An Interdisciplinary Research Group's Collaboration to Understand First-Year Engineering Retention

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Abstract

This Evidence-based practice paper documents the collaboration, research, and future work of the interdisciplinary research team, the Guild for Engineering Education, Achievement, Retention and Success (GEARS) at the University of Louisville's J.B. Speed School of Engineering. Over the last 9 years (2010-2018), GEARS has investigated factors that contribute to first-year retention as well as the effectiveness of various interventions in the first semester. GEARS follows an interdisciplinary Faculty Learning Community (FLC) structure; members meet monthly and review all ongoing projects, develop new projects, and gather interdisciplinary feedback. Due to the unique team and meeting structure, GEARS has produced many novel research projects. While the GEARS mission of improving engineering student retention and success has not changed over time, the collaboration and sharing of expertise has caused new research questions and ways of studying retention to emerge. This paper discusses the progress of our collaboration and highlights the insights of a variety of specialists, looking at first-year engineering retention.

Introduction

Interdisciplinary research holds great value in today's academic environment as researchers pursue the betterment of teaching and learning within all fields of study. Among the most influential organizations that promote interdisciplinary activity are the National Science Foundation (NSF) [1], the Association for the Study of Higher Education (ASHE), the American Educational Research Association, and the National Academy of Sciences (NAS) [2]. NSF rewards funding submissions that maintain interdisciplinary structure, and in addition, promotes education and training focused on interdisciplinary approaches to research. Calls continue for interdisciplinary research, yet the traditional nature of higher education institutions is burdened with barriers that, in many ways, discourage or prevent such activity from materializing. Higher education disciplinary cultures and structures habitually celebrate individual efforts and outcomes, which often hinders researchers from collaborating. A specific example of this perpetuation of single-author research lies within the funding, promotion, and tenure criteria held by many disciplinary departments within colleges and universities. Sometimes referred to as silo syndrome, instructors in these single-author paradigms can be protective of their intellectual property, not wanting to share information or knowledge with individuals of other departments. Silo syndrome persistently generates barriers to progress in academic or pragmatic research efforts toward effective teaching and learning. Interdisciplinary work that provides a format for conversation can lead to new knowledge around a topic and therefore can be one of the most productive and inspiring research environments.

This paper describes a longitudinal, interdisciplinary collaboration among various higher education faculty that has sustained due to the consistent participation of individual discipline specialists. The overall interdisciplinary research goal of GEARS is to address gaps in academic achievement and retention among first-year engineering students at the University of Louisville J.B. Speed School of Engineering. While the mission has remained the same over time, faculty's individual contributions as discipline specialists have coalesced and generated on-going innovations toward a robust and gratifying educational experience for the engineering school's first-year students. As an interdisciplinary research team, GEARS meets regularly to review ongoing projects and propose new endeavors that focus on first-year engineering student retention. Individual specialists share a collective interest in addressing first-year engineering student retention gaps. This shared interest has motivated the progression of new research questions and ways of studying first-year retention in creative and innovative ways. GEARS outcomes discussed in this paper include an established longitudinal database, a streamlined annual survey containing psychometric constructs focused on engineering retention and performance, and the evolution of research projects over the time in GEARS.

Literature Review

Interdisciplinary research groups. Interdisciplinary practice in higher education refers to the integration of two or more disciplines or fields of study in relation to research, instruction, and/or programs [3]. Many types of interdisciplinary practice in higher education exist, including: critical interdisciplinary [4], [5], geographical distal interdisciplinary [6], instrumental interdisciplinary [7], interdisciplinary capacity building [8], [9], interdisciplinary teamwork [10], multidisciplinary [11], participatory interdisciplinary [12], and transdisciplinary [13]. All the types of interdisciplinary practice in higher education encounter barriers due to traditional culture and structural norms that tend to discourage or do not promote possible productive activity or research. To combat these barriers, a paradigm shift is necessary to help provide interdisciplinary research and pedagogy. The Consortium of National Arts Education Associations [14] suggests eight conditions for higher education leaders to facilitate to enable an interdisciplinary environment. Among the conditions they suggest are: a common planning time or sufficient opportunities to meet other faculty, flexible scheduling, appropriate resources, as well as community and administrative support and involvement. Nancarrow et al. [10] offers suggestions in the form of ten key characteristics essential for sustaining successful interdisciplinary groups: 1) leadership and management, 2) effective communication, 3) personal rewards, training, and development, 4) appropriate resources and procedures, 5) appropriate skill mix, 6) positive and enabling environment, 7) individual characteristics, 8) clarity of a shared vision, 9) quality and outcomes, and 10) respecting and understanding roles. An interdisciplinary group lacking in any of these ten characteristics is often what causes many higher education interdisciplinary collaborations to fail [3].

