Five teams outlined a formal process of recruiting, such as outlined by one faculty advisor: “[we use] heavy recruitment followed by a rigorous training program and set of performance expectations to earn leadership roles and points to qualify to attend competition.” [#38]. Establishing performance goals and a points system to judge competition attendance helps new team members to focus their level of activity and commitment. However, this method might also cause potentially valuable members to tune out just as quickly. Arbitrarily set metrics may also risk reinforcing a system were those who make the cut do so in a competitive process, which can lead to a homogeneous group that may be blind to alternative perspectives. The success of such a model does depend a lot on what the metrics measure and why. That noted, #38’s team does have a strong history in competition so I suspect this method has served their team well.

Other teams try to be more targeted in its recruiting, requiring application processes and interviews common in many jobs. Respondent #29 noted that their team identifies specific roles that will be holes in the coming year and makes specific appeals to individuals to fill those roles, recruiting individuals before competition to train them on-site. Strategically identifying specific individuals whose departure might be particularly negative shows attention to potential to the long term sustainability of the organization and the value of key participants. Near the end of the academic year, it should be clear who is graduating and who will be returning, and by admitting new team members a month or two before competition, new entrants get to experience the ultimate outcome of the activity first hand. Those joining the team in the spring do not have much more seniority over those who join in the fall, but the experience they gain from merely being present at competition can be invaluable. Six teams noted explicitly that they recruited team members for future years just before attending competition to help bridge the potentially significant gap in experience that comes from losing members due to graduation.

Also common is an organic and evolving recruitment process where students are retained based primarily on effort. As #4 notes, “we acknowledge individuals that put in more effort. They in turn get consulted more and become obvious unspoken leaders.” [#4]. New team
members who put in effort are given more responsibilities, and if they rise to those challenges, they eventually develop their own sphere of influence. Six teams noted they structured their recruiting process this way – respondent #24 noted that team membership is determined through accepting anyone who expresses interest and seeing how they turn out.

“We allow them to make the call – if they’re interested in doing things, we’ll see more of them. If they just signed up for a club because they thought it was cool, we’ll see less and less of them as they realize real work is expected. By the end of the year, we know who’s on and who’s not.” [#24]

As with other CHAT contradictions, there is no one “right” path for recruiting and developing team members and leaders. While an organic emergence model generally works well and requires less administrative overhead, focusing on specific team needs can help avoid a homogeneous team roster of intense workers and provide space for those team members who may play a valuable secondary role in the overall activity.

5.4.4 Multi-year projects and Systems Integration

High organizational turnover is not the only issue FSAE teams face with respect to the core activity changing with the passage of time. While most teams operate on an annual cycle of design, development, and testing culminating in competition, there are some projects that may be too complex to fit into this one academic year cycle, requiring work to be done over multiple years. This can be complicated to achieve in an environment where senior team members are leaving due to graduation, and often requires attention within teams to ensure reliable knowledge transfer over generations.

It is arguable that systems engineering (INCOSE, 2016) is a key learning outcome of the FSAE series. Various subsystems of a car operate in concert, with any one system often providing critical inputs that impact the performance of others. Integration of the larger system can be challenging, especially as subsystems are designed by different subteams that may or may not envision the effect of interactions among them. Teams that attend to such interactions as part of the design process reduce the possibility of significant failure and create interdependent
systems that mutually reinforce their strengths. However, accounting for and designing around all these interactions may take some time, which may require attention to multi-year projects and systems engineering concerns.

For example, as design judge respondent #41 described in his interview, a contemporary trend is integration of partial or full aerodynamics packages to increase downforce and maximize power delivery to the ground. New track designs have made aero packages increasingly relevant design alternatives. Front and back “wings” (designed to operate opposite to airplanes, pushing the car down vs. lifting it up) and underbody air flow channels are increasingly common features of design as a result. While adding weight and system complexity, aero-enabled cars perform better on larger tracks by maximizing downforce, maximizes lateral acceleration in cornering.

However, a team cannot just randomly install aerodynamic components. Any attempt would attract the ire of design judges who would quickly ask questions about systems integration and would find the answers wanting, as respondent #41 noted in his overall evaluation of cars in 2015. Integrating new systems that have system-wide implications may require multiple iterations over years.

It would seem from respondents that many teams have come to a general awareness of systems engineering, but may find it difficult to support multi-year projects, largely due to organizational turnover issues and the required organizational knowledge retention to support a project that requires development by multiple generations.

Consider the generalized CHAT in the figure below:
In figure 15, a design subteam working on X might find themselves engaging various instruments/tools only to encounter significant systems integration issues that may require more attention and thought. The immediate community may be other subteams who are concerned about how X’s design might impact their own work – in the case of an aero package discussed above, increased downforce would increase suspension and chassis loads, and parts in those systems would need to be redesigned to accommodate that load else they may fail. Team leadership may have to intervene to declare X as as multi-year project, constraining research and development to early prototyping and providing time so that such systems interactions are addressed. In later years, a reconstituted subteam can learn from past documented work and recent alumni, work with other subteams to negotiate any remaining contradictions, and test a more complete system to the point team leadership agrees it is ready to run on the car.

Seven teams stated they did not have the time or human resources to dedicate to multiple year projects, and thus lived within the confines of the academic year in their design. #9 suggested a solution of hard work and consideration of a plan B:

“Work longer hours! The more time you put in, the quicker you run into obstacles and the sooner you work through them. The other thing that I like to do is have a
quick simple will-definitely-work solution for things before exploring more complex solutions. For engine stuff, that means that we had a simple bucket-style oil pan before looking into baffles on the pan, and for the fuel tank we made sure our old, reliable tank and pump would fit in before exploring our new plastic molded tank. These ended up being good calls because they were what we had to use at the end of the day. While not the best, lightest, most engineered solutions, this car has had no oil or gas issues.” [#9]

In this suggestion, a complex change that might take longer to execute may happen through raw effort. In the event that does not happen however, a simple, perfectly serviceable solution is ready to go for the current year. While probably not the greatest approach for long-term complex systems change, awareness of a plan B shows awareness of the need to trading off innovation with reliability, a common systems tradeoff.

Respondent #4 noted a more complex organizational model serves to extend the design cycle and operates similar to the generalized model above.

“"What approximately 15 1-3rd year members will do is work on multi-year development projects. This allows for implementation of larger changes to take place in more realistic time frames. The individuals assigned to these areas will become extremely familiar with the new systems they are designing, and then transition roles to implementation when their design is being implemented on the car. " [#4]

In this workflow, the senior students on the team are charged with finalization and implementation of systems the organization has been working on over multiple years, while junior and earlier students are charged with the development of new ideas for future years. This is a example of what Lave and Wenger (1991) consider legitimate peripheral participation, which privileges active learning but also protects novices from the stresses of full responsibility and risk as they learn their craft. With some advance preparation, first to third year students can approach competition as a learning experience and prepare for a summer where their designs can be worked on with the input and inspiration of what they have seen.

One potential drawback to this process is an experience gap – first year students in particular are probably not qualified to offer more than a laypersons’ perspective to good design,
and even third year students may not yet have the academic knowledge to correctly identify and develop a strong design. Charging junior members of the team with sophisticated design may cause these members to focus on partial, incomplete and ultimately incorrect mental models learned through backward learning (Mandin et al, 1997) and thus frustrate future development in the process.

Respondent #26 offers another solution for multi-year projects – simply come back another year.

“Two of us are actually going to be back next year for our master’s – we’ve already identified our master’s projects and they’d definitely be helpful for the team’s development, plus we’ll probably have the financing to do it right. We’re taking lots of notes on what’s going on here and are riding back to California tomorrow so that’s a couple of days to talk it out.” [#26]

While this solution is not available to everyone, it can certainly be beneficial to the team to hang on to senior students for an extra year. The work of graduate students can expand the depth of knowledge available to a team, especially if done by students already familiar with the team’s context and workflow.

The above also shows the value of simple conversation in knowledge generation – sharing a ride from Nebraska back to California provides considerable time to debrief and integrate new observations formed at competition. The cab of a truck can thus serve as a good exercising, originating and systemizing ba (Nonaka and Konno, 1998) – a temporary environment required by necessity to be sure, but one if appropriately leveraged can provide ample time for reflection, brainstorming and planning. Two other teams noted they send their returning potential team leaders home from competition together. While these students are likely exhausted from the demands of competition, the period of down time on the way home can be an effective learning experience if used strategically to encourage reflection on the past year, lessons learned from observations at competition, and early brainstorming on potential future year research and development directions.
5.4.5 Summary for RQ4

**RQ4:** How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on knowledge to future generations?

Organizational renewal is a necessary concern for all FSAE teams wishing to sustain themselves beyond any given cohort. By definition, student engineering project teams are subject to high levels of organizational turnover, with the most qualified team members and leaders leaving every year due to graduation. This requires that the team plan for organizational renewal through recruitment of new team members and development of existing team members to rise to leadership positions. Such high levels of turnover of the most qualified members makes it quite difficult for a team to maintain a sustained record, but successful teams have adapted to this challenge through multiple means.

