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Living With Contradiction: Cultural Historical Activity Theory as a Theoretical Frame to Study Student Engineering Project Teams

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Living With Contradiction: Cultural Historical Activity Theory (CHAT) as a Theoretical Frame to Study Student Engineering Project Teams

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Problem-based learning supports collaborative constructivist learning by encouraging students to engage in independent investigation of specific problems[30]. Engineering tends to engage in project-based learning opportunities such as capstone projects or competitive intercollegiate project teams, characterized by longer engagement with more complex projects [5]. Such extended complex projects provide students with multiple contextually grounded challenges to overcome to meet the group's objectives.

This paper suggests that cultural-historical activity theory (CHAT) is an appropriate theoretical frame to unpack and begin to understand the challenges engineering problem-based learning (PBL) student groups face. Like traditional PBL, CHAT builds from Vygotsky's social constructivism [32] and situates human activity in sociocultural context [14]. Contemporary CHAT highlights multiple potential points of contradiction that may shape a given activity[12]. These contradictions are often social, organizational and political in nature and resist simple analysis or resolution.

This paper discusses CHAT analysis through a particular engineering PBL context: the management of Formula SAE (FSAE) student engineering teams. The core activity of a FSAE team is to design, manufacture and race a small racecar in intercollegiate competition. In pursing this activity, FSAE teams must learn to negotiate a range of technical, interpersonal and organizational contradictions, many of which do not have simple or correct answers. This paper suggests that CHAT as a theoretical frame highlights these points of contradiction, allowing teams to share experiences, determine best practices, and mitigate the frustrations some engineers might face in accepting such messy, contextually-based and inherently political obstacles to their intended activity.

An overview of project-based learning in engineering education

Problem-based learning pedagogy has a long history in medical education, where PBL has increasingly been integrated into core curriculum, even in more conservative educational institutions [2, 10]. Medical PBL encourages collaborative investigation of medical cases, where students take the lead on case research and resolution and faculty play an expert advisor role. Meta-analysis of PBL effectiveness studies suggests the move to PBL has shown weak but positive effects on test results [2, 27] but strong positive effects on development of professional skills such as critical thinking, problem-solving, teamwork, interpersonal communication, and project management skills [15].

Given such "soft" skills are increasingly in demand by employers and accrediting agencies such as ABET[1], engineering schools have similarly warmed to an adapted form for PBL for engineering education. Kolmos describes PBL in engineering as involving five key differentiating factors:

Traditional Education	Project-Based Learning
1. Given a professional problem	1. Identify a professional project based on inclination, interest, experience or curiosity
2. Accept the problem momentarily	2. Accept it seriously as one's own project to be analyzed and solved.
3. Work towards a final examination	3. Work realistically towards resolution of the project.
4. Assume established professional knowledge structuring practices as given	4. Professional structuring is connected with personal inclination, interest and curiosity. Reflection loop creates integrative knowledge.
5. Finish with final examination.	5. Finish with ideas of how knowledge may be implemented in practice.

Table 1: Traditional vs. Project-Based Learning in Engineering Education [21]

PBL in engineering education tends to gravitate to creative projects engaged by larger teams with longer and more complex lifecycles[5]. Engineering education has begun developing student-centered learning projects, particularly "capstone" projects done at the conclusion of a student's degree program[11]. Project based learning opportunities have emerged in a number of applied science fields, including computer programming [17] environmental science [26], systems engineering[8], and mechatronics [9].

A common factor in engineering PBL teams is the presence of external requirements (e.g., external client requirements, student design contest regulations, etc.) External rules and regulations help structure the student team's activity, creating deadlines and requirements under which engineering PBL teams must operate. Another external force worthy of consideration is academic administration, which imposes its own necessary constraints. Some engineering schools have been particularly active in encouraging PBL efforts, actively supporting teams with the space and financial resources essential for such efforts [22]. However, with resources come responsibility - financial and space allocations provided by universities to engineering PBL teams comes with strings attached, such as adherence to university standards of behavior and attention to administrative priorities such as budgeting, recruitment, marketing and branding.

