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Understanding Diverse Pathways: Disciplinary Trajectories of Engineering Students: Year 3- NSF REE Grant 1129383

Susan M. Lord
University of San Diego

Matthew Ohland
Purdue University

Richard Layton
Rose-Hulman Institute of Technology

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Dr. Susan M Lord, University of San Diego

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 IEEE 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.

Dr. Matthew W. Ohland, Purdue University

Matthew W. Ohland is Professor of Engineering Education at Purdue 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 $14.5 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 Chair of the IEEE Curriculum and Pedagogy Committee and an ABET Program Evaluator for ASEE. He was the 2002–2006 President of Tau Beta Pi and is a Fellow of the ASEE and IEEE.

Richard . Layton, Rose-Hulman Institute of Technology

Richard Layton is an Associate Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received a B.S. from California State University, Northridge, and an M.S. and Ph.D. from the University of Washington. His areas of scholarship include student teaming, longitudinal studies of engineering undergraduates, and data visualization. His teaching practice includes formal cooperative learning and integrating communications, ethics, and teaming across the curriculum. He is a founding developer of the CATME system, a free, web-based system that helps faculty assign students to teams, conduct self- and peer-evaluations, and provide rater training. He can occasionally be found playing guitar at a local open mic.

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Abstract

Engineering as a whole continues to suffer from a low participation of women of all races and Black, Hispanic, and Native American men. To diversify pathways for students to and through engineering and to improve student success, we must first know how to measure success and provide baseline data describing the current situation for all students. Our previous work has shown that persistence or success varies by race and gender, and how we measure persistence matters in understanding this variation. Once women matriculate in engineering, they graduate in six-years at the same or better rates than their male counterparts of all races. This finding, however, shows considerable variation by engineering subdiscipline. Aggregating all engineering disciplines tends to produce a skewed view of the field given the large numbers of students in Electrical and Mechanical engineering. Disaggregation by race and gender is imperative because not all populations respond the same way to similar conditions. Building on earlier findings that trajectories of engineering persistence are non-linear, gendered, and racialized as a whole and for electrical and computer engineering, we are extending these analyses to other engineering disciplines. Using an existing dataset that includes whole population data from eleven institutions throughout the U.S. spanning more than 20 years, we have an unprecedented opportunity to conduct analyses of student persistence disaggregated by race, gender, and engineering discipline. This gives us a unique opportunity to paint a more complete picture of the current situation for students in engineering and to identify successes and areas of concern. Our research question is ***How do the trajectories of engineering students in different engineering disciplines vary by race and gender?*** Trajectories are measured at matriculation, four years later, and six-year graduation for matriculants to the disciplines as well as all students in the major, including first-time-in-college (FTIC) and transfer students. The impact of first-year engineering (FYE) programs is also considered. We focus on the most popular disciplines of engineering: Chemical, Civil, Electrical, Mechanical, and Industrial. In addition, we have considered Aerospace Engineering given its similarity in curriculum to Mechanical and Computer Engineering given its similar curriculum to Electrical. We have begun to work on comparisons of the five most popular engineering disciplines.

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.—the former because feedback from the community indicated that it was inappropriate to leave out one of the five most common disciplines, and the

latter because its enrollments and pathways are sufficiently interrelated with those of Mechanical Engineering students that studying some outcomes require the consideration of both disciplines.

Major activities

Since September 1, 2013, the project team has been productive working together well and making progress on all planned tasks from the proposal. We are publishing in other disciplinary venues as we build on our success in being recognized for the best paper in the IEEE Transactions on Education in 2011[1] for the first of our disciplinary studies and with the Betty Vetter Award for Research from the Women in Engineering ProActive Network (WEPAN) for our "exceptional research committed to understanding the intersectionality of race and gender." The Chair of our External Evaluation Panel (EEP), Dr. Bevlee Watford, is now at the National Science Foundation (NSF). Dr. Rebecca Brent has now become the chair. The team met with Dr. Brent at ASEE in June 2014.

Work during this third year focused on producing journal papers in the various disciplines. We had journal papers accepted on Mechanical Engineering,[2] Chemical Engineering,[3] Electrical and Computer Engineering,[4] and Civil Engineering.[5] At ASEE 2014, we presented a poster (with paper in proceedings) on the overall project,[6] a paper considering the exchange of students between Mechanical and Aerospace,[7] and an interactive panel on Electrical and Computer Engineering.[8] We presented a paper at Frontiers in Education (FIE) in 2014 comparing all disciplines.[9]

Mechanical Engineering (ME)

A paper on ME appeared in 2014 in the *International Journal of Mechanical Engineering Education*. A conference paper focused on the exchange of students between Aerospace and Mechanical Engineering was not initially planned but provided useful insights for our analyses. This was presented at ASEE in 2014. Another paper focused on Mechanical Engineering and Electrical Engineering, the two largest disciplines, was presented at FIE in 2013.

Chemical Engineering (ChE)

A paper on ChE appeared in the Fall 2014 issue of *Chemical Engineering Education*. This focused on quantitative measures similar to the other disciplinary papers. An additional paper which combines quantitative and qualitative data to examine pockets of success for White and Black women in ChE is in progress.

Electrical Engineering (EE) and Computer Engineering (CpE)

A paper on EE and CpE was accepted and became available on August 21, 2014 via Early Access in the *IEEE Transactions on Education*. This extends our work published in 2011 to include a more diverse set of matriculation pathways—students of first year engineering (FYE) programs and transfer students. A panel on student outcomes and demographics in Electrical and Computer Engineering was presented to the ASEE ECE Division in June 2014.