Thirteen respondents noted the value of creating and maintaining digital archives of reports, photographs, design specifications and other artifacts of the design process, leveraging this explicit knowledge base to retain organizational history. Aided by ubiquitous internet connectivity through mobile devices with nationwide data plans, most American team members are arriving at competition with the tools necessarily to gain access to their information repository on site. Team members can also generate even more information on site while troubleshooting their vehicles and taking pictures of competing teams in the competition venue. The sophistication of such online data stores and on-site information generation varies, however, and international teams may find international data roaming fees to be a significant barrier to accessing cloud-based team information services.

While teams like the currently dominant Global Formula Racing organization have an impressive mobile technology and cloud-based data infrastructure, other teams are left saddled with less optimal solutions and access. However, much of this challenge in documenting team progress and building organizational knowledge comes from lack of attention to this as a team priority. Accounts of misclassified and disorganized information stores noted above suggest that teams who have not invested the time and human resources to appropriately document and annotate resources will find it complicated to retrieve and discern the relevance of material later.
While focusing on explicit records is a priority for some teams, there are also more social approaches to organizational learning and knowledge generation used. Seventeen teams noted sustained contacts with team alumni, who agree to consult with current team members on past design strategies. One school noted their use of an internal forum which allows for asynchronous discussion with alumni over documents in their internal database. Such solutions enhance the existing explicit knowledge base by tapping into socialization as a key driving force for knowledge creation. However, this depends on the continued interest and availability of graduating team members, which as respondent #4 noted can time out after approximately 5 years as alumni move on to more pressing personal concerns.

With respect to recruitment and development of future team members and leaders, teams use a variety of strategies. While some teams prefer a more organic selection process where new team members prove their mettle through work, others have a more formal recruitment process, similar to job interviews, that targets developing holes in the organization and look for specific characteristics in future members that may compensate for specific skill sets in the organization’s makeup. Once on the team, leadership status tends to be an emergent process where high performing team members take on more serious responsibilities. Teams vary in the quality and formality of mentorship provided, with some having structured mentorship relations and sub-team structures that deliberately mix experienced and rookie team members with the intent of passing on tacit knowledge through socialization. Other teams suggest organizational renewal “just happens” [#40] – but given their mediocre results over the decade, other teams are probably not advised to leave such an important organizational process to chance.
5.5 Research Question 5: Interteam Collaboration and Competition

RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private?

Research question 5 looks at the quaternary contradiction of CHAT. When one team’s intended outcome overlaps with another team’s similar outcome, this contradiction can lead to conflict, but also can be fertile ground for interteam collaboration.

![Diagram](image)

**Figure 16: Interactions between competing teams**

The photo in Figure 16 is a panoramic picture of all competing teams at the 2014 Nebraska completion (the panoramic photo of all teams is a competition tradition.) All these teams are there to participate in the same activity and are aiming towards the same end goal, which creates multiple opportunities for conflict and contradiction. As will be discussed here, the reality is surprisingly as cooperative as this photograph – the common bond of working hard on this project often transcends competitive pressures among teams.

In the context of FSAE as an activity, this happens at two notable junctures – within the FSAE competitive environment, and back at the team’s school, where an FSAE team may have to compete with similar project teams for financial, space and human resources.
As with the previous discussion of RQ4, respondent observations should be seen as individual reflections on interteam knowledge sharing, and does not necessarily engage questions of the efficacy of specific learning processes noted. The challenges of a survey-level study of multiple teams vs. in-depth investigation of any one team’s learning will be discussed later in Chapter 6.

5.5.1 Contradiction and Collaboration Within the FSAE Competitive Environment

Given the competitive narrative structuring this racing series, it is natural to assume that competing teams may keep certain facts and figures close to the chest and be wary of competitive teams, especially when decisions benefitting an opposing team might jeopardize one’s own results. Given this, one of the interesting observations one makes on entering the competition venue is how cooperative the event is. It is immediately evident on observation that teams are sharing knowledge through reciprocal discussion, and the public address system regularly puts out calls for tools/parts, which teams strive to meet. Even schools with intense competitive rivalries in other domains will find a way to collaborate, as seen here in figure 17, a depiction of Auburn’s surprise meetup with their football arch-nemesis, Alabama.
In early research, given dwindling activity on forums such as FSAE.com, I initially suspected that secrecy among teams may have increased as the series became more complex and competitive. From respondents, it is clear that cooperation has simply moved elsewhere and grown in other forms.

“I'm open to helping other teams with pretty much anything. It's really not that much of a competition. My whole team just did a google hangout tonight with the [school X] aero team to share data and ask each other questions. We asked most of the questions since they've done aero before, but I'm always open to helping other teams out.” [#9]

One would think that a team entering into direct competition with other teams would guard their design expertise, especially on complex systems such as a full aero package.
Competition scores in dynamic events are based on ratios of one team’s time vs. others, and in such a zero-sum game, the above story makes no intuitive sense. Indeed, if these were competitors in the professional industry, such an informal exchange of information might be grounds for dismissal with cause. Yet, examples like the above are surprisingly common, both in the leadup to competition and at the event itself. Respondent #5 noted they even share engineering drawings – with caveats.

“We share SolidWorks files and advice with other teams. We do not share our “unique” parts. Other teams have helped us with housing and transportation at competitions and we plan to return the favor.” [#5]

Here we see some of the expected benefits for sharing information. Having benefitted directly from housing and transportation at competition, this team likely feels the need to help others in need. But this quote also suggests a point to which sharing is limited. Unique parts might be off-limits, as might some of the reasoning why, which you are supposed to figure out on your own. Respondent #9 shared another perspective on that:

“…we spent about 3 weeks trying to figure out that we'd never get the stock flywheel crank-angle sensor working properly and that we’d have to design our own. I'd immediately tell that to a team considering our model engine, but I wouldn't give them the actual designs of the custom sensor that we made. Honestly, the second part is the easy part IMO, but is what actually requires engineering design. I think that's a fair cutoff point.” [#9]

From this, there seems to a meritocracy in the culture of information sharing at play. The above advice tells a competing team that there is going to be a problem, but not necessarily what the solution is – the core work of resolving the problem remains to be done by the team requesting the information. In doing so they are playing a role of a supportive expert – but not necessarily replacing the requisite process of forming one’s own tacit knowledge on this matter.

The above suggests that sharing of information is not only tolerated in this series, it is encouraged. The premier example of this would be the FSAE Tire Test Consortium. As noted earlier, reliable tire data should be the departure point for all suspension design – but data for
FSAE tires is unreliable given small production runs, inconsistencies in the production process, and reluctance of tire manufacturers to transparently provide data. A small group of teams solicited interest in a joint research and testing concern to purchase tires, hire professional testers to do industry standard analyses, and share the results with those who paid for the service. Milliken Research Associates took over administration of this collaborative research project and now has over 450 participating members worldwide (MRA, 2016), a near complete sample of the worldwide FSAE population.

Cooperation is evident even at the competition itself. One might expect self-interest to kick in in such a competitive context, but it seems the opposite is often true. The competition tightly packs all teams together, allowing multiple opportunities for team members to explore what other teams have done. The public announcement system continually broadcasts requests for assistance, and teams go out of the way to help their competitors by lending tools and materials, and even offering assistance on more complex matters. There is a pervasive interest in the community to ensure every team has a fair chance to compete. Respondent #10 noted that:

“During competition, we’ve helped out teams by lending them or giving them tools or materials. It’s in the spirit of the competition to help each other out, that’s part of the beauty of FSAE. We helped [X] University modify their silencer which allowed them to pass sound tech. We’ve given several teams our endurance event data and given or traded other items with dozens of other teams.” [#10]

Respondent #42, an alumni returning to visit their former team, shared a story of a team that rescued their competition effort entirely.

“Three years ago, our engine package had lubrication issues and seized up as we were trying to pass noise. We were a pretty new team, so we only had that one engine because we hadn’t got around to getting another…so, completely screwed. [X] team were our neighbors in the paddock and used the same engine. They had two more or less ready to go backups if we wanted to buy one. We scraped together some money between all of us – about half what they offered, which was already low. They said we could line up the rest later. Some of their team members helped us drop the old engine and help install the new one – which was a total pain in the ass because our frame design was pretty crap. They gave us some hints on how to fix that for future designs, and also helped identify the likely source of our oil flow issues. We managed to get it all together somehow, basically adopting three of their team members for half the competition, and were able to
run in endurance. Just incredible how much work they put in to help us out, then and still – we have a great relationship with X now. I just helped line them up a carbon fiber sponsorship from my company because it’s the least I can do.” [#42]

There are numerous similar stories of a team coming to the aid of others at competition, with 17 teams noting instances of helping other teams and/or being helped by others. While there may be some influence of social desirability bias at play in such self-reports, observations at the competition site suggest that interteam collaboration is a very real and authentic phenomenon. The competition site could very easily be an environment of secrecy and suspicion – instead, it is often the opposite, with team members freely exchanging ideas and information and rightfully showing pride in their work and even, like above, helping the competition directly.