The larger project scope and administrative integration of engineering PBL suggests understanding engineering PBL may benefit from a similarly robust theoretical frame that accommodates such complexity. Cultural historical activity theory (CHAT) is a strong contender for such a theoretical frame, and will be discussed in detail in the following section.

Cultural Historical Activity Theory (CHAT) as an Integrative Theoretical Approach For The Study of Engineering PBL Teams

Engineering PBL teams provide a context for motivated students to expand their education through engagement with complex applied projects. An appropriate theoretical frame to analyze such teams should be one that incorporates individual and collective agency while considering the many social, cultural and organizational challenges that might influence the group's work. Cultural-historical activity theory (CHAT, sometimes referred to as activity theory) has shown significant promise in accomplishing this goal in similar domains such as organizational learning [12, 14], human-computer interaction [25, 28], computer-supported collaborative work [18, 31], and information systems development [6, 24].

CHAT traces its roots to Vygotsky's work in social constructivism. For Vygotsky, building knowledge is an active process of engagement with the world, done by a motivated individual using various instruments to interpret their environment, towards the end of realizing a given result [32]. This relationship between a motivated individual and his/her objective is still seen as the core activity model in CHAT [3]. The core activity process is iterative in nature, cycling between externalization of knowledge through the creation of knowledge objects and the internalization of new knowledge from interaction with the knowledge objects of others. This process of experiential engagement, reflection and conceptualization is similar in kind to experiential learning models advanced by Kolb[20]

Vygotsky's core activity model was further developed by his contemporary Leont'ev [13, 23]. Leont'ev grounded Vygotsky's individual model of social constructivism more squarely in material and sociocultural conditions such as community, established rules, and power relations. This was arguably done to lessen ideological tensions resulting from Vygotsky's theory, which in privileging individual idealism over sociocultural forces shaping human activity ran counter to the Soviet orthodoxy of the time. This was not successful - both men were marginalized under Stalin leading to a dormant period of development of CHAT [29].

The resurgence of CHAT is largely traced to Yrjö Engestrom, who interpreted Leont'ev's and Vygotsky's early work on human activity and worked to raise its profile in contemporary Western scholarship[14]. Contemporary development of CHAT was aided by a diagram that has become iconic in contemporary CHAT-based theoretical models. This diagram, included below, will be dissected and discussed further in the following section.

The Core Components of CHAT

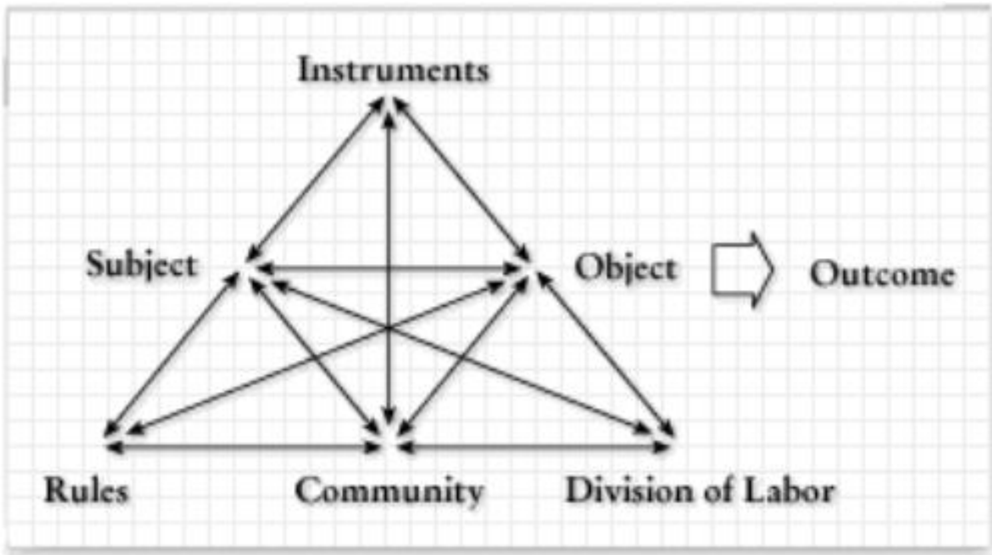

Figure 1: Engestrom's representation of cultural-historical activity theory[12, 14]