Sustaining a longitudinal interdisciplinary research group. While the term interdisciplinary generally refers to the process of integrating two or more disciplines, it can also describe the issues that are located at the intersection of two or more disciplines [15]. When viewed in this context, different challenges to interdisciplinary groups become evident. Öberg [16] describes these challenges toward creating common ground at the intersection of different disciplines as onerous and time-consuming. The key to a successful collaboration is to facilitate the creation of a climate that will stimulate awareness of such challenges and bring understanding around the differences that exist between discipline’s epistemologies, quality, and credibility in research. Bronstein [17] provides a two-part model for interdisciplinary collaboration to find success and sustainment. Bronstein draws from her background with social work to build the two-part model, yet, it is clear the model is applicable among many disciplines. Part 1 of the model specifies the five-core components of interdisciplinary collaboration: 1) interdependence, 2) newly created professional activities, 3) flexibility, 4) collective ownership of goals, and 5) reflection on the process [17]. Part 2 outlines the influences on interdisciplinary collaboration: professional role, structural characteristics, personal characteristics, and a history of collaboration [17]. Figure 1 describes Bronstein’s [17] model and serves as the framework for the remainder of this paper.

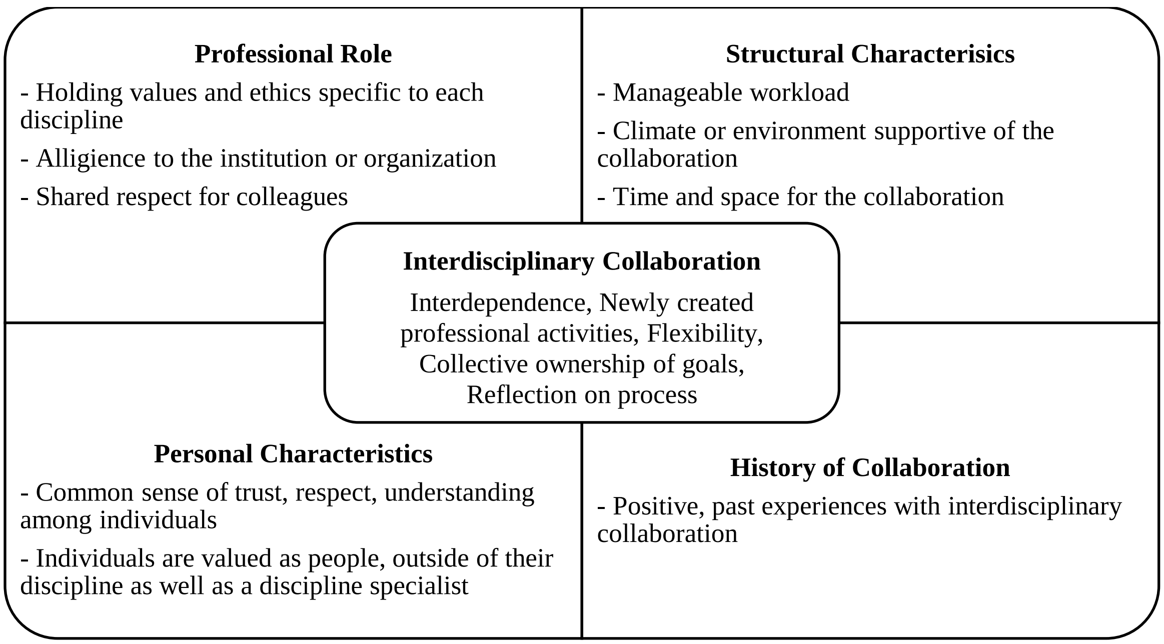

Figure 1: Components and influences of interdisciplinary collaboration

Interdisciplinary research groups as a faculty learning community. A Faculty Learning Community (FLC) is a group of interdisciplinary faculty members (typically between 6-15) engaging in an active, collaborative program of significant duration designed to foster scholarly teaching and enhance student learning [18]. FLCs are considered a special type of community of practice, recognized as groups of people who share a concern or a passion for something they do, and learn how to do it better as they interact regularly [19], [20]. FLCs are structured, intensive, professional learning opportunities designed to provide encouragement, support, reflections, and community building, where participants typically produce deliverables to share their knowledge and accomplishments with the wider university community [21]. Research suggests that FLCs increase faculty interest and confidence in teaching; fostering growth and innovation in scholarly teaching, encouraging active, learner-centered, interdisciplinary approaches to teaching and lead to increased student learning and retention as well as higher rates of tenure for participating faculty [22]. In addition to the components and influences around interdisciplinary research groups [17], the FLC model of interacting regularly around a common goal is being supported as integral strategies toward change in STEM education reform [23]. Our research group has followed this FLC model for almost ten years (2010-2019), exploring means of improvement and methods of research focused on the retention of the first-year engineering students at University of Louisville's J.B. Speed School of Engineering.