That noted, there is an etiquette to learning from others at competition. At times, a team faces immediate concerns that mandate they focus on their own car. It is common to see a huddle of very concerned engineers surrounding the car, trying to solve a last minute problem. Even in non-chaotic situations, respect has to be given to personal space. Respondent #23 noted their frustration with the picture takers:

“There are some teams – mostly new, usually international - who come to the paddock with their camera and photograph the shit out of everything – extreme closeups, multiple angles – all without asking first or even saying anything. One guy even tried to get into the car. We end up crowding them out, because it’s rude. And stupid. I hope they’re not considering intelligence careers, because they’re the most obvious spies out there. What’s weird is that if they just asked us questions, we’d probably give them better information. Not sure what a bunch of photos without the background design work will get you. One team I swear might come up with a close copy of our car next year. They won’t know why, and it probably will never work, but it just might look exactly the same.” [#23]

As noted above, attempting to finely document the car to later reverse engineer it is seen as both sloppy espionage and not productive. If the photographers actually engaged the team in conversation, they would both have created more goodwill and have received better information. In some cases it could be a language or shyness situation, but as noted by #42 earlier, stronger teams are actually quite keen on helping out new and struggling teams – if approached correctly.
Meetups outside of competition are also common. Respondents 1, 2, 4, and 9, 17, 19 all noted attendance at regional meetups and mini-competitions organized during the year. Annual student-run, non-sanctioned events such as University of Toronto’s Shootout and University of Texas Arlington’s Texas Autocross Weekend give schools within reasonable distance the opportunity to replicate the competition experience in a smaller setting, with less pressure to perform. As the UTA faculty advisor noted in his 2016 invitation:

“Please join us for a weekend of pure FSAE racing without the pressure of judging and competition (except for bragging rights). This is a time to observe cars in a more relaxed setting and to see how you stack up against some of the best FSAE cars in the country.” (http://www.fsae.com/forums/showthread.php?12297-Texas-Autocross-Weekend-2016)

While teams share their research and experiences widely in an environment where competition rules directly reward the opposite behavior is a question of interest. Research suggests multiple possible explanations for this phenomenon, however. Part of this may be explained by a overlaying norm of reciprocity in this culture, which has been shown to be a positive force in studies of social capital even where there are not strong rewards for knowledge sharing (Kankanhalli, 2005; Wang & Noe, 2010). Interpersonal trust and a sense of justice may be driving teams to share information, especially with lesser developed colleagues. This is not done on expectations of an immediate return on this exchange, but rather a sense of proverbially ‘paying it forward’ – one’s good deeds may build a sense of trust and social expectations that the good deed will be rewarded eventually. As noted above by #42, good deeds previously extended to his team have indeed paid back as the respondent in his current position has ensured the supporting team receive industry sponsorship for carbon fiber – an otherwise expensive resource, and one that often requires significant material science expertise to use, as noted in previous discussions about composite monocoque design. Reciprocity may also explain frustrations with individuals who invade a team’s space to photograph a car in minute detail – as #23 noted, their team would likely have been more than happy to help if asked, but in not being asked the relationship between these teams was perceived as fleeting, one-sided and rather exploitative.

Another possible motive may be engineering co-opetition as a response to a competitive environment of limited resources. As noted by Gnyawali & Park (2009), small enterprises such
as FSAE teams may find it wise to share resources and results in an effort to further their individual team goals, even if that means their collaborating teams share the same results. Examples such as the FSAE Tire Testing Consortium noted earlier are a good example of teams strategically collaborating on specific projects that would be hard to accomplish on independent effort. Joint teams such as the currently dominant GFR team also give teams pause to consider what might be best done jointly versus independently. Respondent #1 noted the team was considering creating a “sister school” arrangement where information would be freely shared among both partners – an effort to replicate the scale of operations that Global Formula Racing is already showcasing.

Both reciprocity and coopetition are represented in the concept of community of practice. As attendance at regional informal meetups and the informal collaboration between Auburn and Alabama showcase, FSAE team members may see themselves less as competitors than as collaborators working on the same shared activity. As such, participants would be eager to “talk shop” at any given opportunity, even one where their teams’ vested interest are at stake. Wenger (1988) noted that communities of practice are social spaces that link people through mutual engagement in shared activity and knowledge domains. Such shared interests can develop within organizations and between individuals in multiple organizations who share a common goal and worldview (Wenger & Snyder, 2000). Given the social bonding and sense of accomplishment around this activity described earlier in the discussion of RQ1, and that some team members may not feel that others appreciate the extensive effort required to field such a vehicle, it is very possible that teams would be eager to engage and share information in informal meetups where at least their passion is understood and appreciated. Common identification with a shared core activity defined by a shared language and problem set may in such cases trump the fact that their core activity is inherently competitive. As Wenger & Synder (2000) note, such a community of practice might resemble more an industry or cross-industry roundtable where the benefits of sharing knowledge and collaborating on shared goals outweigh any commitments to their own organization’s success.

5.5.2 Collaboration and Conflict Between School Teams
At many engineering schools, FSAE is not the only active PBL* team. For example, there are other SAE sponsored competitions such as Mini Baja, the Clean Snowmobile Challenge, and the Supermileage car. The independent World Solar Challenge is in its 30th year (https://www.worldsolarchallenge.org/). Other engineering societies sponsor their own competitions, such as the American Society for Civil Engineering’s Concrete Canoe (http://www.asce.org/event/2017/concrete-canoe/). Researchers interested in autonomous robot sports collaborated to form the Robocup robotic soccer competition (http://www.robocup.org/). NASA sponsors the Human Exploration Rover Challenge (https://www.nasa.gov/roverchallenge/home/). There are competitions fostering the greater social good such as the US Dept. of Energy Solar Decathlon solar house project (http://www.solardecathlon.gov/) and ones with more problematic outcomes, such as previous DARPA sponsorships of unmanned air, land and sea competitions that nurtured many of the developments required for drone warfare.

These and other options may create a point of contradiction within engineering schools, with project teams having to compete for limited resources. As no school has unlimited budget, schools may face hard choices over which teams to support financially and to what extent. Access to space is often a contentious point, as each team requires their own development and testing area, while some teams may require significantly more space or special purpose facilities than others. With respect to human resources, more teams allow for more options for students, who can pick the experience that best fits their interests. However, it can also lead to competition for especially talented students who could be of help to multiple projects, but barely have the time for one. There is a risk that providing multiple team participation options risks spreading the available talent pool too thin.

As suggested by faculty advisor respondents #35 and #37 and by student respondent #4 in section 5.3, the establishment of joint centers for student engineering project groups helps mediate some of these challenges. By housing multiple teams in one special purpose location dedicated to project-based learning teams, teams are no longer competing directly with other concerns for space. Dedicated technical and administrative resources can also be centralized in one location for co-located teams to share. This can also create a community of students
engaged in similar work, making it possible for teams to share talent and insight, either directly or indirectly through regular exposure.

This is however the gold standard. What is likely more common is smaller spaces shared by multiple teams under less than ideal circumstances. Faculty advisor #40 noted their team shared a 1000 sq. ft. space that at least two vehicle teams share, with the occasional research group also becoming involved. Such sharing among multiple teams working on independent activities in such a limited footprint is less than ideal.

A common pairing of teams is with Mini Baja, another competitive series organized by the Society for Automotive Engineering. The Mini Baja competition involves building an off-road car run in a rally race through trails defined by environmental obstacles such as mud, sand, and water that have to be navigated. This came across in Respondent #18’s assessment of their Baja team.

“We share our lab with Baja. They’re competitive in their series, but they’re also full of team members that we didn’t pick. I’ve read their rules – it’s pretty simple to do what you have to do, and there’s not much beyond that. And they do take up space and machines and occasionally steal our crap which we have to go get our faculty advisor to yell at them for. If they shut down tomorrow, I don’t think any of us would mind, except we do end up stealing some of their best guys sometimes.” [#18]

Mini Baja has a reputation of being a lesser engineering challenge. This is largely because the more unpredictable environment requires a more stringent set of competition rules. With less degrees of freedom, Baja engineers have less latitude for creative engagement and expression. FSAE team members may look down on their Baja colleagues as a result.

This is not always the case to be sure – respondent #4 and #15 noted quite positive relations with their Baja team, with #4 operating as part of a larger SAE student society that covers all SAE competitive teams, thus affording shared labor and knowledge transfer. But in cases of limited space and resources, it is easy to see how such jealousies can come into play. Crossing disciplinary boundaries may increase the disdain factor – while #4 noted good relations
with Baja, on others they were less charitable – “there have definitely been some suggestions to take a week off, make a sick concrete toboggan and smoke our actual team at their comp” [#4].

Even taking into consideration disciplinary rivalries and competition for limited resources, respondents seemed more or less supportive of their cousins in other competitions. Extending the varsity sporting metaphor, relations between teams would be similar to those among school sporting teams – while they compete for attention, resources and at times even athletes, they are all competing under the same banner and will be mutually supportive of each other most of the time. It is common on FSAE team Facebook and Twitter accounts to congratulate other school project teams on their accomplishments, and this makes sense – any attention given to any specific school team might spill over to others, helping everyone in the process. Good interteam relations also helps sustain good relations with the school’s administration, who of course would prefer harmony over petty discord in this matter.