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." [12]. It highlights six core factors in CHAT – subjects, instruments, objects, rules, community and division of labor – that influence the outcome of a given activity. Represented in this form, the CHAT activity triangle has enabled researchers to frame an otherwise dense theoretical discussion in an accessible manner, facilitating a clear way to communicate findings across a variety of domains [3].

Starting from the top-most triangle in Figure 2, we see Vygotsky's core activity model - a relationship between subjects and their intended objective, mediated by tools (also referred to elsewhere as technology, instruments or artefacts[1]) that bridge that understanding, creating external knowledge objects for subsequent internalization by others. The subject can be either an individual or collective, depending on the level of analysis of the activity.

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[1] (Semantic variations in the naming of CHAT elements (especially tools/technology/artefacts), are largely a function of inconsistencies resulting from translation from original Russian texts [4, 19].

The base of the activity triangle represent the components Leont'ev added to ground activity in social, historical and material conditions. *Community* includes all relevant others that may influence or be affected by the subject's desired outcome. *Rules* (also referred to as praxis or norms in some CHAT models) can include both written rules and unwritten norms that govern interaction. These are necessary to mediate social order and help regulate larger questions of justice, ethics, and morality. *Division of labor* acknowledges that subjects require the assistance of others to realize their goals and that power relations among subjects are often unequal.

Identifying and Negotiating Contradictions

While CHAT can be helpful in describing the component forces influencing human activity, it may be most useful in highlighting situations where these forces act in contradiction to each other [24]. The concept of contradiction in CHAT highlights points of tension, potentially creating transformative changes in activity patterns[12]. Engestrom highlighted four levels of contradictions present in activity systems:

Contradiction	**Description**
Primary	Conflict within a given node in an activity system (e.g., competing interpretations of goals by individual subjects)
Secondary	Conflict between two or more given nodes in an activity system (e.g., conflict between subjects, tools and object)
Tertiary	Changes in activity over time (e.g., evolution of an activity such that later versions conflict with previous versions)
Quarternary	Conflicts between two competing activities (e.g., one group's objective directly conflicting with another intentions)

Table 2: Engestrom's outline of contradictions, adapted from [12]

As such ideas become clearer with some context, consider the following activity diagram from Kane's CHAT analysis of a social software design project [19].