First-year engineering student retention. The first-semester of engineering undergraduate education often presents significant hurdles for students [24]. Researchers and educators have been exploring many factors that predict student success, including academic preparedness [25], [26] and the psychological factors of motivation, self-efficacy, and attitude [27]–[30]. Our university's school of engineering mirrors that of many engineering schools across the country as efforts of research to improve teaching and learning are made in hopes of retaining engineering students into engineering careers. The longitudinal interdisciplinary research group, GEARS, that initially assembled around the research goal of focusing on first-year engineering student retention and academic achievement has sustained in their efforts, while expanding their exploration of first-year student retention through innovative, interdisciplinary viewpoints. Our group is now poised to look at first-year engineering student retention across cohorts, with respect to performance and psychometric factors that indicate student success.

Our Sustaining, Longitudinal, Interdisciplinary Research Group

GEARS is a long-standing interdisciplinary research group at the University of Louisville's J.B. Speed School of Engineering, that grew out of an initiative to improve first-year engineering student retention. The number of disciplines included in GEARS expanded over time as initial individuals in the group connected professionally with other discipline specialists within the university.

During the 2007-08 school year, the school of engineering established a new department specifically designated to the design and implementation of most of the first-year engineering student coursework. This new department, Engineering Fundamentals (EF), was responsible for teaching the undergraduate mathematics courses for the engineering school as well as the required introductory engineering and graphics courses. EF would also have some advising and student outreach responsibilities, pertaining to the first-year engineering students. Through the creation of the EF department, the necessity for a research group emerged; identifying this need was the beginning of GEARS.

As mentioned in Nancarrow's suggestions for interdisciplinary success [10], the leadership and support around a group is critical to forming and sustaining the group initiatives. The department chair of EF, a senior engineering faculty, together with the dean of the engineering school, were equally interested in improving first-year retention of engineering students and improving the introductory engineering courses. A graduate research assistant (GRA) position was created with job responsibilities devoted to first-year engineering student retention data. The interdisciplinary research team, GEARS, grew out of the collaboration of the EF department chair and the first EF GRA. The first EF GRA was a doctoral student pursuing a PhD through the college of education, coming to the position with a background in engineering, holding bachelor's and master's degrees in Industrial Engineering.

Initially, the two founding members of GEARS (the department chair and GRA) were interested in conducting research that identified possible reasons why so many engineering students were leaving the engineering school before entering their second year. They began administering surveys to all first-year engineering students in their first-semester, starting in the fall of 2010. The initial survey included factors such as commitment to engineering, achievement goals, and many others were identified as indicators toward engineering student success. The outcome of this initial investigation indicated that student retention is due to various factors that should be considered holistically [28]. The initial survey data was collected through the university's Institutional Research (IR) department, and through this collection GEARS grew in membership. Among those joining was a data analysist from IR who became interested in the research goal of improving first-year engineering student retention. The knowledge imparted from the IR data analyst provided a streamlined direction for continued data collection that is protective of all student participants.

GEARS officially began its formalized meeting structure in 2012: meeting once a month at the engineering school. With two-years of survey data collected, attention mounted as various interdisciplinary faculty who shared interest in researching academic achievement, retention, and success in first-year students started attending the regularly scheduled GEARS meetings. Among them included a senior psychology and brain science faculty member and psychology graduate student, joining in 2012. Their expertise as discipline specialists in experimental psychology brought focus to the GEARS mission toward potential testable interventions to increase first-year engineering student retention.

An early intervention study was designed by the GEARS faculty specialist from the psychology and brain sciences department and implemented by the EF department by adding spaced retrieval practice to the precalculus course, offered by the EF department. This precalculus course was designed for students who were admitted to the engineering school but had demonstrated need for remediation, prior to taking the first calculus course. Approximately one-third of the first-year engineering students found themselves in need of the precalculus course. An EF faculty instructor and a computer scientist with expertise in educational technology joined the spaced retrieval project by determining how spaced retrieval could be implemented in the course using an online lab software. This work resulted in a funded NSF grant (NSF DUE-IUSE award 1431544, "Can the spacing effect improve the effectiveness of a math intervention course for engineering students?"), and the educational technology specialist became an additional participating member of GEARS.