5.5.3 Summary for RQ5

RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private?

Given the ultimate objective of an FSAE team is competition against other school teams, one could naturally infer that interteam rivalry both at and beyond competition would be intense. What is interesting is that many teams are much more cooperative than required, on matters both big and small.

On special projects such as the FSAE tire consortium, there is an objective argument for interteam cooperation – tire testing data from manufacturers is not available or particularly helpful, and tire testing requires destruction of expensive tires that would be beyond some team budgets. Pooling resources to generate key data sets gives all sponsoring teams access to the same data at a fraction of the cost.
The spirit of cooperation in development, testing and at competition is more surprising. At all stages, there is arguably a real competitive benefit in withholding information and assistance, especially for teams in similar stages of development. While it makes sense an experienced team might help out a first-year outfit while not seeing them as a direct threat, teams that help out and exchange information with competitive teams risk helping them beat them in competition.

Further investigation suggests the common activity of building a racecar transcends any interteam rivalry. Teams regularly lend each other parts, tools and even labor and part descriptions. While it makes some sense for teams to be nurturing of new teams who pose no immediate threat, increasingly alliances are forming between established teams who are more likely to be direct competitors.

Much of this can be traced to shared passions around the same activity – while competitive, members of FSAE teams share similar goals, ambitions and values and probably appreciate the ability to talk shop with peers, especially since others in the university community may be confused by their dedication. Also evident is a sense of reciprocity – while there might not be any direct benefit to collaborate or share with a competitive team, such sharing opens up the opportunity for future exchanges that might be of benefit later on. Paying it forward becomes not only an act of comradery, but an act of selfish altruism. Shared passion and a norm of reciprocity create a community of practice (Lave & Wegner, 1991) that often transcends the competitive impulse set up by competition rules.

Beyond competition collaboration, FSAE teams also must share space and human resources with other project-based learning teams. This actually seems to be more a point of conflict, likely due to the lack of common objective, and a zero-sum game situation where FSAE teams have to compete with other project teams for limited financial, space and human resources. While generally supportive of other team activities, FSAE teams can be hostile towards teams that do not seem to be using resources as efficiently, or whose goals they treat as being of lesser importance. This is mitigated in some locations where SAE-sponsored teams all share a
common structure and organizing structure, but this does not extend to other non-automotive projects that can be seen as lesser endeavors by some.

5.6. Summary of Findings

What follows is a brief summary of results from all five research questions examined in this chapter.

- FSAE team members spend a considerable amount of time on team work, with 17 respondents noting more than 20 hours a week spent on this activity. As Karau and Williams (2001) note, individuals can be expected to exert such effort only to the degree their efforts are instrumental to collective outcomes they personally value. Balancing personal motivations and coordinating them with team outcomes becomes a potential primary contradiction at the subject node as a result.
- Respondent motivations for participation in FSAE were mostly intrinsic in nature, with social bonding, a sense of accomplishment, and intrinsic interest in the activity emerging as themes. Extrinsic motivations such as resume building were noted less frequently, with some respondents expressing displeasure with team members oriented to their own self-promotion.
- An appeal to team outcomes and engineering logic can help mitigate individual conflicts, but in cases where goal or procedural uncertainty is high or when interpersonal conflicts are not resolved early, this may not always be possible. In one case, a primary conflict among subjects morphed into a quaternary contradiction between competing visions of the team outcome, causing the resignation of a team member and derailing team progress towards a collective outcome.
- Traditionally, automotive racing culture is intensely focused on task and built on arguably exclusionary social norms and practices. This risks creating a homogeneous culture in FSAE teams that might alienate under-represented populations and individual team members who require more work-life balance. However, changes in cultural norms and the work of some team leaders are helping to change these cultural practices. In so doing, such individuals may create a tertiary contradiction where team rules and norms
shift to accommodate a broader range of talent, allowing future members to benefit from their leadership.

- Students reported using multiple instruments/tools in their exploration of their core activity, as noted in Table 6. The challenge teams face is to leverage the most relevant sources of information to arrive at a satisficing decision (March & Simon, 1993) given time and resource constraints. Common information sources were published academic and trade papers, internal team reports and testing data, photo/video libraries, and informal testing and experimentation.

- “Sketchy” projects and informal experimentation can be valuable in encouraging a sense of play, testing out potential ideas, and developing a foundation of tacit knowledge. However, some sketchy parts are underdeveloped simply due to lack of time or attention to detail, and these parts can lead to failure points in competition. Appropriately handled, underdeveloped parts can be serve as launching points for more in-depth research and more sophisticated designs in the future.

- Competition judges play a valuable role as the ultimate arbiter of a team’s design and development work. This creates a potential secondary contradiction between the core activity and division of labour, as there is an unequal power dynamic at play. Established teams tailor their arguments to specific judges and their perceived preferences, and judges are generally supportive in providing more feedback on design if requested. While there are specific points of conflict, teams generally value the expertise and feedback of most design judges.

- Faculty advisors and technical staff also play a valuable role in mediating student exploration of the core activity. As Golding (1999) notes, faculty support can range from highly structured and instructor-led learning to leaving students largely to their own devices. Student and faculty respondents converged on a preferred balanced advisory role where students take responsibility for the direction and execution of their activity, with faculty and staff playing a facilitative expert role.

- Every FSAE team exists within a larger context of an academic institution, creating the potential of secondary contradictions between the team’s core activity and the institution’s norms/rules and community, structured by an unequal division of labour.
Faculty advisors can play a valuable role mediating this relationship, but many teams do not have active faculty advisors, which means many students must negotiate this contradiction themselves.

- Some schools proactively address the requirements of project-based learning teams such as FSAE by creating special-purpose buildings and providing financial, administrative and technical staff support. While this does not necessarily guarantee team success, such support clears some barriers faced by teams whose schools may not be as supportive. Respondents noted that they are happy to repay administrative support by acting as student ambassadors in recruiting and alumni events. Commonly noted points of tension with school administration were around lack of financial support, lack of space, and negotiating the complexity of school bureaucracy, especially with respect to purchasing.

- Another community relationship that is important to sustain is with industry sponsors, who provide teams with financial, technical and material assistance beyond that provided by the host school. Teams engage in a variety of outreach efforts to keep sponsors satisfied and to recruit new sponsors as required.

- As student teams, FSAE teams are subject to very high levels of organizational turnover, with expert students and leaders leaving annually due to graduation. This creates a tertiary contradiction as the roster of subjects rapidly changes over time, creating specific challenges in building and sustaining a knowing organization that will operate over multiple years.

- Teams are responding to this challenge by creating and maintaining digital archives of internal team data, as noted by 13 respondents. These archives are increasingly stored in the cloud and are accessible and updated via mobile devices in multiple locations, including the competition venue. Some teams like Global Formula Racing are recognized by respondents as being particularly sophisticated in their use of information systems in the design and development process. Other respondents noted particular struggles with providing the technical and human resources required to organize a growing repository of internal team data.

- Seventeen respondents addressed organizational turnover by setting up active communication channels with team alumni. Such strategies encourage recent alumni to
remain active in the design process by acting as subject matter experts and providing context and explanation to internal team data.

- Multi-year projects are a particularly complex challenge for FSAE teams as most teams operate on an academic year design cycle, with many students graduating at the end of the year. Respondents noted various strategies to bridge development over years, with some simply rushing work to cram in a given year or returning for another year. Alumni connections and well-structured team data can help teams sustain multi-year complex projects but this remains an underdeveloped domain.

- With respect to recruiting and developing new team members and leaders, some respondents noted a more formal recruiting process whereas others noted a more organic model where membership and leadership positions emerge through work on the project. Respondents also reported using mentorship strategies at varying level of formality to help develop new team members.

- Given FSAE is structured around participation in a competitive event, it is natural to assume teams might be reluctant to share information with other teams during and outside of competition. This would be an expected quaternary contradiction among teams simultaneously aiming to achieve the same outcome.

- Surprisingly, the competitive environment did not adversely affect collaboration and information sharing, even during competition where zero-sum reward structures would suggest privacy and confidentiality would be a beneficial approach. Shared passion for automotive engineering, a prevailing norm of reciprocity, and a feeling of participating in a larger community of practice (Lave & Wegner, 1991) generally transcends the pressures of competition scoring and creates a coopetition-oriented information environment. Respondents shared multiple instances of reciprocity and collaboration with other teams, including investigating “sister team” relationships similar to current competition favorite Global Formula Racing, which is a joint project between two schools.

- FSAE teams may also experience quaternary contradictions with similar project-based learning teams at their home institution, which may be in direct competition for limited financial, space, human and technical resources. While some respondents noted that they
collaborated with other teams relatively well, other respondents shared some frustrations with having to share key resources with teams they saw as endeavors or lesser importance or sophistication.
6. Conclusion

6.1 Summary of Research

Applied science education has been searching for methods to ground instruction in more job-ready skills, both technical and social. Accrediting agencies such as ABET (ABET, 2011) and academic research on program matriculation and graduation (NSF, 1997) have pointed to difficulties in recruiting and retaining a diverse population and then developing expertise relevant to the employment market.