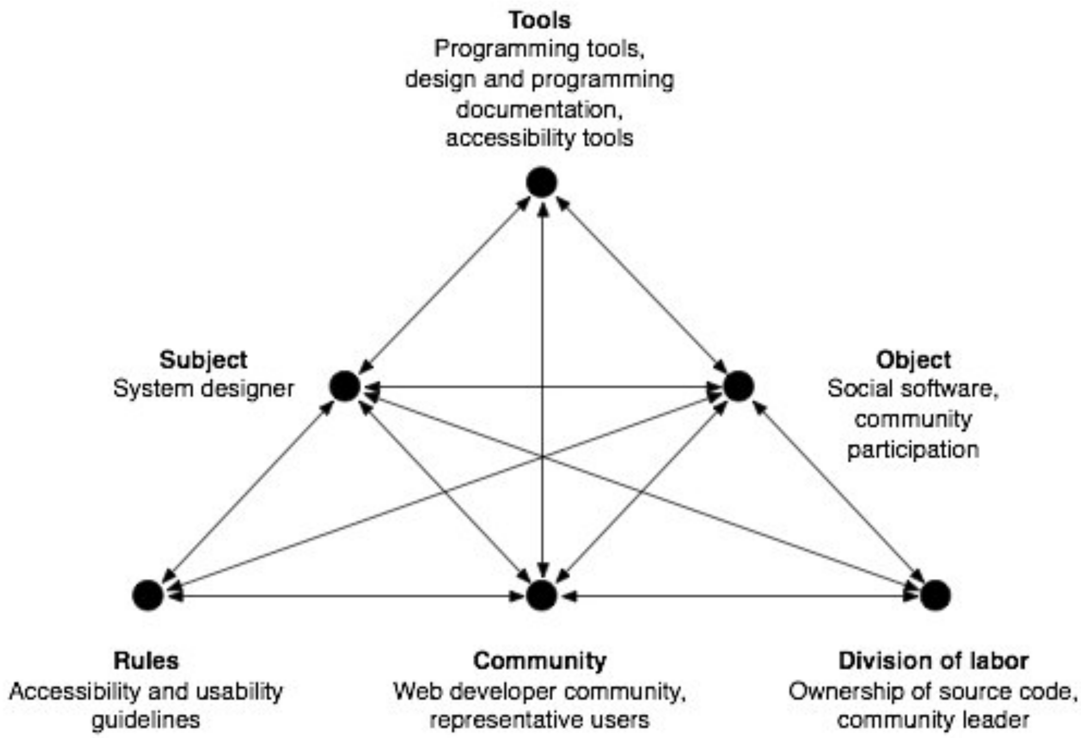

Figure 2: Social software design from the perspective of a system designer, as represented by [19]

In this activity, the system designer uses programming tools and assorted documentation to enable the creation of social software that encourages 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.

There are many other possible contradictions within the diagram above, however. For example, the system designer's point of view of the system may conflict with that of the end-user (a quaternary contradiction between activity models). If the system designer has a particular model in mind for the final object but the end-user base expected something radically different, these competing activity models would have to be negotiated to determine the final result.

Similarly, the systems designer in her research may discover two contradictory sets of guidelines on designing for accessibility (a primary contradiction within the rules). Which should she follow and why? The designer may use a variety of development technologies to achieve her outcome (a secondary contradiction between subject, tools and object). Should she program the system in Java? PHP? .NET? Ruby? Each of those platforms may lead to the same intended outcome, but platform choice is often structured by the influence of stakeholder communities and may create division of labor issues. The software designer may be inheriting code from a previous designer (a tertiary contradiction between a previous activity and a new version). Should she simply extend the code already provided? Rewrite some parts to her liking? Scrap it all and start from scratch? Does her choice create conflict with the previous designer?

None of these contradictions have "right" answers - they are simply points of tension that arise when exploring the underlying social, political and technological complexity of human activity. These contradictions exist at multiple points and at multiple levels of analysis. Identification and resolution of contradiction is a key mission of management, and the most appropriate resolution is often not clear or obvious. In engineering PBL domains, where students may be accustomed to discovering "right" answers, such ambiguity may prove to be a particular point of discomfort, especially given such contradiction often falls to student group leaders learning how to manage such considerations on the fly. CHAT does not dispel this ambiguity by providing "right" answers – its value is more in describing and highlights potential contradiction for consideration, negotiation and debate.

Living with Contradiction – Activity Contradictions in FSAE Teams

As a theoretical frame, CHAT is a helpful tool to uncover potential points of contradiction in engineering PBL contexts and can be used to identify best practices regarding shared contradictions. CHAT has been used by the author to identify points of contradiction in one particular engineering PBL activity domain: the Formula SAE intercollegiate engineering competition. FSAE (so named after the sponsoring professional association Society for Automotive Engineers) is a project-based learning opportunity with a 35 year history and international reach, involving over 500 automotive engineering teams who compete in over 10 competitions worldwide [16]. Student teams are charged with designing, manufacturing, testing and racing a small open-wheeled racecar while negotiating a host of administration, financial, human and time-management concerns.

