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Theorizing Core-Periphery Model to Engage and Retain Students via Engineering Competition Teams throughout the Undergraduate Engineering Programs

Dr. Siqing Wei, Youngstown State University - Rayen School of Engineering

Dr. Siqing Wei is an Assistant Professor at the Youngstown State University. He received a B.S. and M.S. in Electrical Engineering and a Ph.D. in Engineering Education program at Purdue University as a triple boiler. He was a postdoc fellow at the University of Cincinnati under the supervision of Dr. David Reeping. His research interests span several major research topics, which are teamwork, AI in education, cultural diversity, and international and Asian/ Asian American student experiences. He utilizes innovative and cutting-edge methods, such as person-centered approaches, NLP, ML, and Social Relation Models. He studies and promotes multicultural teaming experiences to promote an inclusive and welcoming learning space for all to thrive in engineering. Particularly, he aims to help students improve intercultural competency and teamwork competency through interventions, counseling, pedagogy, and mentoring. Siqing received the Outstanding Graduate Student Research Award in 2024 from Purdue College of Engineering, the Bilsland Dissertation fellow in the 2023-24 academic year, and the 2024 FIE New Faculty Fellow Award.

Eric Haake, Youngstown State University - Rayen School of Engineering
Richard Deschenes, Youngstown State University - Rayen School of Engineering

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Abstract

This complete research theory paper describes a unique, longitudinal engineering engagement and retention model centered on engineering competition teams (ECTs). ECTs engage students in interscholastic competitions, usually organized by professional societies (e.g., ASCE), which require participants to design, manufacture, build, and test engineering prototypes or products for specific purposes. After years of implementation and revision, our program establishes its culture by using engineering competition as the context of senior design projects. Furthermore, underclass students are also encouraged to engage for ECT projects via professional student organizations (e.g., local ASME student chapter) participation, where they conduct smaller-scale, complementary projects to aid competition teams. This structure constitutes a Core-Periphery participation model, in which senior students form the core of competition teams while early-year students participate through legitimate, lower-intensity peripheral roles. This model is further enhanced via early exposure in first-year engineering classes and sustained visibility of competition outcomes and student success stories. The purpose of this paper is twofold: 1) to disseminate the Core-Periphery ECT engagement and retention model, and 2) to interpret its potential effectiveness with theorizing, using an integrated conceptual framework of Tinto's Student Integration Model and Bean and Metzner's Student Attrition Model. The implication of this work extends to showcase an example for other smaller-size, particularly primarily teaching institutions to better engage and retain engineering students to further enrich the shorted engineering workforce. Over time, underclass students are becoming more engaged earlier, and a growing number remain with the team through their senior design experience. Clubs have also seen stronger retention as semesters progress, largely because side projects and complementary tasks give newer members meaningful ways to contribute.

Introduction

Student engagement and retention remain persistent challenges in undergraduate engineering education [1]. While national demand for engineers continues to grow, many engineering programs struggle to sustain student persistence across the undergraduate trajectory [2]. Increasingly, retention and persistence are understood not as a single, isolated decision point but as a dynamic, developmental process shaped by academic, social, psychological, and environmental factors that vary over time [3]. Consequently, engagement strategies may be less effective to support long-term persistence when operating only at discrete stages, i.e., first-year interventions or senior capstone experiences alone.

Engineering Competition Teams (ECTs) have emerged as a widely recognized form of co-curricular engagement in engineering education. Organized by professional societies such as ASCE, ASME, SAE, and IEEE, ECTs provide students with opportunities to engage in authentic engineering practices, including problem scoping, design, fabrication, testing, and project management, and technical communication [4], [5]. Prior studies across multiple institutions consistently report that participation in ECTs enhances students' educational experiences, technical and professional skill development, and career readiness, while also improving students' perceptions of their programs and institutions [6] - [11]. As a result, ECTs are often regarded as high-impact educational experiences that complement formal coursework [4], [12].

Despite their documented benefits, ECTs are commonly implemented as optional co-curricular activities or as senior-year capstone design projects. While competition-based capstones can provide rigorous, professional, and authentic design experiences, particularly in small programs [4], [8], [9], these existing models typically concentrate engagement at the end of the undergraduate curriculum. As a result, early-year students may have limited access to competition-related experiences, and the potential of ECTs to support engagement and retention across multiple stages of undergraduate education remains underexplored.