Soon after the department of psychology and brain science faculty joined GEARS, and concurrently with the development of the mathematics intervention, an innovative researcher and faculty member from the department of educational psychology and human development joined the GEARS team. The addition of this faculty member brought the GEARS focus on first-year engineering student retention toward factors of motivation among engineering students; most specifically, the implicit beliefs about intelligence and effort beliefs. These factors have been shown as predictors of academic success in first-year students [27], [31]. Several graduate students joined GEARS through the invitation of the joining faculty members; further emphasizing the importance of personal characteristics among interdisciplinary collaborations.

Early engineering retention literature directed the group to address the mathematics courses taught by the EF department. Through the GEARS collaboration, a summer math preparatory intervention was evaluated [32]. While the intervention was not successful in improving math performance, results identified that students lack sufficient algebra skill, study environment management, internal goal orientation, and test anxiety; all of which, impact their performance in the first-year engineering math course. It was concluded that psychological interventions and study habit interventions were needed to raise first-year engineering student retention. These conclusions expanded the interest in the activity of GEARS even further. Faculty and graduate students from the department of experimental psychology became more involved by investigating the impact of test anxiety [33] and interventions of belonging [34]–[36]. The initial GEARS survey of all first-year engineering students was modified to include items from validated instruments that could track repeated measures of engineering belonging.

In 2015, GEARS membership grew tremendously. A member of the university's student academic achievement center (REACH) gained interest in the research goals of GEARS, acquiring one of their leading researchers as a member. Additionally, the director of the university's planetarium and science education faculty member, the engineering school's student success coordinator, and a physics faculty member who taught many first-year engineering students joined and began attending regular GEARS meetings. Also, the university's Delphi center for faculty development in teaching and learning became more involved with GEARS, by sending an interested staff member to the GEARS meetings. In addition to the membership growth, the first-semester survey given to all first-year engineering student expanded with the inclusion of more items designed around student success indicators.

In 2016, research projects that had begun at the beginning of the GEARS continued and broadened. The annual survey was modified each year, based on the research interests of GEARS members, and given to all freshmen students in their first semester. Additional NSF funding was granted for the retrieval spacing study (NSF DUE-IUSE award 1609290, "Retrieval practice and spacing: Independent and additive effects on precalculus learning among engineering students"). A GRA from experimental psychology with an engineering background joined the project and added additional technical skills to the team.

In collaboration with the EF chair and the IR specialist, GEARS performed a data exploration of engineering student's longitudinal progress through the EF math courses. Collaboratively working with the EF department chair and the IR data analysist, time-based and course-based recirculation and attrition patterns within the mathematics sequence were identified [37]. Based on findings from this study, the EF faculty implemented a flipped classroom intervention in the math course that showed the highest recirculation of students. This intervention was investigated also by the GEARS collaboration, and through analysis, GEARS found that the flipped classroom model reduced the number of withdrawing students while increasing the number of students not-recirculating [38], [39].

After collecting eight years of student survey data and seeing the results from longitudinal investigations of students' paths through the EF program, members of the GEARS team began thinking about assembling a longitudinal database combining performance data with existing survey and demographic data. Primarily driven by the educational technology specialist, who has a strong background in computer science, members of GEARS including the EF chair began meeting with several members of IR to establish data collection procedures in support of the longitudinal database. In 2018, degree and performance data for all primary engineering courses related to progress in an engineering major was collected for all engineering students from 2010-2018, and a path forward was planned to continue gathering data. Additionally, key demographic factors that have been shown to affect retention were also collected, including but not limited to minority status, financial support, high school GPA and college admissions test performance.

With this data in the form of a searchable database, the GEARS group intends to continue to ask novel research questions related to engineering retention. For example, we can investigate retention with respect to completion of the math sequence, or math GPA in the first year. The database will also provide the ability to measure outcomes that could have resulted from past and future interventions. To this end, a faculty member from the Computer Engineering and Computer Science Department has joined GEARS along with three graduate students to develop a data model and perform data pre-processing. This will allow the future use of data mining techniques to discover relationships between performance and persistence and aid us in developing new interventions. affords

Figure 2 depicts GEARS' interdisciplinary, FLC collaboration model. Within this model, GEARS can sustain a FLC model through their regularly held meetings and reviews of on-going and potential research projects that focus on first-year engineering student retention. Essential to the FLC model is GEARS' established core mission of continuing to improve first-year engineering retention. Focusing on improving first-year engineering student retention advances GEARS members to the benefits of the fluid interdisciplinary collaboration. This accessibility is due to the array of discipline experts that regularly attend meetings and genuinely participate with feedback on new or on-going research projects that further promote the GEARS mission to improve first-year engineering student retention.