A high-level CHAT analysis of management concerns in building an FSAE car may look as follows:

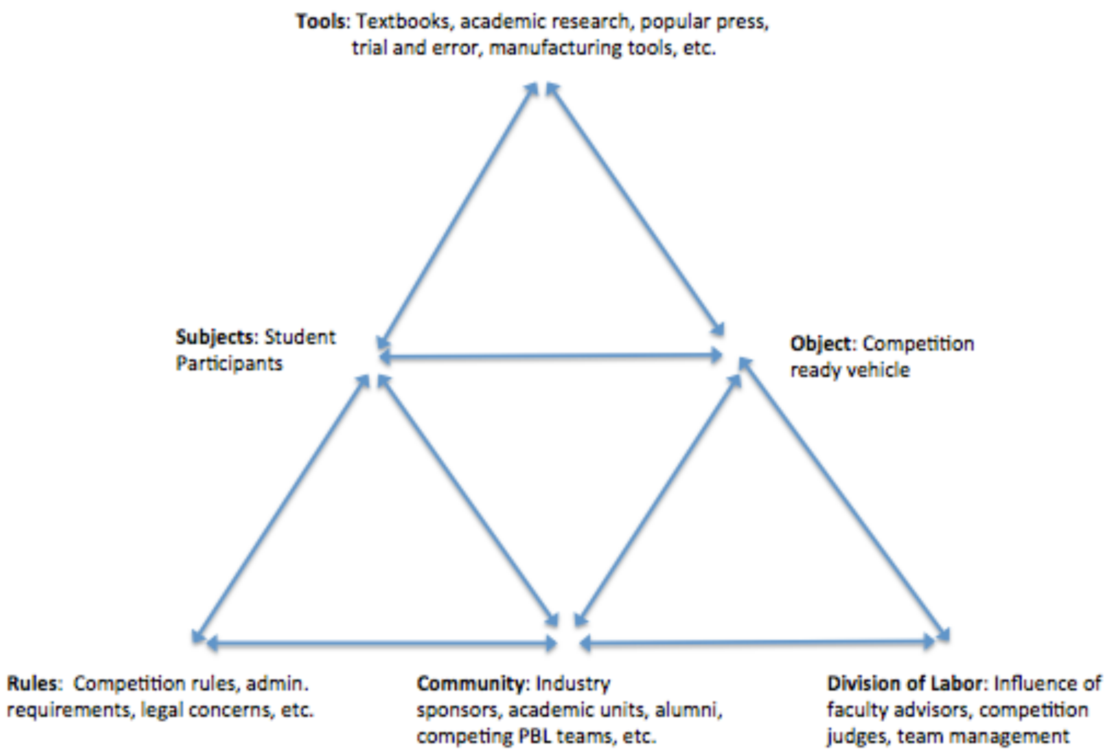

Figure 3: High-level CHAT diagram for Building an FSAE Car

As with the previous example of social software design, there are multiple points of potential contradiction inherent in the above diagram.

FSAE teams attract a range of students with varying levels of interest, skill and motivation (a potential primary contradiction among subjects). How do FSAE teams manage potential conflicts among students with different levels of individual motivation, skill and commitment and corral disparate interests towards the team's objective?

FSAE team members have multiple technologies and tools available to them in attempting to design and manufacture their systems (Vygotsky's core activity, a secondary contradiction between subject, tools and object). Not all paths through this core activity are created equal – some paths of research and development are more likely to yield effective results than others. Moreover, a variety of resource, intellectual and time constraints means the optimal approach to research and development is unclear and/or not feasible. This often leads to "sketchy" solutions team leadership may be forced to hope are sufficient. How do teams identify and critically evaluate available technologies and tools for information discovery? How do they balance resource limitations with competition rules and regulations (a secondary contradiction between the core activity and rules) and the judgment of external evaluators such as faculty advisors and competition judges (a secondary contradiction between core activity and division of labor?)

