



Understanding Diverse Pathways: Disciplinary Trajectories of Engineering Students

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Susan M. Lord received a B.S. from Cornell University and the M.S. and Ph.D. from Stanford University. She is currently Professor and Chair of Electrical Engineering at the University of San Diego. Her teaching and research interests include electronics, optoelectronics, materials science, first year engineering courses, feminist and liberative pedagogies, engineering student persistence, and student autonomy. Her research has been sponsored by the National Science Foundation (NSF). Dr. Lord is a fellow of the ASEE and is active in the engineering education community including serving as General Co-Chair of the 2006 Frontiers in Education (FIE) Conference, on the FIE Steering Committee, and as President of the IEEE Education Society for 2009-2010. She is an Associate Editor of the IEEE Transactions on Education. She and her coauthors were awarded the 2011 Wickenden Award for the best paper in the Journal of Engineering Education and the 2011 Best Paper Award for the IEEE Transactions on Education. In Spring 2012, Dr. Lord spent a sabbatical at Southeast University in Nanjing, China teaching and doing research.

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Matthew W. Ohland is Professor of Engineering Education at Purdue University and a Professorial Research Fellow at Central Queensland University. He has degrees from Swarthmore College, Rensselaer Polytechnic Institute, and the University of Florida. His research on the longitudinal study of engineering students, team assignment, peer evaluation, and active and collaborative teaching methods has been supported by over \$12.8 million from the National Science Foundation and the Sloan Foundation and his team received Best Paper awards from the Journal of Engineering Education in 2008 and 2011 and from the IEEE Transactions on Education in 2011. Dr. Ohland is past Chair of ASEE's Educational Research and Methods division and a member the Board of Governors of the IEEE Education Society. He was the 2002–2006 President of Tau Beta Pi.

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Project goals

This project focuses on examining the research question “How do the trajectories of engineering students in different engineering disciplines vary by both race and gender?” Trajectories are measured at matriculation, four years later, and six-years later (i.e. graduation) for matriculants to the disciplines as well as all students in the major including first time in college (FTIC) and transfers. The impact of first year engineering (FYE) programs is also considered. We focus on the large fields of mechanical, electrical, and computer engineering, that have few women and the smaller fields of chemical, biomedical, and industrial engineering that attract more women. In the supplement approved in 2013, we extended this work to also include Civil Engineering and Aerospace Engineering.

Major activities

Since September 1, 2012, the project team has been productive working together well and making progress on all planned tasks from the proposal. PI Susan Lord, CoPI Matt Ohland and senior personnel Richard Layton, Cathy Brawner, and Russell Long were also involved in the previous Gender in Science and Engineering (GSE) grant that began on September 1, 2007. The results from that project have been well received by the engineering education community including recognition for the best paper in the *Journal of Engineering Education*¹ and the best paper in the *IEEE Transactions on Education*², both in 2011. The IEEE paper is most directly relevant to this current grant and its recognition indicates that the community is interested in this type of work. In June 2013, this research team was awarded the Betty Vetter Award for Research from the Women in Engineering Programs Advocates Network (WEPAN). This award recognizes notable achievement in research related to women in engineering and our citation was for “exceptional research committed to understanding the intersectionality of race and gender.” The External Evaluation Panel (EEP) has been formed including three distinguished members. This group has convened twice to provide feedback to the project team on current progress and plans.

Work during this second year has focused on finalizing methodology for including transfer students. We have also refined the analysis including designing displays, considering the exchange of students between similar fields such as Electrical and Computer Engineering and Mechanical and Aerospace Engineering. A conference paper focused on the large fields of Electrical and Mechanical Engineering was not initially planned but provided useful insights for our analyses. This was presented at FIE in 2013.³

A supplement was requested and granted to extend this work to include Civil and Aerospace engineering. This also included an extension of the grant funding until December 31, 2014.

Significant results

From FIE13 Paper “Student Demographics and Outcomes in Electrical and Mechanical Engineering” Using longitudinal data from eleven institutions in the U.S., this study explores the persistence of students in the two largest engineering disciplines: Electrical (EE) and Mechanical (ME). These programs have large enrollments of students but small percentages of women. Despite these similarities, enrollment and persistence in these majors is qualitatively different. In this research, we adopt an intersectional framework and consider both race/ethnicity and gender. Our results show that ME attracts more White students while EE attracts more Black and Asian students. Hispanic men and women are attracted in similar numbers to EE and ME. Overall, ME has higher graduation rates than EE and women have higher rates than men in both disciplines. Transfer students of nearly all race/gender groups are more likely to persist to graduation than starters in the same disciplines. Black and Hispanic female transfer students are particularly successful in EE and ME, which suggests enhancing the transfer pathway as a strategy to improve diversity. The success of ME starters causes a shift in the demographic profile between starters and graduates. ME could learn from EE how to diversify its enrollment and EE could learn from ME strategies to retain its diverse students. These findings suggest that program factors affect each race-gender group differently. Therefore, the success of recruitment and retention strategies may depend on considering both the target population and the discipline.