This research suggests looking at the history of medical education, which faced similar challenges fifty years ago. Pioneered at McMaster University in the 1960s (Neufield & Barrows, 1974), problem-based learning in medical education opened up new instructional approaches that have since spread to multiple locations including esteemed medical colleges such as Harvard (Dienstag, 2010). Based in social constructivism (Vygotsky, 1978), experiential learning (Kolb, 1984) and critical information literacy (Slawson & Shaunganessy, 2005), problem-based learning encourages students to collaboratively investigate problems in real-world contexts and derive solutions on their own timing, based on a critical analysis of key academic resources as well as patient stories.

Kormos (1996) offers an extension to this model to the domain of engineering education, noted here as project-based learning or PBL*. Engineering projects tend to be longer in term and often require teams of related talent (Bedard et al, 2012). PBL* efforts that have emerged are usually also governed by external agents who set common ground rules and provide a context for collaboration.

This research focuses on one specific domain of PBL* - Formula SAE (FSAE), a competitive series where teams build a small formula style racecar. FSAE as a competitive series has a long history and wide audience with nearly 500 teams competing in over 10 sanctioned competitions worldwide (FSAE World, 2016). Teams of students, mostly mechanical engineers, collaborate in teams to design, manufacture, test, optimize and eventually race their
car. The team must also manage their internal affairs, recruiting new team members, arranging financial support and sponsorship, smoothing over relations with school administrators, and building an organization that transcends the individual team members and leaders, all of whom will eventually and quickly leave due to graduation. Students do this with limited experience of running an organization of this size and complexity and are learning both the technical and organizational skills on the job.

In doing this, such teams develop a sustained identity and develop into knowledge-based organizations that build tacit, explicit and cultural knowledge over time (Choo, 2006). Knowledge based organizations have structured and objective-centered approaches to information behavior, organizational sensemaking, knowledge creation and decision making and are aware of their own history and requirements for continuity.

In investigating problem-based learning, project-based learning, and knowing organizations, one conceptual theory emerged as a unifying theoretical frame: cultural-historical activity theory (CHAT). CHAT is also based in Vygotsky’s social constructivism and offers a theoretical perspective that extends from the individual to the collective level. It also grounds any given activity in larger social context, posing questions about how community, rules/norms and division of labour can enable or constrain any given action. This allows for many of the considerations of information behavior and knowledge management noted in Choo (2006) to come into play.

Particularly powerful in contemporary CHAT is the investigation of contradictions. As Engestrom (1989) noted, the nodes of the traditional activity theory model exist in dialectical tension on four levels, from primary (internal to node) to secondary (between nodes), tertiary (contradictions over time) to quaternary (conflicts between activities). All this complicates matters a fair deal from the initial Vygotskian model – one subject can use multiple different tools to drive multiple potential outcomes, and do so in a context structured by larger community concerns, other competing interests and the passage of time. Given that, there are multiple possible outcomes of any given activity, some better than others.
This research is structured around the following research questions derived from the above CHAT contradictions, and were developed in part by past participatory research in the domain.

| RQ1: What motivates individuals to join PBL* teams? How do PBL* teams negotiate contradictions between individuals with different motivations? |
| RQ2: How do PBL* team members negotiate core activity contradictions in their work? How do faculty advisors assist team members in negotiating this contradiction? |
| RQ3: How do PBL* teams negotiate contradictions between team activity and intended outcomes and school administration and established norms of practice? |
| RQ4: How do PBL* teams learn from the experiences of past team members? What actions do they actively take to pass on knowledge to future generations? |
| RQ5: What do PBL* teams learn from their competitors? What information do they actively try to keep private? |

**Table 7: Research Questions Revisited**

This research uncovers many of the contradictions of CHAT as experienced in this particular context. Students have to channel individual motivations towards a common collective objective. Given students are managing their peers, there are often deeply personal conflicts that can be difficult to negotiate through appeal to technical factors alone. What is more, this is often the first time leaders have been in charge of an organization of such diversity and complexity. Complicating matters further is when some team members strive for work/life balance and/or come from social backgrounds that depart from traditional racing culture, which historically has been ethnically homogeneous, heteronormative and masculine. It seems from those interviewed that the new generation is more receptive to people from a diverse range of backgrounds holding a variety of skill sets, but such diversity can make the task of creating and guiding a collective objective all the more complicated.

With respect to technical design challenges, teams must negotiate a large and growing body of existing knowledge, from published sources to internal reports to less verifiable but still potentially viable internet forums. In design and development, team members may explore many possible paths through Vygotsky’s core activity, only to find that some paths are more beneficial than others. Moreover, some of the information discovered through research and investigation is
only tangentially linked to the activity at hand, requiring critical thinking and information literacy skills to parse out what is of importance. Teams engage in a number of sensemaking strategies to balance potential sources of information, with specific sources being assessed as being more important and valuable.

Even with considerable information available, teams are sometimes forced by necessity to engage in “sketchy” solutions, which emerge organically through trial and error experimentation, informal testing, or simply are the best available option given limited tools, resources or time. Most teams are aware that having sketchy solutions as a final product is less than ideal, with some noting that their weak links were the cause of team failure at competition. However, they can be the launching point for later investigation leading to results that are more formally defined and defensible.

Scanning of this information environment is partially structured by the formative assistance of faculty advisors and what is known about competition judges, who act as the final arbiter of design quality in the design event at competition. Some faculty advisors are accused of micromanaging design decisions, which strips students of the autonomy and responsibility of making their own decisions. More common, however, are advisors who play a limited administrative role, leaving teams with limited professional guidance to forge an efficient path through the morass of data they discover and create. Advisors who are well appreciated strike a balance between over-engagement and absenteeism, acting as “guides on the side” (King, 1993) empowering students to make their own decisions but being ready to assist when asked.

With respect to competition judges, successful teams try to discern the opinions and world views of key judges and tailor their approach to those interests. This research suggests that there remains at times an adversarial relationship between teams and judges but for the most part teams recognize the fairness of most judges, and that judges are often happy to share their expertise and further feedback even after the design event is completed. Teams who cultivate good relations with judges and learn from that feedback can benefit a great deal.
Teams interviewed have variable relations with their school administrations, from very tight coupling to tangential and often hostile relationships. Teams that have ample budgets, access to technical assistance, specialized tools, substantial lab facilities, and champions at the administrative level have fewer barriers in their way towards building a competitive racecar. Responding teams seemed generally in agreement that they had a mutually beneficial relationship with their administration. In exchange for space, money, and support, schools are keen to use the racecar in promotional messages, to attract attention and money at homecoming/alumni weekends, and to attract new students to the school. There do however remain points of tension, largely with the requirements of university bureaucracy, perceived lack of support compared with varsity sporting teams, and occasionally with problematic behavior targeted by administrators and security personnel. Teams also often have strong relations with their local and professional communities outside of school. This is often essential in establishing and retaining corporate sponsorship, a very common facet of professional and amateur racing.

A common concern for all FSAE teams is organizational renewal over time. Like varsity sporting teams, FSAE teams routinely experience very high levels of organizational turnover due to graduation. What is more, those leaving are often the leaders and most qualified members, potentially walking out the door with a deep and recent organizational memory. Teams wishing to build a consistent record of success must dedicate themselves to a strategy of organizational renewal, thinking ahead to next generations while planning their immediate activities. Unlike varsity sporting teams, this task usually is left to student leaders themselves.

Increasingly, FSAE teams are seeing the value of building knowledge repositories storing past research and design options internally developed. Cheap cloud-based services and the near ubiquity of wireless internet access has enabled teams to have quick access to their body of knowledge at any time and in multiple locations. The current dynasty team Global Formula Racing has taken this to a new level, stitching together two schools from USA and Germany into a common front that shares information and designs, manufactures core parts in both continents, and fields well-refined cars in American and European competitions. They are also very active in documenting progress and problems on site, feeding information into the cloud from the
paddock. Other teams are seeing this as a gold standard and are aspiring to emulate their approach, although technical and human resource limitations are a main challenge.

There are also more tacit means of information exchange over generations noted by respondents. Engaged teams try to keep in touch with alumni, inviting them back in for assistance on design briefs and having recent alumni act as on call consultants for team questions. One team reported an internal system that combines document storage with an online forum that allows all past members to contribute extra information as required.

Teams also noted mentoring as a common method of passing on information through generations and training new team members. Some teams have formal training and mentorship arrangements – others noted simply that this was a priority of the culture.

One potentially surprising finding of this research is that while the core activity is a competition, the culture itself is quite collaborative. Even the competition itself has multiple examples of teams helping each other by lending tools, giving parts away, even lending surplus labor to teams struggling to enter the race. New teams are especially well treated, as they pose no immediate threat to established teams and usually have problems that are simple to resolve. This extends beyond competition – teams feel more or less comfortable sharing information, asking questions of each other, meeting up at informal racing events, and even creating “sister school” relationships similar to the aforementioned GFR. The bond of the shared activity seems to trump what could easily be a hostile and confrontational relationship.