This manuscript aims to present and theorize a longitudinal engagement mechanism of ECTs over a standalone activity, referred to as the **Core-Periphery Participation Model**, as shown in Figure 1. At the center of the model are senior-level ECTs that are formally embedded within senior design courses. These teams constitute the **core** of competition activity and are responsible for the full scope of competition work, for both technical and management tasks. It serves three purposes: 1) it legitimizes participation by integrating competition work into the curriculum and degree requirements; 2) it ensures sustained faculty mentorship and alignment with program learning outcomes; and 3) it elevates ECTs as a professionally authentic culminating experience of engineering practices. Surrounding the core is a structured peripheral participation layer that intentionally engages underclass students to make loose connections with ECTs. Such peripheral participation occurs primarily through professional student organizations (e.g., ASME student chapters) and related extracurricular structures. Those students contribute to smaller-scale, complementary projects that support competition teams, such as subsystem prototyping, materials testing, fundraising, or preliminary design exploration. Only low barriers are required for students to engage as limited time commitment, performance pressure, and prerequisite technical knowledge. Yet such participation opens the door for underclass students to observe competition processes, interact with senior peers, and gradually develop competence and confidence for later enrollment in senior design courses and graduation, ultimately reinforcing students' sense of belonging to engineering. Students are encouraged and supported in taking peripheral roles into more central responsibilities, culminating in core participation in senior design. Advertisements and advising also contribute to helping students transition from periphery to core participation in ECTs, where students are exposed to the success stories of prior years' participation in engineering and an invitation to join professional student clubs through multiple venues, like the first-year engineering mandatory seminar course, university website pages, posters within the engineering building, and student advising. By making this developmental pathway visible and attainable, students are inspired by future engagement, learning, and employment possibilities with reduced uncertainty.

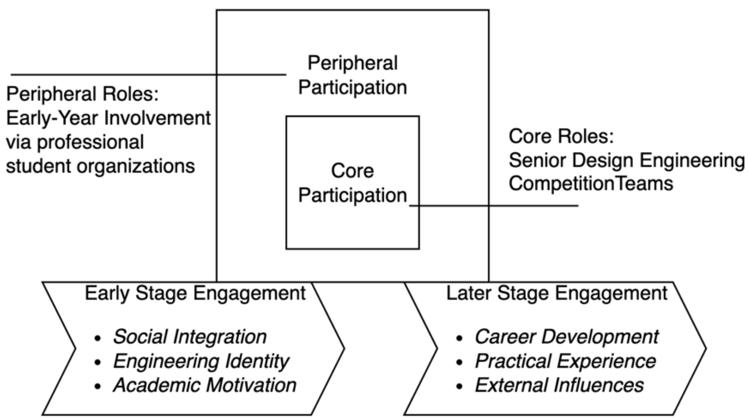

Figure 1. Core-Peripheral Engineering Engagement and Retention Model

Drawing on Tinto's Student Integration Model [13] and Bean and Metzner's Student Attrition Model [14], this work also attempts to analyze plausible reasons for the Core-Periphery ECT Participation Model's effectiveness. Therefore, this work contributes to advance engineering student retention literature by exemplifying how ECTs can be leveraged to support student engagement and retention throughout the undergraduate engineering program.

Background and Theoretical Framework

Engineering Competition Teams as Experiential and Co-Curricular Learning Contexts

ECTs have long been recognized as effective experiential learning environments that expose students to the realities of engineering practice. Through interscholastic competitions, students engage in sustained, project-based work that requires balancing technical rigor with constraints such as budgets, schedules, safety requirements, and external evaluation [4], [5]. These experiences allow students to apply classroom knowledge in real-world contexts while developing professional competencies that are difficult to cultivate through traditional coursework alone [4], [12].

One common strategy for institutionalizing ECT participation is the integration of competition projects into senior capstone design courses. Studies of Formula SAE and SAE Baja capstone design implementations demonstrate that competition-based capstones can meet accreditation requirements while providing motivating and professionally authentic design challenges, particularly for small and teaching-focused engineering programs [4], [8], [9]. In some cases, programs adopt vertically integrated participation structures that allow students to engage with competition teams across multiple academic years [9]. A student's role in such a setting can vary from supporting the major team by fabrication, fundraising, to a more central role, such as assisting with subsystem design, providing leadership, and system-level responsibilities. This longitudinal model suggests that competition teams can serve as developmental pathways rather than isolated senior-year experiences.