From Paper submitted to IEEE Transactions on Education “A Multi-institution Study of Student Demographics and Outcomes for Electrical and Computer Engineering Students in the U.S.” Despite similar curricula, Electrical Engineering (EE) and Computer Engineering (CpE) have different demographics and student outcomes. This work extends earlier longitudinal studies to a larger and more diverse dataset that includes over 90,000 first-time-in-college and over 26,000 transfer students who majored in engineering at U.S. institutions, including students entering EE and CpE through first-year engineering programs, switching from other majors, and transferring from other institutions. This work includes an analysis of transfer student pathways and the study of students who switch between EE and CpE. Although men consistently outnumber women in EE and CpE, the rates of matriculation and six-year graduation vary by race and gender. EE is the most popular choice for Asian and Black students (males and females) at matriculation, but while Asians graduate at high rates, Blacks (particularly males) are not retained. Retention is higher in EE than in CpE for all races. Women of all races in CpE and Hispanic women in EE are less successful than men. Some students of all races and genders leave their starting major, but others migrate in from other majors or institutions, compensating for some of this loss. Trajectories of EE and CpE students are racialized. CpE loses more students and attracts fewer students than EE. While the graduation of CpE students in EE provides an alternative explanation for low CpE persistence, it does not explain the poor persistence of Black students and Hispanic females. Transfer students are generally more successful than non-transfers as shown by higher stickiness. Hispanic women transfers in EE have very high stickiness but not in CpE. These results generate important questions that faculty and administrators of EE and CpE programs must answer if these disciplines are to become more diverse and, in particularly the case of CpE, to resolve national concerns regarding the ability of the discipline to attract sufficient numbers of students.

From Paper accepted by International Journal of Mechanical Engineering Education “Student Demographics and Outcomes in Mechanical Engineering” Using a dataset from universities in the U.S. that includes over 90,000 first time in college and over 26,000 transfer students who majored in engineering, this work describes the demographics and outcomes for students starting in and transferring into Mechanical Engineering (ME). This aims to inform the decision making of faculty, department heads, and Deans. Although men consistently outnumber women in ME, the rates of matriculation and six-year graduation vary by race and gender. Retention is higher in ME than in the aggregate of all engineering majors for Asian, White, and Black students, but not for Hispanic students. While about half of ME starters leave, most are replaced by switchers and transfers. Black males are noticeably absent from this “replacement” population. Black males are also the least likely to stick with ME through graduation. Asian females are the most likely to graduate in ME. Pathways of ME starters and ME graduates are illustrated. Nearly half of all ME graduates started somewhere other than ME.

Key outcomes

This research has involved considerable work in developing effective data displays. As a result, an additional outcome of this project is a new course, ME 497/597 Visualizing Data, developed and taught by Dr. Richard Layton at Rose-Hulman Institute of Technology. The course is about the principles and practices of designing truthful and compelling visual displays of quantitative data. This work involves principles of rhetoric, human perception, graphic design, data analysis, and computer programming.

The course goals are that after taking this course, students will be able to:

- Critique a data display, citing principles of rhetoric, human perception, or graphic design.
- Design effective and truthful data displays and explain their design rationale.
- Demonstrate programming competence by producing publication quality visuals.

The course was taught for the first time in Fall 2012 with 12 students. It will be taught again in Winter 2013.

Dissemination

Results have been presented at key engineering education conferences such as Frontiers in Education (FIE). A manuscript has been accepted by the *International Journal of Mechanical Engineering Education* focusing on Mechanical Engineering.⁴ Manuscripts are under review at the *IEEE Transactions on Education* considering Electrical and Computer Engineering⁵ and *Chemical Engineering Education* considering Chemical Engineering.⁶ These journals were chosen because they target the appropriate disciplinary audiences.

Several journal manuscripts are in preparation and expect to be completed during the next year.