That noted, there is an etiquette to this process, which seems governed by norms of reciprocity. Teams that seem more interested in stealing or spying versus inquiring and learning can find their efforts shut down, people who interfere with a team at competition when they are busy are shunned, and teams that receive help but are then hostile towards giving are not appreciated. Teams that are willing to engage in mutually beneficial exchange of information usually are rewarded, as most teams see this help as paying it forward, helping weaker teams or building good karma in the event they later may need help.
6.2 Theoretical Contributions and Transferability

The main theoretical contribution of this research is to apply cultural-historical activity theory (CHAT) as an integrative theoretical framework for the investigation of engineering project-based learning team contexts. While there is some research expanding problem-based learning into engineering domains (e.g., Dym et al, 1995, Kormos, 1996; Bédard et al., 2012), a scan of research presented at recent annual conferences of the American Society for Engineering Education and the CDIO Initiative found that PBL-related papers tend to be individual case studies of capstone design projects worked on by ad-hoc teams who cease to exist on project completion. A scan of literature in the Interdisciplinary Journal for Research in Problem-Based Learning noted little attention to an overarching theoretical foundation to PBL research beyond constructivist learning and experiential education, nor much attention to PBL* teams aiming to develop into sustained knowledge-based organizations. While this research is certainly important in showcasing how PBL/PBL* can be a formative learning experience that helps build problem solving and communication skills, individual stories about ad-hoc teams makes it difficult to transfer lessons learned beyond specific cases, or see how such lessons can inform teams with a longer-term sustained orientation to knowledge building. CHAT may well serve a role in providing such an integrative theoretical platform to address PBL* teams and the work they do to develop into sustained knowing organizations.

This research shows how CHAT can be used as an integrative theoretical framework to help enhance PBL* research. CHAT is based in the familiar foundations of social constructivism and experiential learning, investigates individual and collective levels of human activity, and can be applied broadly to many information challenges. Expanding from Vygotsky’s (1978) core activity, CHAT as a theoretical frame is grounded in larger social, political and economic forces that dialectically influence the activity of subjects as they work to attain their intended outcomes (Engestrom, 1987). Particularly powerful in CHAT is the identification of specific points of contradiction within and among activity models. These contradictions can apply across individual activity domains and allow for transferability of experience. As done in this research, CHAT contradictions can be used both to identify and
operationalize research questions in a given domain and be used as a framework to interpret resulting data.

This work also leverages growing interest in CHAT-based research in information studies (Allen et al., 2011; Wilson, 2009) by extending its application to a new domain of analysis in PBL* teams, which are seen here to be acting as emerging knowing organizations (Choo, 2006). Contradictions in the CHAT framework showcase specific points where teams face organizational sense making, knowledge creation and decision making challenges. CHAT in turn relays those contradictions back to experiential learning and social constructivism.

While this research uses CHAT in a relatively standard manner, it does suggest how this model may be extended. For example, the “core activity” of subjects using particular instruments/tools to derive particular objects does imply a certain unidirectional nature of this process. However, as SECI (Nonaka & Takeuchi, 1995) and Choo’s knowing organization model (Choo, 2006) suggest, the knowledge creation cycle is not linear but cyclical in nature. CHAT implicitly assumes a cyclical nature through its foundations in dialectical philosophy – however, standard implementations of CHAT and especially its reduced form in Engestrom’s triangular model can be fairly critiqued as representing activity in a much more linear fashion than should be assumed. An excessively unidirectional use of CHAT could lead to cyclical phenomena such as internalization and double-loop learning (Argyris & Schon, 1992) remaining underexplored. CHAT could be expanded to envelop cyclical change over a longer time period, which may require some reinterpretation of the reductionist triangular model. This would require more longitudinal research in specific team development processes, as will be described in the following section.

CHAT helps bridge knowing organization and PBL* research domains and provides a foundation for further research for similar PBL* teams. The immediate practical contribution of this research would be to inform FSAE team members, leaders and faculty advisors, who can most readily identify with the contradictions noted here. This research highlights best practices towards contradictions that may inform team management.
However, FSAE is just a small section of the engineering PBL* universe. As noted earlier in Chapter 5, there are similar PBL* engineering student teams in other subdomains of engineering. It is hoped that this work would inspire similar CHAT-based research in related PBL* contexts to investigate how this theoretical frame can inform and link together research across multiple domains. Primary contradictions regarding managing conflicting individual motivations, secondary contradictions within the core activity and between the core activity and the priorities of administrative and legal concerns, tertiary contradictions regarding organizational turnover over time and quaternary contradictions regarding interteam collaboration are arguably shared among similar PBL* domains and may be applicable and relevant to similar competitive team contexts.

This work may also help convince institutions to better support PBL* learning opportunities to provide the financial, space and administrative support for upcoming teams. As this research shows, a strong and stable relationship with school administration helps address many of the baseline challenges a PBL* team may face. As noted by CDIO Standards 6-10 (CDIO, 2011), significant institutional support is needed in order to develop required engineering facilities, as well as fostering and ideal faculty approach to such teams as noted by Golding (1999). While financial, faculty, and administrative support does not necessarily guarantee FSAE team success, such support can go a long way to help such teams handle their core activity in concert with their home institution as opposed to seeing their activity operate in opposition to larger forces.

Given universities are increasingly looking at supporting experiential learning (e.g., Council of Ontario Universities, 2014), I hope this research may persuade administrators to consider the value of enabling their intrinsically motivated students and provide them baseline financial, space, human and curriculum support as well as identify and reward effective faculty advisement of such projects. Some schools are actively building this level of support – for example, after visiting with technical staff at University of Calgary at the 2017 CDIO conference, I was enthused by their substantial renovation plans that will lead to facilities that directly support their PBL* teams, including their Formula team. However, it should be noted that dedicated spaces such as Penn State’s Learning Factory (Lamancusa & Simpson, 2004) remain
the exception not the rule, largely because of the substantial financial and space requirements such efforts require.

This research may also prove valuable in similar non-applied science PBL* contexts. This CHAT-based model of analysis should find itself relatively easy to transfer to similar competitive events such as the Ontario Colleges’ Marketing Competition (http://ocmc.ca/) or Level Up’s game design competition (https://levelupshowcase.com/contest/). Similarly, this research may extend to analysis of other student-organized special events such as the Young Entrepreneurs’ Challenge (http://demsociety.com/yec16/). These efforts require the same kind of devotion, leadership and energy required by FSAE teams, and student leaders of these efforts may experience similar contradictions and challenges such as creating a knowing organization that is sustainable over years of high organizational turnover due to graduation.

Some elements of this research might also inform non-student led teams that share common challenges. As noted in section 5.5, common allegiance to a given activity may create a community of practice (Lave and Wegner, 1991) that transcends competitive impulses and allows for knowledge building based on norms of reciprocity and coоперетиор. CHAT can help identify other activities that might transcend competitive boundaries and help provide structure and support for coоперетиор in professional communities of practice.

Many knowledge based work teams operating in complex problem contexts would have to contend with contradictions within their core activity, as noted in Section 5.2. Selecting the appropriate tacit and explicit knowledge sources in an era of internet search, information overload and ambiguity is a challenge for a variety of work teams. More professional work teams likely would have more developed heuristics to filter valuable signal from online noise, but the general concept of teams having to interpret and balance contradictions in the core activity could feasibly apply to other work teams contending with complex problem domains.

The potential role of “sketchy” solutions and trial and error experimentation as a precursor to final results would also be an interesting extension of this research to other work teams. Work teams likely share similar concerns about presenting final work as complete,
coherent and logical when in practice a lot of learning likely happens through divergent thinking, ineffective and incomplete efforts, and failure. Such dead ends are arguably more interesting and indicative of organizational knowledge building processes than the final product, yet more messy, risky or dangerous attempts at problem solving may be suppressed in an effort to save face or avoid sanction. As with FSAE teams, some sketchy activities might be rightly curtailed by those in power for legal or safety reasons – but spontaneous, experimental or half-hearted experiments might be good learning opportunities which are often dropped or hidden from the official record.

This research may also prove extensible to other high turnover organizational contexts such as retail or hospitality, where it is also common for any given team to experience high and regular rates of attrition. One qualifying factor there would be that much attrition in those industries can be for less positive reasons, with qualified people who may leave to competitors for better pay or hours, and others let go due to poor performance or layoffs. Such individuals would likely not be as bonded to the organization and less likely to voluntarily assist with the organization’s continued knowledge building.

Another possible point of extension and transferability would be to startup businesses which share a common foundation of a team of individuals striving towards a particular activity but who are operating under less than ideal conditions in terms of resources. As noted in Chapter 5.4.1, FSAE teams are leveraging a number of free or cheap cloud-based tools and technologies to engage project and information management concerns, at varying levels of efficacy. This is arguably similar to the challenges small startup companies face, searching for satisficing solutions on limited budgets. Further research on the dynamics of cheap/free information management tools as a replacement for a more expensive IT infrastructure will be discussed later in Section 6.4.