Engagement Barriers and Uneven Participation

Despite the documented benefits of ECTs, participation in co-curricular engineering activities remains uneven. Research indicates that many engineering undergraduates perceive co-curricular involvement as high cost in terms of time and effort, particularly when such activities are voluntary and disconnected from formal coursework [11]. The perceived costs may disproportionately affect students with competing academic work or family responsibilities [15]. We contend that students who might benefit most from early engagement may be least likely to participate. Therefore, lowering barriers to entry and providing clearly articulated pathways are critical for broadening engineering participation and engagement. Offering legitimate, lower-intensity roles for early-year students may reduce perceived risk while fostering gradual integration into engineering community of practice.

Retention as a State-Propagated Process

Understanding student retention in undergraduate engineering programs requires moving beyond static or single-factor explanations, where retention is increasingly conceptualized as a as a multifaceted and developmental process influenced by academic, social, and environmental factors [3]. One core evolved perspective was that the factors influencing students' decisions to persist or depart change over time. This perspective is supported by an empirical study showing that different factors predict retention at different stages of undergraduate education. [3]. Also, this perspective aligns with and extends foundational retention theories, particularly Tinto's Student Integration Model [13] and Bean & Metzner's Student Attrition Model [14], which explicitly foregrounds the temporal dimension of retention.

Tinto's Student Integration Model

Tinto's Student Integration Model conceptualizes student retention as a function of academic and social integration within an institution [13]. Tinto contends that students are more likely to persist when they develop meaningful connections to both the academic system (e.g., coursework, faculty interactions, intellectual engagement) and the social system (e.g., peers, sense of belonging). In this framework, early experiences play a critical role, as students evaluate their "fitness" with the institution based on perceived alignment between personal goals and institutional culture.

Tinto's model has been widely used to explain why students leave programs during early undergraduate years, particularly when they experience academic difficulty, social isolation, or a lack of belonging [16], [17]. Learning communities, collaborative learning environments, and peer-based engagement opportunities are often cited as mechanisms that enhance integration and support persistence [18], [19]. However, Tinto's framework has also been critiqued for its limited attention to external influences, such as employment, family responsibilities, and financial constraints, which may shape students' decisions independently of institutional integration [3], [14], [20].

Bean and Metzner's Student Attrition Model

Bean and Metzner's Student Attrition Model complements Tinto's work by emphasizing the role of external and environmental factors in student persistence [14]. Originally developed with nontraditional students in mind, the model highlights four categories of influences: academic variables, backgrounds and defining characteristics, external factors (e.g., career, finances, family responsibilities), and psychological outcomes (e.g., satisfaction, stress, confidence).

Unlike Tinto's model, Bean and Metzner's framework recognizes that students' decisions to persist are not solely determined by intuitional experiences [14]; further, external pressures might outweigh academic or social integration, particularly when students progress through their programs and face increasing practical considerations related to future employment and career planning [21]-[23]. Although initially applied to nontraditional populations, subsequent research has demonstrated the relevance of Bean and Metzner's Model to a broad range of undergraduate students [20].

Dai and Tan's Integrated, Temporal Model of Retention

Building on these two foundational frameworks, this model was proposed grounding in engineering and computing student population, synthesizing Tinto's emphasis on academic and social integration with Bean and Metzner's attention to external and psychological factors. This model characterizes six dimensions of factors: demographic and personal characteristics, academic preparation, institutional type and support, psychological factors, social support, and other external factors (e.g., personal finance, location and commuting situation). Moreover, they argue to conceptualize retention as a longitudinal process in which the relative importance of different factors shifts over time.

Their findings suggest that early-stage retention (e.g., persistence through the first and second years) is more strongly influenced by academic preparation, psychological factors such as confidence and satisfaction, and social integration within the institution. On the other hand, later-stage retention (e.g., persistence to degree completion) is increasingly shaped by practical, career-oriented, and external factors, including employment status, financial considerations, and access to career support. It's also worth noting that peer support has been found to be salient across stages, underscoring the enduring role of social connections in student persistence. As such, it provides a particularly useful lens to examine engagement structure that span multiple academic years.