1. Work has begun on a manuscript for the *Journal of Professional Issues in Engineering Education and Practice* focusing on Civil Engineering

2. Work has begun on a manuscript focusing on Bioengineering. The target venue is *Annals of Bioengineering*
3. As this work has evolved, we decided to split the Mechanical Engineering and Aerospace Engineering analyses into two papers. Work of such detailed nature on these topics is not familiar to these communities so we wanted to be sure that the presentation was appropriate for the audience. Thus we did one paper focused on ME and are now working on a separate one focused on Aero.
4. Work has begun on a manuscript focusing on Industrial Engineering. Target venues: *Institute for Industrial Engineers (IIE) Transactions* or the *Institute for Industrial Engineering (IIE) Industrial Engineer*
5. An additional manuscript on Chemical Engineering is in process which combines quantitative information from MIDFIELD with qualitative focus group information obtained during a previous GSE grant. The target venue for this is *Chemical Engineering Education*.
6. An extension of the FIE 2013 article comparing the engineering fields with the largest enrollments but smallest percentage of women, namely Electrical and Mechanical Engineering is also being considered. This was not originally planned in the proposal but has been a useful analysis.

Finally, a consideration of the exchange between Mechanical and Aerospace Engineering is the focus of an ASEE 2014 conference paper.⁷

Publications Related to this Grant

M. K. Orr, S. M. Lord, R. A. Layton, and M. W. Ohland, (in press). Student Demographics and Outcomes in Mechanical Engineering in the U.S.. *International Journal of Mechanical Engineering Education*.

M. Madsen Camacho and S. M. Lord (2013). Latinos and the Exclusionary Space of Engineering Education. *Latino Studies*. 11(1), 103-112.

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M. K. Orr, C. E. Brawner, S. M. Lord, M. W. Ohland, R. A. Layton, and R. A. Long (2012). *Engineering Matriculation Paths: Outcomes of Direct Matriculation, First-Year Engineering, and Post-General Education Models*. 2012 Frontiers in Education Conference. Seattle, WA.

M. W. Ohland, M. K. Orr, S. M. Lord, R. A. Long, and R. A. Layton (2012). *Introducing 'Stickiness' as a Versatile Metric of Engineering Persistence*. 2012 Frontiers in Education Conference. Seattle, WA.

Impact on engineering education

In our previous work, we have shown the importance of disaggregating race and gender in studying engineering student pathways. The fundamental contribution of this work is to uncover the importance of disaggregating engineering disciplines. The climate and culture of engineering is diverse, resulting in diverse inputs and outcomes. We have already begun to demonstrate how the various disciplines of engineering exhibit differences in the demographics of the students they initially attract, in the retention of students, in the ability to attract students, in the openness to transfer students, and in other ways. Differences that also vary by race/ethnicity and gender.

Noting that few researchers (and fewer administrators of single institutions) have access to a dataset that is large enough to disaggregate by race/ethnicity, gender, and discipline all at once, another critical contribution of our work is the design of multiple data displays that make it possible to visualize all these effects. Finally, using the large MIDFIELD dataset, we are able to identify certain effects and provide a baseline for comparison in other analyses.

Impact on other disciplines

Our work is relevant to other disciplines, including but not limited to research in higher education, behavioral sciences, gender studies, ethnic studies, sociology and anthropology of education. Our contributions are both substantive and methodological. By examining the intersectionality of race, gender, and discipline within engineering education our research illuminates variability and prevents “systematic majority measurement bias”, a term we coined in our article in the April 2011 issue of the Journal of Engineering Education (JEE), which was selected as the best paper in the journal in that year.¹ Several reviewers mentioned this term and its meaning as an important and long overdue contribution. The journal editors selected this paper to be featured in the ASEE Prism magazine in JEE Selects, which highlights distinctive and innovative contributions in research that have appeared in JEE and that have the potential to have an impact on the practice of engineering education. While the term was coined considering only the bias introduced by aggregation of race and gender, the same principle applies - that aggregating by discipline results in a perspective that is biased to represent the larger disciplinary populations, particularly Electrical and Mechanical Engineering.

The impact on the development of human resources

By disaggregating matriculation, retention, switching among engineering majors, and switching into engineering from non-engineering majors, we will be able to separate the issues of recruitment, retention, and the ability to attract students enrolled in other majors. These are all important forces in human resource development. The inclusion of transfer students in this work, unlike our previous work, is also critical since transfers potentially draw from a more diverse pool.

Impact on physical resources that form infrastructure

Because of its ability to characterize students entering engineering from multiple pathways, the stickiness metric designed in this work holds great promise for both simplifying research and educational assessment and making it more authentic.

Impact on information resources that form infrastructure

Our methodological innovations affect diverse fields. Our “stickiness” metric has application to all disciplines.⁸ The methodological conclusions we have drawn are of particular interest, since these affect persistence studies in all disciplines.

Acknowledgements

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