6.3 Limitations of Research

While the research design used in this study did serve the intended purpose of surveying FSAE team approaches as framed by specific CHAT contradictions, as always the case, this design necessarily did so through excluding alternative means of investigation.
As noted earlier in Chapter 4, previous participant observation was leveraged to serve as foundational knowledge of the overall problem domain of Formula SAE, but specific observations from that time were not included in this research. In-depth analysis of one specific team’s experience with contradictions would have provided more detailed expositions of contradiction negotiation at the time those contradictions were being experienced. Interviews and surveys necessarily capture respondents at one particular point in time, making observations post-facto reflections on a process that might not be fully or correctly recalled. As noted earlier in Chapter 4, the competition environment in particular may encourage students to cast the design and development process in a clean and polished manner, neglecting key details or burying embarrassing events that are inconsistent with the polished narrative.

Relying on single respondents also opens this research up to challenges that these individual accounts might not be fully reflective of the team’s experience. This particular concern is mitigated by the fact teams self-selected respondents best suited to answer these questions, including inviting others to participate in interviews when they felt unable to engage in good faith. However, it remains entirely possible that any given response here may have been a partial account that would have been qualified in a more in-depth study of a specific team and its dynamics.

All this noted, this population was generally open to sharing stories of “sketchy” projects and momentary failures, especially with those such as myself who were past members of the community of practice and thus already familiar with the messier details of the design and development lifecycle. However, a participant observer embedded in any given team would have first-hand knowledge of these moments and their eventual resolution, allowing for a more honest and transparent exposition of the conception and design process. As noted in section 4.2.1, a number of professional concerns made personal participant observation in this context difficult, but an expanded version of this research could benefit from the input of an embedded reporter of one specific team’s progress and struggles through contradiction.
As single points of intervention, surveys and interviews also make tracking longitudinal data difficult, as respondents can only reflect on past events or project potential future developments as they experience them at that one time. This can make tracking some research questions involving learning and development difficult – as noted earlier, RQs 4 and 5 are best understood as one-off reflections on organizational renewal and interorganizational knowledge sharing processes versus tracking organizational learning from genesis to result. Again, participant observation in a specific team environment over a multi-year cycle might help uncover such information. It should also be noted in response to this critique that given the cyclical nature of the SECI cycle (Nonaka & Takeuchi, 1995), there is no one appropriate time to begin or end such longitudinal research – any arbitrary start or end date will necessarily preclude relevant information that preceded or further information to be uncovered.

### 6.4 Future Research Directions

While this research does cover a lot of ground, there are a number of research directions and questions that remain to be investigated. For primarily financial reasons, the scope of this research was limited to North American teams running the two internal combustion competition events in North America. This does have the effect of excluding the emerging electric-drive competition (e.g., McGill’s Formula team announced post-defense their intention to drop the combustion car and complete only in electric events), emergent FSAE communities in India and China who are starting up their own cultures and competitions based on SAE rules, and the European Formula Student events, which are very well attended and are generating world-caliber teams, including many recent winners in Michigan.

Given German and Austrian teams have shown themselves to be dominant competitors in Michigan, a look into what makes their approach to this competition different would be interesting. As noted earlier, part of this success may be traced to resources diverted to academic collegiate teams and not towards sporting teams, luxury residence halls or student social centers. With less competition for school resources, collegiate teams in Europe may have more of the school and community’s attention and support.
Another fundamental difference was suggested by a machining instructor at George Brown College, where University of Toronto’s team makes a fair number of their parts and whom I talked to in exploratory research for this dissertation. In the German system of engineering education, engineers must first complete vocational training – in mechanical engineering, mostly machining and tool/die fabrication – before starting the more abstract practice of engineering design. The instructor’s belief was that the extra two years of education not only makes for more mature student engineers, but also increases the odds that engineering designs consider the constraints of the manufacturing process. I believe both universal technical training and two further years of life experience would indeed give students in the German model of education a significant advantage over North American competitors.

An interesting future research project would be to further explore the role of mobile computing, knowledge management and cloud storage options in transforming the design, manufacturing and competitive environment of these teams. The near ubiquity of smartphones and tablets that can be accessed easily in context through wireless data plans has the potential of embedding digital information retrieval and creation at all phases of the design lifecycle. As previously noted, the joint Oregon State/Ravensburg Global Formula Racing team has been recognized by its peers for its use of cloud computing to build an information store to facilitate its joint team effort, and other teams are investigating how these technologies might be integrated into their workflow. There are many low-cost software as a service options teams may consider to integrate information in a manner accessible on a student’s existing mobile device. How teams are choosing to integrate these technologies – or not – in their workflow would be an interesting future expansion of this research.

A main outstanding question from this research is how team participation influences the professional development of alumni as they enter and develop in their careers. Given the focus of this research was primarily on current team members, answering this question would have required expanding the research population substantially to include the diverse range of career paths alumni find themselves on years after graduation. I had initially proposed a case study with SpaceX, a company that deliberately does recruit those who have excelled in project teams for internship and first career jobs. This is partially due to there being a strong match between
the workflow of the FSAE environment and that of a startup aerospace firm with lofty ambitions. Indeed, FSAE experience is likely a strong complement to any startup organization driven by innovative thinking and exploration of new ideas.

Less evident is how FSAE fits with other professional domains, including the big North American automotive manufacturers and original equipment manufacturers that feed the supply chain. While these companies sponsor and actively recruit at competition, some of these large industrial concerns are highly bureaucratic organizations where new hires are slotted to do a very small piece of a much larger puzzle, and a lot of the work is iterative improvements on existing technology rather than anything particularly innovative. Alumni team member #42 talked briefly of his job and seemed rather disappointed with being a cog in a much larger machine.

“I started work at [X, a OEM in the Detroit area], two years ago after being recruited from competition. I do miss the FSAE experience a lot though – at X, my team does a lot of cost rationalization and weight reduction work on existing parts, and the opportunities to create new more efficient systems so far have been pretty limited. You do feel a bit isolated from the whole when you’re looking into making X part 1% lighter or cheaper and not even really aware where X part ends up going. There’s a lot of meetings and procedure too, and hardly any opportunity to work with your hands. A lot of graduates end up going into the big companies and I suspect end up a bit cynical about the realities of big industrial engineering. I had a lot more impact on the overall design process on car team.” [#42]

It is indeed arguable FSAE trains students for a lifestyle and a workflow that is not particularly compatible with large bureaucratic enterprises, which is why the draw of a smaller organization like SpaceX or a special purpose research segment of a larger organization might be a better fit for some of the more innovative and dynamic students.

Another complication on judging how FSAE impacts professional outcome is that often engineers only practice technically for a few years after graduation, eventually moving up to management or switching career paths later in life. In exploratory research on this question, I looked at LinkedIn profiles from the Cornell team and found a number of former colleagues who had ended up in completely unrelated industries, often after taking unrelated professional graduate studies programs. Preliminary discussions as to how these paths have diverged have
been started, and there is a range of answers, from restructuring of the major automotive players to early burnout within the industry as experienced by respondent #42, to unfortunately seeing the opportunity to make better money in other disciplines such as finance. This preliminary research convinced me that looking at the professional outcomes of FSAE alumni 10 years down the road would require a pretty substantial sampling to uncover the multitude of possible career paths within and outside of engineering that alumni have taken. This would be useful but likely require a significantly larger sample of a much larger population than the one currently targeted in this research study.

6.5 Conclusion

The purpose of this research was to explore how cultural-historical activity theory (CHAT) could be used to better situate research into PBL* engineering student project teams as they developed into sustained knowledge-based organizations. CHAT as a theoretical framework is based on the constructivist learning theories of Vygotsky (1979) and situates individual and collective activity in a larger understanding of rules and norms, community influences and division of labor (Engestrom, 1987). CHAT poses specific moments of potential contradiction that can shape a team’s progress towards their intended collective outcome. As CHAT proposes no universally correct resolution to contradictions, different subjects will approach these contradictions in different ways leading to different outcomes.

This research looks specifically at Formula SAE teams, an automotive racing collegiate design project sponsored by the Society for Automotive Engineers. This research solicits input from 42 respondents on their experience of a variety of primary, secondary, tertiary and quaternary contradictions. Results show a diverse range of responses to CHAT contradictions, including the need to channel a variety of individual motivations, managing and balancing information from multiple information seeking pathways as the team engage the core activity, balancing scientific inquiry with trial and error experimentation, negotiating relationships with larger administrative powers, managing knowledge transfer in a context of very high organizational turnover, and negotiating when it is best to cooperate with vs. compete against teams striving towards the same outcome. In highlighting these contradictions, it is hoped that
FSAE and similar student engineering project teams can learn from best practices and common pitfalls as they develop as knowing organizations, and through CHAT can identify potential points of contradiction proactively so that these contradictions can not only be handled, but celebrated as occasions for new organizational learning by the team and its individual members.
Appendix A: Questions for Survey and Interview Discussions

• Being on an FSAE team requires a lot of work above and beyond the traditional school schedule. What motivated you to make such a commitment to your team?