The final tier of GEARS' interdisciplinary FLC collaboration model allows for a holistic perspective of first-year engineering students. This final tier emphasizes the broad and local impacts that can come from maintaining an FLC structure that affords the interdisciplinary flexibility and collective ownership of overall goals. Broad impact outcomes of GEARS, that can translate outside our university, include student retention, measures of student well-being, and student persistence to degree. Local impact outcomes of GEARS, that appear to have direct connection to our university, include exploration efforts among FY courses and intervention strategies to improve the likelihood for first-year engineering retention, additionally investigation into outreach endeavors to encourage more engineering school applicants to become first-year engineering students.

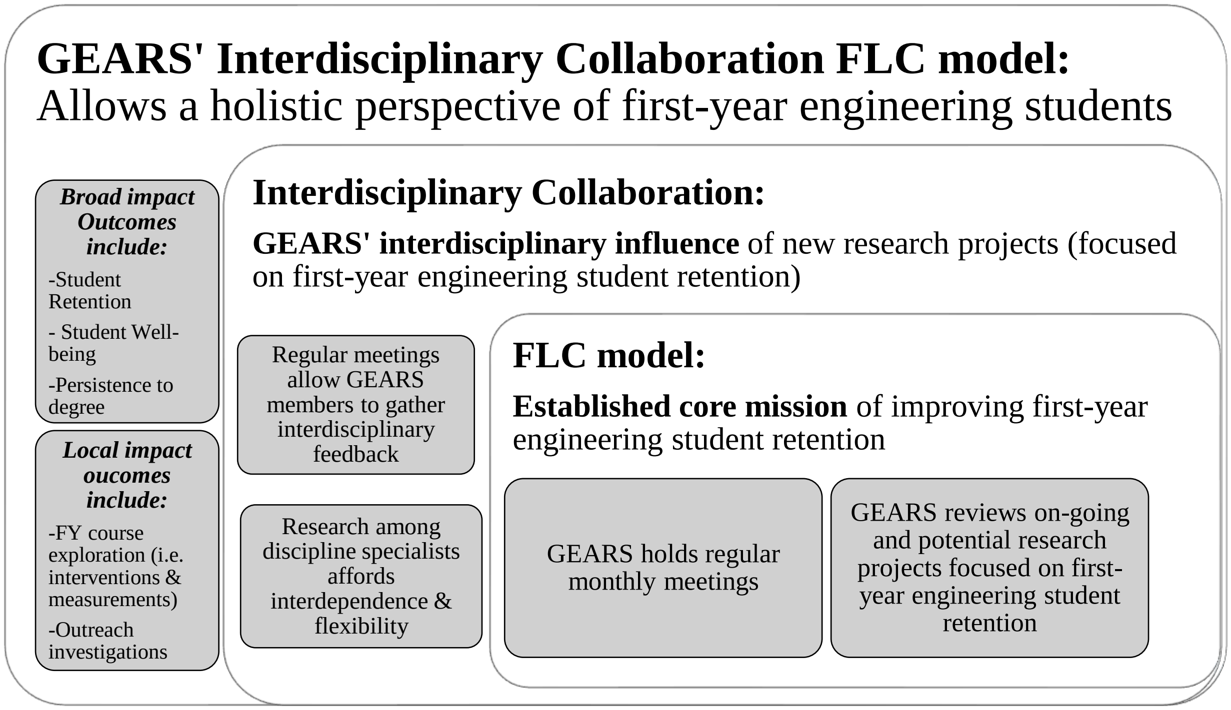

Figure 2: Interdisciplinary FLC collaboration model of GEARS

When interdisciplinary components and influences collide. Higher education literature trends show indications that interdisciplinary research will continue to increase, as teaching and student degrees continue to become more interdisciplinary [3]. The overlap of professional roles, history of collaboration, and structural and personal characteristics between the EF department chair and director of the university's planetarium and science education faculty member (also a GEARS member) brought forth a unique interdisciplinary collaboration, focused on student success and retention with directed efforts toward faculty support in educational research. The project mimicked the FLC structure, like GEARS, formally inviting faculty members to form a new Center for Teaching and Learning Engineering (CTLE) aimed at meeting research aims of faculty from each of the respective colleges. Again, support was given from the respective deans, and a formal collaboration of the two schools of engineering and education emerged.