FSAE teams are supported by community interests including academic units, industry sponsors, and student and alumni associations. There are quite different levels of community support in the FSAE community, with some schools providing considerably more money, time and space to support team activity than others. And in some cases, conflicts between the priorities of a team and competing community forces can emerge. When such battles involve university administration, the consequences to the team can be harsh. How are secondary contradictions between the core activity and community stakeholders (and their rules and priorities) identified and resolved?

As student organizations, the membership of FSAE teams is highly fluid, with teams regularly losing very experience members and core leaders due to graduation. How do teams prepare for such a regular and profound cycle of organizational renewal (a tertiary contradiction of current and future activity models) to create a more permanent knowing organization[7]?

FSAE teams enter their car in competition against similar teams facing similar contradictions (a potential quarternary contradiction among competing activity models and objectives). This competitive environment may lead to direct competition (e.g., deliberately keeping some research private and confidential) but may also engender opportunities for cooperation (e.g., sharing best practices, joint research and development efforts, supporting new teams with startup concerns, etc.) How do FSAE teams engage their competitive teams?

The questions noted above have no specific "right" answer, as their effective resolution depends on a range of contextually based factors that are often social or political in nature. In discussions within the FSAE community, these particular contradictions are consistently vexing questions that FSAE team leaders wrestle with as they attempt to achieve their ultimate objective of a competition-ready vehicle. In this research, CHAT has been invaluable in highlighting where such contradictions exist, framing research questions that can be engaged through qualitative research in the FSAE community. It is hoped at the conclusion of this research that through exchanging stories of how teams have addressed (or failed to address) such contradictions, the FSAE community will have a broader understanding of the complexity of their work and may leverage best (or at least better) practices as they engage their struggle.

Application of CHAT in FSAE and Related Engineering PBL Domains

CHAT does not propose any specific resolution to contradictions, but highlights domains of conflict worthy of advance consideration by FSAE team members, leaders and faculty advisors. CHAT provides a theoretically sound foundation tied to PBL-based pedagogical research and a basis to propose and engage relevant research questions that aim to better understand how the FSAE community copes with common challenges.

The culture of FSAE is such that there exists a strong interest among students to share their experiences and struggles with management issues. Beyond informal discussion at competition, the online community FSAE.com is a common point of engagement by team members and leaders worldwide to exchange ideas in both technical and organizational domains. As part of continuing research, the above contradictions are being seeded into FSAE.com and discussed in this online forum to encourage FSAE team members, advisors and judges to share best practices around areas of common concern.

Beyond FSAE, such a structured investigation of contradiction may also be extended to other engineering PBL contexts. Team member motivation, adherence to community and competition rules, sustaining a knowing organization, and balancing cooperation and competition are common concerns among similar intercollegiate competitive series (e.g., Robocup, Mini Baja, UAV, Concrete Canoe, Solar Decathlon, NASA Lunar Mining etc.) More ad-hoc efforts such as one-off capstone projects may also benefit from such an analysis of potential points of conflict and contradiction, although such projects may not face the same concerns of building a permanent or sustained knowledge base for future years.

While engineering students may not find comfort in a theoretical approach that deliberately refuses reducing human complexity to a simple, correct solution, CHAT-based research could still assist student leaders by at least identifying and naming potential contradictions in our inherently messy world of cultural, social and organizational complexity. While CHAT cannot develop universally correct solutions, by identifying common problems CHAT can mitigate some of the stress resulting from ambiguity and encourage a mutual exchange of strategies and techniques to rein in such complexity. CHAT-based research may not solve managerial concerns outright but can provide a foundation for dialogue and purposeful discussion of common concerns.

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