Situating ECTs within a Stage-Dependent Retention Framework

Engineering competition teams can be meaningfully situated within this integrated, stage-dependent framework of retention. As experiential, team-based learning environments, ECTs offer mechanisms that align with both early-stage and later-stage retention factors. For early-year students, participation in ECT-related activities in peripheral or lower-intensity roles can support social integration, peer connection, and emerging engineering identity, aligning closely with Tinto's model [13], and the early-stage predictors of intention to persistence by Dai and Tan [3]. When engagement opportunities are accessible and visibly connected to the curriculum, ECTs may reduce perceived barriers to participation while fostering a sense of belonging within the engineering community.

For upper-division students, especially those engaged in competition teams in the senior design course, ECTs align more strongly with career-oriented and practical considerations emphasized in Bean and Metzner's model [14] and Dai and Tan's later-stage findings [3]. Senior students experience ECTs as professionally authentic contexts that reinforce career relevance, provide leadership opportunities, and support transitions into the engineering workforce.

From this perspective, the effectiveness of engineering competition teams as retention mechanisms depends not merely on their existence, but on how they are intentionally structured spanning over the entire undergraduate period. The Core–Periphery ECT model described in this paper is grounded in this theoretical insight, positioning competition teams as a longitudinal engagement anchor that aligns with the evolving factors influencing student retention over time.

The Core-Peripheral Engineering Competition Team Model

Implementation

The Core–Periphery model is developed by first selecting a flagship engineering competition, SAE BAJA, and mapping its technical and managerial requirements directly onto senior design learning outcomes. From there, the program builds the structural layers that support longterm sustainability: establishing lab space, budgeting processes, faculty supported leadership and management structure, documentation systems, and training pipelines; establishing ways to engage underclass students to participate through student organizations, complementary subsystem projects, and structured shadowing; and creating visibility and engagement opportunities for early-year students. As the model matures, annual cycles of design reviews, competition debriefs, and documentation updates ensure that knowledge flows from one cohort to the next, gradually strengthening the pipeline and embedding the competition into the culture of the department.

Faculty involvement is central to making the model function. Faculty design the overall structure of student experience and participation in ECTs, align the competition with senior design curriculum requirements, and ensure academic rigor. They act as advisors to senior design teams, guiding technical decisions, facilitating design reviews, and maintaining safety and resource oversight in labs and fabrication spaces. At the same time, faculty cultivate the Periphery by coordinating with student organizations, creating scaffolded learning experiences for underclass students, and ensuring continuity through mentorship ladders and documentation practices.

Another factor grows in importance to ensure the success of the Core-Peripheral model is the intentional inclusion of industry advisors into ECTs. For instance, within ASCE, our industry advisors serve as both external evaluators and mentors to oversee the ongoing competition projects. They tend to stay around longer than students and pass on knowledge to the next generation.

Outcomes

Over the years, clear patterns have emerged across many competition teams. Underclass students are becoming more engaged earlier, and a growing number of them remain with the team all the way through their senior design experience. Clubs have also seen stronger retention as semesters progress, largely because side projects and complementary tasks give newer members meaningful ways to contribute. Another notable trend is the rise in teams filled entirely with students who genuinely want to be there; competitions that once struggled to attract interest now regularly reach full membership with students who identify that team as their top choice.

Discussion, Implication, and Lessons Learned

The Core-Periphery ECT model described in this paper is a stage-appropriate developmental pathway, aligned well with the research characterizing engineering and computing student persistence as a stage-dependent process [3]. This manuscript provides a theoretical grounding for such a structure design and positions it as a longitudinal engagement pipeline that supports students' academic, social, and professional development across the undergraduate engineering education period. This section further highlights design principles, synthesizes lessons learned from our previous implementation, aspects of the model perceived most effective, areas requiring iteration, and key resource considerations.

Design Principles for Similar Institutions

A central design principle emerging from this work is the importance of a pipeline-centered engagement structure. Prior research has shown that co-curricular engineering activities are unevenly accessed and often concentrated among upper-division students [12]. In contrast, the Core-Periphery model intentionally builds student involvement over time, beginning with peripheral participation through subsystems and complementary projects and progressing toward full participation in senior year competition teams. This approach aligns with findings that sustained engagement and peer networks are more influential for long-term persistence [3].