From this project creation, a new GRA position was supported collaboratively by the respective college (education) and school (engineering). The first GRA for this project, a doctoral student in the college of education, had experience with K-12 engineering education and prior engineering coursework. Through the CTLE collaboration, this GRA also joined GEARS. The two GRAs in GEARS (from the disciplines of education and psychology) together quickly identified the need for streamlining the first-semester, first-year engineering student survey. As a collective endeavor and based on a built sense of personal trust, the two GRAs organized and restructured the initial first-semester, first-year student survey. The instrument went from an 88-factor, itemized instrument to a cohesively organized instrument, containing 8-factors of core significance. GEARS discipline specialists were consulted as the items were refined to better reflect validated measures of factors that research indicates aligning with improved student retention. The regularly scheduled GEARS meetings were helpful in gaining consensus and collaboration among all discipline specialists. Figure 2 shows the evolution of the first-semester, first-year engineering student survey, starting with an original list of factors and ending with the current core-factors of the current survey.

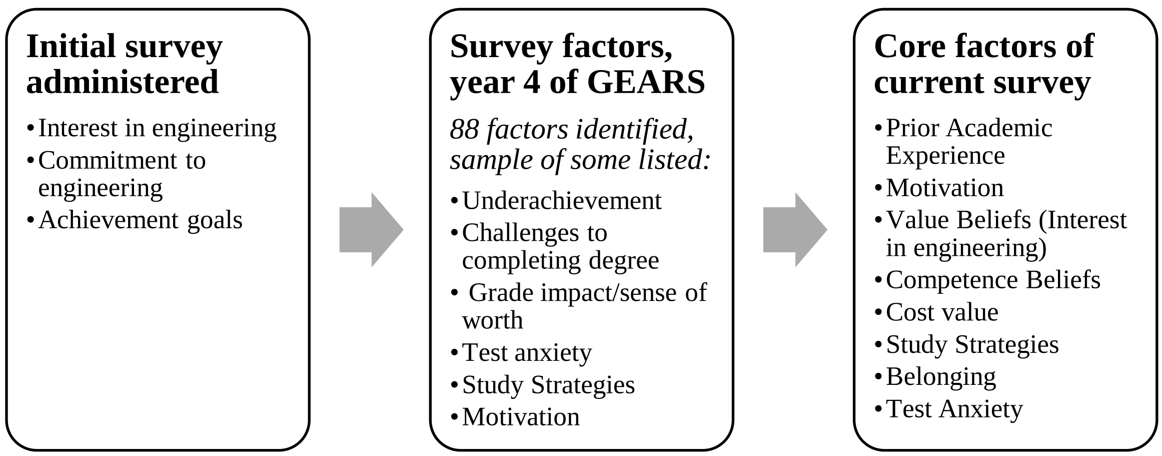

Figure 3: First-semester, first-year engineering student survey factor evolution

Outcomes of GEARS, the Longitudinal, Interdisciplinary Research GEARS

From the description of the evolution of GEARS above, it is clear that each of the members of GEARS were critical and influential to this interdisciplinary collaboration [17]. Led by the EF chair, changes and modifications to the process of interdisciplinary collaboration and sharing of expertise have been made in a flexible, respectful manner. The individual discipline specialists and all the graduate students that have aided in the progression of GEARS to the FLC-like research team have enacted professionalism and proactive innovation with fellow-GEARS members. Some of the published outcomes that have resulted from this effective interdisciplinary collaboration are as follows:

- **Understanding first-year engineering students**
  - There are differences between students who leave engineering after one semester, and those who leave by fall semester of the second year [28].
  - Since engineering students typically had high performance in the past, many are overly optimistic about their abilities and have high expectations for their performance in college [28].
  - However, many students feel they are not adequately prepared for math and science classes in engineering [28].
  - College students now report spending less time on school work and receiving higher grades in high school than in previous years [40].

- **Understanding performance and retention**
    - After accounting for general academic ability (as measured by students' ACT composite scores), changes in students' interest, attainment value, and perceived psychological cost value for engineering explain a modest amount of variance in first semester overall GPA [31] as well as engineering retention.
        - Change in interest is a critical predictor of first-year retention; specifically, an increase in interest predicted which students remained in engineering.
    - Students' perceptions of the relative contribution of effort (versus ability/ intelligence) to academic achievement is robust [27].
    - A greater sense of social belonging is associated with higher grades in a remedial engineering mathematics course [34].
    - Mindfulness benefits math performance by reducing anxiety associated with high-stakes testing conditions [33].
    - Engineering students can be categorized according to a 2x2 framework based on interest in engineering and initial engineering performance, and this categorization is predictive of retention [41]. Figure 4 illustrates the framework.