• In a team environment, people will have a variety of different motivations to join the team and what they hope to get out of the experience. Can you think of any time where differences in motivation or commitment to the team caused conflict?

• Given limited financial, time, human and/or technical resources, FSAE teams often have to make do with piecemeal or sketchy solutions vs. what would be ideal for the job. What solutions have you team come up with due to resource issues? Did they work? Did they inspire a more formal solution?

• There are many sources of information one can consult in designing a given part/system on the car. Thinking of a specific part you’ve recently designed, what sources of information did you consult? How did you handle situations where available information was found conflicting, wanting or wrong?

• While every team has to have a faculty advisor according to competition rules, the level of engagement ranges widely, from largely absent to arguably overly engaged. How would you describe your team's faculty advisor engagement in the design and direction of your car?

• FSAE teams enjoy varying levels of support from school administration. Some schools give course credit for participation. Some schools provide a good deal of financing for their FSAE. Some provide an FSAE team with the required space and technology to realize their objectives. What kind of curricular, financial and infrastructure support does your team receive from the school?

• As university projects, teams have to conform to the legal, administrative and regulatory frameworks of the college. This sometimes causes tension between a team and administration goals and objectives. How would your characterize your relationship with school administration?

• University administrations are treating issues of student hazing, harassment and discrimination very seriously in an effort to create a more inclusive educational environment. This arguably runs counter to traditional racing culture, but it is arguable that racing culture itself is becoming more accepting of a diverse group of participants. Does your team actively promote an inclusive environment?
• Especially after a long evening/early morning of project teamwork, engineers can come up with some rather silly side projects. What is something your team has done when stir crazy around a bunch of toys at 3am?

• FSAE teams experience very high turnover, with experienced members and team leaders leaving annually due to graduation. How and when does your team recruit and train new members? Does your team actively encourage alumni to continue advisement or participation in team activities?

• An FSAE car is an interconnected mix of functional subsystems. Complicated changes to a system can take months or even years to design. How has your team balanced the short-term goal of getting this year’s car on the ground vs. more long-term projects that may (or may not!) yield considerable gains in performance in the future?

• Both FSAE.com and competition are pretty cooperative spaces, with teams often helping each other out with advice and assistance. How has your team helped another team out? What information might you not consider sharing with others?

• FSAE teams are often one of a range of engineering project teams run by a school. How does your team cooperate with other project teams at your school? What conflicts arise?
Appendix B: Questions for Faculty Advisors and Competition Judges

Faculty Advisors

- A team leader comes to you with a technical proposal you believe is significantly flawed. How do you react to this? At what point, if any, do you intervene?
- Faculty advisors serve as the bridge between the team and school administration. How would you characterize your school’s support for your FSAE team?
- Have you ever had to intervene with team activity to ensure team practice conformed with school policy and regulation? How? What was the outcome?
- How does your team prepare for the eventual graduation of team members/leaders? Does the team have a plan for recruitment and succession/promotion of team members?
- Does your team have a plan to document what it has learned? How?
- Does your team maintain active contact with previous team members? How?
- Where have your FSAE alumni ended up professionally? Have those placements returned value to your team in advice/support?
- What skills do you believe FSAE develops that may be valuable to potential employers?
- What is your policy/perspective on FSAE teams sharing information amongst each other?
- Does your school support other engineering teams? Which ones? Do they share resources/space? If so, how does your team cooperate with other teams on campus?

Competition Judges

- What information sources and research strategies do your find particularly impressive or effective in your event? What information sources would you recommend teams avoid?
- When you first see an FSAE team in your event, what impresses you the most? What disappoints you the most?
- What one thing would you recommend teams prepare to do for your event? One thing they should avoid?
- Have you ever recruited an FSAE team member for your business? What attributes does your corporation/business value in FSAE team alumni?
Appendix C: Informed Consent Form for Interviews and Surveys

Consent Form

Information Contradictions in Project-Based Learning (PBL*) Student Engineering Teams: A Cultural-Historical Activity Theory Approach

Principal Investigator

Michael Jones, Doctoral Candidate
Faculty of Information, University of Toronto
140 St. George St.
Toronto, ON M5S3G6

Phone: 416-697-8701 Email: mlw.jones@mail.utoronto.ca

Study Purpose:

Traditional models of engineering education have come under critique from academic leaders and accrediting boards concerned that the traditional lecture-based mode of information transmission may neglect active learning, integrative design thinking and development of non-technical skills such as time management, team leadership and effective communication (ABET, 2011; National Science Foundation, 1988).

Facing similar challenges 50 years ago, medical education began moving to a problem-based learning model of education featuring student-led investigation of applied problems, aided by faculty who play a facilitative advisory role (Savery, 2006). Meta-analysis of medical education research suggests PBL increases student motivation and develops key professional skills for medical practitioners (Albanese, 2000; Schmidt, Vermeulen, & van der Molen, 2006) while not jeopardizing mastery of core skills.

This research project investigates similar emergent approaches in applied science education. Many applied science problems - from designing a motor vehicle to creating a new mobile application – are project-based. Project-based learning (PBL*) is structured around broad, integrated design goals and require significant sustained effort by a larger group of participants (Bédard, Lison, Dalle, Côté, & Boutin, 2012; Kolmos, 1996). To support PBL*, professional engineering associations have sponsored student design competitions where teams of motivated students engage a given activity, structured by specific rules and deadlines set forth by the governing body. Over years, these student teams develop into knowledge-based organizations (Choo, 2006) that face similar information and knowledge management questions to those faced in industry.
This study chooses cultural-historical activity theory (CHAT) as a theoretical frame to understand how PBL* teams negotiate these information challenges. CHAT is founded in human agency towards the resolution of a given action, but situates that agency in social, informational, cultural and historical forces that often are in contradiction (Engestrom, 1987). CHAT provides a multifaceted and complex lens to examine these contradictions.

**Study Methodology**

This study looks at one specific PBL* domain – Formula SAE (FSAE) – and aims to investigate how students engage and resolve common information contradictions and how competition rules, administrative requirements, and the guidance of more senior professionals help guide that investigation. A secondary interest is to investigate how FSAE participation shaped the approach of team alumni as they enter the professional world.

Research domains include:

a) engagement with participants of the public open forum FSAE.com to solicit input from a global student community in an asynchronous manner
b) semi-structured interviews with faculty advisors and competition judges to investigate how senior professionals influence and guide student decisions
c) visits to the major North American FSAE competitions in Michigan and Nebraska
d) a visit to a major industry sponsor and employer of FSAE alumni to discern how the FSAE experience has influenced later professional development

This consent form applies to those solicited to participate in domains b) and d). Your participation will help contribute to a dialogue of best practices in the FSAE domain and a better understanding of the information contradictions FSAE teams face in achieving their end goal of building a competition-ready racecar.

**Privacy, Confidentiality and Right to Withdraw Consent**

If you agree to participate in this study, the PI will contact you to schedule an interview time and send a list of questions to help prepare for the interview. If you require any clarification about questions or the interview generally, feel free to contact the PI before the interview date.

All interviews will be conducted by the PI and are expected to last approximately one hour. Interviews will take place by phone or voice over Internet services such as Skype.

**At the time of the interview, the PI will ask your permission to audio-record the interview. Recording the interview will help ensure your answers are faithfully and completely recorded. You may choose at any time to suspend or resume audio recording, at which point the PI will take notes on the conversation instead.**

All notes contributed to the research record will be kept privately and securely on the PI’s computer and will be accessible only to those formally associated to this research project.
Following the interview, notes and recordings will be transcribed and a summary will be returned to you for your review. At this point, you may revise, add, or clarify the summary, you will be asked to reconfirm your consent to participate, and if you choose to provide contact information so the PI can send you research updates/publication information.

You may choose to withdraw consent for some or all of your observations at this time. You may also choose whether to have information attributed to you in the research record in an anonymous non-identifiable form.

Your identity will be kept in strict confidence unless you explicitly consent to the disclosure of your personal and professional identity. The transcript and summary notes of your interview will be kept in a secure data store, with identifying information stored separately.

**On the rights of research subjects:**

The Office of Research Ethics at the University of Toronto requires all investigators to submit an official ethical review before commencing research. If you have any questions or concerns about your rights as a participant or the actions of the PI, please contact the Office of Research Ethics at ethics.review@utoronto.ca.

**Consent:**

Your participation in this study is entirely voluntary and you may refuse or retract consent to participate at any time without jeopardy.

Your signature below indicates that you consent to participate in this study and that you have received a copy of this consent form for your own records.

<table>
<thead>
<tr>
<th>Participant Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Principal Investigator Signature</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix D: Screenshot of Trello Card Deck
References


Albanese, M. (2000). Problem-based learning: why curricula are likely to show little effect on knowledge and clinical skills. Medical education, 34, 729.


Engestrom, R. Miettenien, & R.-L. Punamaki (Eds.), *Perspectives on Activity Theory*. Cambridge: Cambridge University Press.


Maudsley, G. (1999). Do We All Mean the Same Thing by “Problem-based Learning?” A


Interdisciplinary Journal of Problem-Based Learning, 1(1), 9–20.