A second principle is the intentional integration of competition work with academic coursework and program learning outcomes. Research on competition-based capstone consistently emphasizes that students derive greater learning and professional value when competition deliverables are explicitly mapped to curricular outcomes [4], [8]. Embedding competition teams within senior design courses, while simultaneously creating academically meaningful peripheral projects for underclass students, strengthens students' perception that competition participation is directly connected to their degree pathways rather than an extracurricular add-on. This integration also addresses concerns raised in the literature that co-curricular engagement may be perceived as high-cost or peripheral to academic success [12].

A third design principle concerns organizational sustainability. Prior studies of competition teams, particularly at smaller or teaching-focused institutions, emphasize that long-term success depends on stable infrastructure, including budgeting mechanisms, workspace, and institutional recognition [5], [9]. Without such support, competition teams risk becoming dependent on a small number of faculty champions or fluctuating student leadership, undermining continuity and retention benefits.

What Worked

We contend that one of the most effective elements of the model was the use of subsystem-level and smaller-scale projects as entry points for underclass students through professional student organizations. These projects lowered barriers to participation while still offering authentic engineering tasks, supporting early social integration, and engineering identity development. This finding aligns with prior research showing that incremental, legitimate participation opportunities promote engagement and persistence more effectively than all-or-nothing models of involvement in engineering education [24].

Another successful practice was the incorporation of regular design reviews involving faculty beyond the immediate competition team advisors, such as the industry advisors. These reviews provided external perspectives on design decisions, exposed students to diverse engineering viewpoints, and reinforced professional norms associated with engineering practice. From a retention perspective, such interactions expand students' faculty networks and reinforce academic integration, which has been shown to support persistence [3].

Beyond previously mentioned organizational support, another critical event to welcome and recruit underclass students was an annual event called STEM Showcase. In this venue, all ECTs are requested to present onsite along with their design products. With such a vivid demonstration with synchronous interactions with lower-class students, their interests and motivation to participate in the ECT structure early are inspired.

What required iterations

Despite the sustained implementation of the Core-Peripheral Model at our institution, this model requires ongoing iteration, particularly in relation to knowledge transfer and continuity across academic years. We experience and agree with prior literature on competition teams that student turnover and graduation can lead to loss of institutional memory if documentation and mentoring structures are not deliberately maintained [4], [9]. In the early years of implementation, inconsistencies in how design decisions, data and lessons learned were passed between cohorts limited efficiency and occasionally increased frustration among new team members.

Addressing this challenge required more formalized documentation practices, clearer role definitions, and explicit mentoring relationships between senior and junior students, particularly utilizing underclass students actively participating in the professional student organizations. These adjustments echo broader literature that sustained peer support and continuity mechanisms are critical for maintaining engagement and reducing attrition over time [3].

Resource considerations

Finally, implementation of a longitudinal ECT engagement model carries important resource implications, especially for faculty workload and physical space. Faculty advising competition teams often extend beyond normal instructional hours, as design, fabrication, and testing activities frequently occur outside scheduled class time. Prior studies of competition-based capstones have similarly noted the substantial time commitment required of faculty mentors, especially in programs with limited staffing [8], [9].

Spacing and equipment needs also tend to grow nonlinearly as competition teams mature. As teams advance, machining complexity, storage requirements, and safety considerations increase, placing additional demands on institutional facilities. Our institution renovated a building as a workshop dedicated to ECT uses, where all capstone team students have building access anytime and have a safe space to store all equipment and projects. Research on sustainable competition team operations emphasizes that early planning for a scalable workspace and shared resources is essential, particularly for smaller institutions with constrained physical infrastructure [4], [5].

Conclusion

This paper theorizes a Core-Periphery Engineering Competition Team model as a longitudinal engagement and retention mechanism in undergraduate engineering education. Grounded in an integrated framework drawing on classical retention frameworks, our proposed model reframes ECTs as a developmental pipeline rather than isolated co-curricular or senior-year experiences. By aligning peripheral, low-barrier participation for early-year students with curriculum-embedded, professionally authentic competition experiences for seniors, the model plausibly supports student engagement and persistence as retention-relevant factors evolve over time. Beyond its theoretical grounding, this work offers a transferable example for small, primarily teaching-focused institutions seeking scalable ways to integrate experiential learning with retention goals. While not intended to establish causal effects, the Core-Periphery model demonstrates how competition teams can be intentionally structured to support sustained engagement, peer integration, and career preparation across the undergraduate trajectory. Future research should empirically examine student outcomes associated with such models across institutional contexts, further strengthening the connection between retention theory and engineering education practice.

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