		GPA	
		Below Average	Above Average
Interest	Low	STEP-OUTS: 21% retention	SEARCHERS: 67% retention
	High	STRUGGLERS: 61% retention	STARS: 94% retention

Figure 4: Retention framework for engineering students, from [41].

- **Improving first-year engineering student academic performance**
    - Algebra weakness is a factor in poor performance in Math 101 (blinded for review). A summer intervention improved algebra skill for incoming students, however did not impact performance in Math 101.
    - Spaced retrieval practice enhances learning in pre-calculus [42].
    - Increasing the amount of retrieval practice impacts short-term but not long-term retention in precalculus, whereas more spacing of retrieval practice does impact both short-term and long-term timescales [43], [44].
    - Physics students who explored a difficult concept with novel problem-solving prior to instruction gained greater conceptual knowledge than students who received instruction followed by the same problem-solving activity [45].
    - Physics final exam scores did not reveal differences due to a deliberate representations intervention [46].

- Flipping the Differential Equations classroom was successful in preventing students from withdrawing from the course [38], and continued modifications to the course design are improving student performance and satisfaction as well as teacher satisfaction [39].

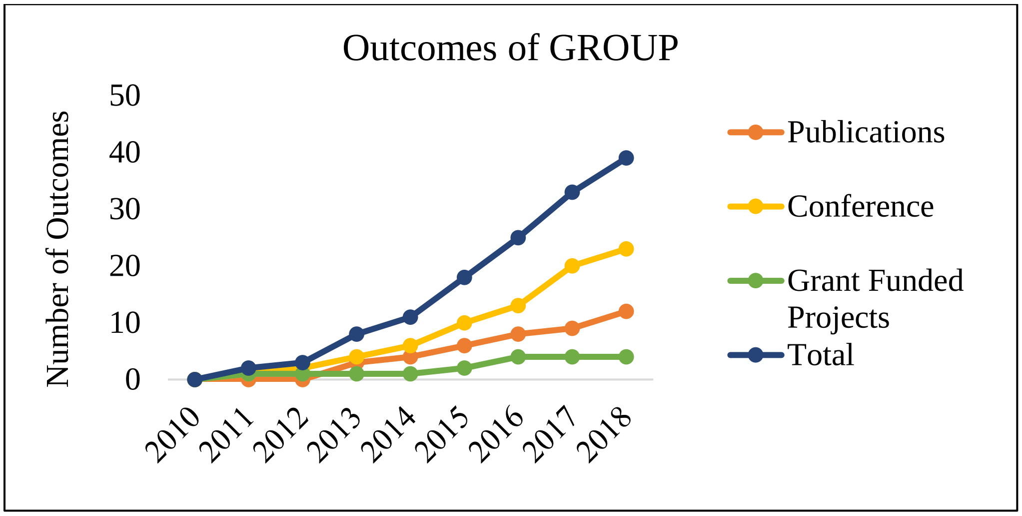

Figure 5: Outcomes of GEARS over time. This graph empirically demonstrates the effectiveness of GEARS, since its inception.

Current Active Projects

GEARS is currently meeting monthly and members are working together on many projects. Our newly assembled longitudinal database has enabled us to ask novel research questions and answer them in unique ways. Figure 4 shows a quick investigation into the student retention with respect to choosing an engineering major using the U. C. Davis Ribbon Tool. The figure shows that the most popular declared major for incoming students is Mechanical Engineering (ME). From that population, some students transition into Biomedical Engineering (BE), Civil Engineering (CE), Computer Engineering and Computer Science (CECS), Chemical Engineering (CHE), Electrical Engineering (EE), and Industrial Engineering (IE). In addition, a large portion of these students exit (shown as Undefined in the figure) after the first, second, and third semesters. It remains the most popular major in the fourth semester.

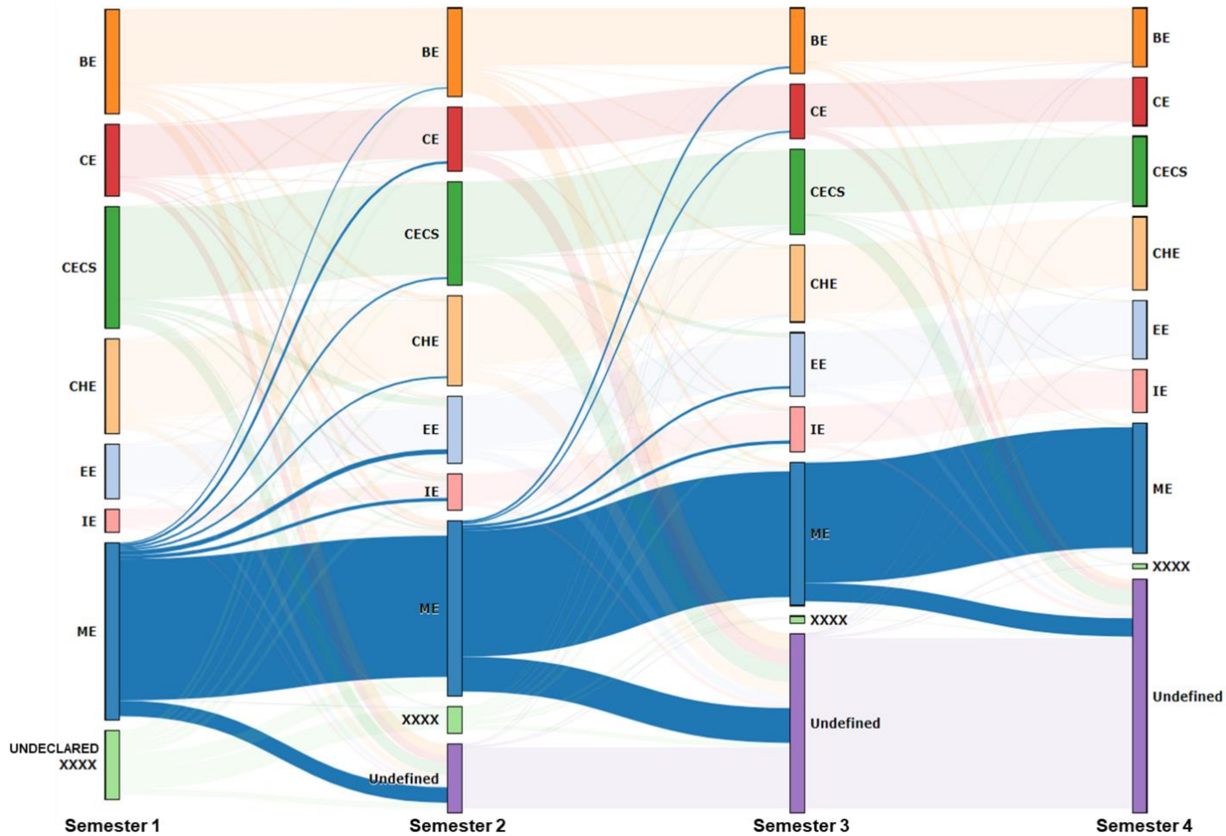

Figure 6: Ribbon Tool output of mechanical engineering majors' retention in engineering and change of major, semester-to-semester, cohorts 2010 through 2015 (*n=2605*)

Conclusions & Future Work

The interdisciplinary group GEARS has had great success in generating meaningful research work to aid student performance and retention at J.B. Speed School of Engineering. The collaborative monthly meetings provide the opportunity to share expertise that otherwise would have been difficult, if not impossible, given the current tenure-track structure of the university. The FLC model, integrated with the interdisciplinary components, enhanced our ability to make progress on large scale research and intervention projects, and therefore, the experience of our first-year engineering students has been improved due to GEARS's efforts. The success of GEARS is due to the support from the deans of the engineering and education schools and the leadership of the EF department chair, as well as the work done by all GEARS discipline specialists.

As the first-semester engineering student survey continues to be administered, GEARS plans to validate the instrument through a confirmatory factor analysis of the items. In addition, our interdisciplinary research team is now poised to look at first-year retention longitudinally across nine cohorts of engineering students. We have psychometric data (e.g., motivation and test anxiety) as well as student performance data in EF engineering courses, and critical demographic data. GEARS has established a data collection, maintenance and storing process that properly ensures student confidentiality and adheres to all IR standards. The longitudinal database provides opportunity to use new tools designed for big-data analysis.

With each cohort of first-year engineering students, characteristics may change (i.e. demographic diversity, interest and reasons to become an engineering, and motivational factors to persist). As GEARS continues, changes within cohorts, changes within the EF department, and changes within the university are adaptable and able to be explored.

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