Civil Engineering

A manuscript has been accepted to appear in the *Journal of Professional Issues in Engineering Education and Practice* focusing on Civil Engineering. The Civil/Environmental and Environmental populations are not only much smaller (at least an order of magnitude) than the Civil Engineering population in national ASEE data and MIDFIELD, but they each have a similar demographic composition. For simplicity, therefore, we restricted our work to Civil.

Bioengineering

In working on the Bioengineering/Biomedical Engineering paper, we sought out a collaborator with specific knowledge of the discipline. This gives the work credibility in that community and, more importantly, it helps us interpret the results in the context of the discipline. We consulted with Dr. Naomi Chesler, Associate Professor and Vice Chair of Biomedical Engineering (BME) at the University of Wisconsin-Madison, who has done research on gender diversity in BME as well as mentoring. She emphasized the importance of distinguishing between Bioengineering and Biomedical Engineering, particularly in that our data spans the time period that marks the emergence of BME as a separate entity. In light of this advice, we investigated how MIDFIELD data compares with the ASEE national data.

ASEE data from 2013 shows that Biomedical Engineering has more than six times the students that Bioengineering (which also includes Agricultural Engineering) has. In contrast, the MIDFIELD data has about three times as many Bioengineering majors as Biomedical Engineering majors. Thus we do not have sufficient data to speak to the current situation in Bioengineering/Biomedical Engineering. Our analyses would tell us only about the past and not be representative of the future. We have decided not to pursue a paper on this field as part of the scope of this project.

Significant results

*From ASEE 14 Paper "*Student Demographics and Outcomes in Mechanical and Aerospace Engineering Including Migration between the Disciplines"

There is a large amount of overlap in Mechanical (ME) and Aerospace Engineering (AsE) curricula, and yet the student populations look quite different in terms of race and gender representation. This study includes institutional data from 6 institutions, all of which offered ME and AsE over the period 1987-2010. This large sample (over 20,000 first-time-in-college engineering students) allows us to adopt an intersectional framework to study race and gender together. In this paper, we examine the demographics of students in ME and AsE and their six-year graduation rates. Then we consider the exchange of students between these two similar disciplines and how that affects the graduation rate of each.

Overall, ME does not recruit many women, but it retains many to graduation. AsE, however, has recruitment and retention patterns that highlight the intersectionality of race and gender. For example, being a Hispanic female in AsE is more complex than just the superposition of being a Hispanic student in AsE and being a female in AsE. Within each racial/ethnic group, men who start in engineering choose AsE and ME at higher rates than women who start in engineering. In Aero, the gender gaps are small to moderate among White, Hispanic, and Asian students, with a larger gap between Black men and women choosing AsE (9% vs. 4%). Mechanical Engineering on the other hand, has large gender gaps within all racial/ethnic groups with more men than women choosing ME.

Many students switch from AsE to ME and vice versa. By studying the differences between AsE and ME and the exchange between them, both disciplines can learn from each other about how to improve their recruiting and retention of underrepresented groups.

From paper in Chemical Engineering Education "A Multi-institution Study of Student Demographics and Outcomes in Chemical Engineering"
Using a large multi-institutional dataset, we describe demographics and outcomes for students starting in and transferring into Chemical Engineering (ChE). In this dataset, men outnumber women in ChE except among Black students. While ChE starters graduate in ChE at rates comparable to or above their racial/ethnic population average for engineering, women choose and graduate in ChE at similar or higher rates than men of the same race/ethnicity. Trajectories of ChE students differ by race/ethnicity, but gender differences are small compared with the differences by race/ethnicity and the gender differences observed for engineering as a whole and in other engineering disciplines.

*From paper in IEEE Transactions on Education "*Multi-institution Study of Student Demographics and Outcomes in Electrical and Computer Engineering in the USA*"*

Electrical Engineering (EE) and Computer Engineering (CpE) have similar curricula, but different demographics and student outcomes. This work extends earlier longitudinal studies to a larger and more diverse dataset with 90,000 first-time-in-college and 26,000 transfer students who majored in engineering at USA institutions, including students who started in first-year engineering programs, those switching majors, and those transferring from other institutions. Black men and women and Asian men in engineering are strongly attracted to EE when they start in college. Black students and Asian and Hispanic men are attracted to CpE more than other engineering disciplines, but at lower rates than EE. Asian students have the highest graduation rates in EE. EE students are much more likely to graduate than CpE students. Compared to other engineering disciplines, CpE graduation rates are low for women of all races/ethnicities and Black men. Both EE and CpE lose many starters but switchers and transfers compensate for some of the loss. Considering Asian students and White men, switching to EE accounts for the high attrition rate from CpE, but attrition in other populations cannot be explained so easily. Trajectories of student enrollment differ by race/ethnicity. The approach used in this work could serve a model for others studying their own demographic distributions.

*From paper to appear in Journal of Professional Issues in Engineering Education and Practice "*Student Demographics and Outcomes in Civil Engineering in the U.S.*"*

Using a dataset from universities in the U.S. that includes over 17,000 Civil Engineering (CE) students, this work describes the demographics and outcomes for students starting in, switching into, and transferring into CE to inform the decision making of faculty, department heads, and deans. Pathways in CE vary by race but not gender. Although women generally outpersist men in CE, the difference is small. While Asian and Hispanic Men choose CE at lower rates than others, the Asian and Hispanic men who do major in CE have higher graduation rates than expected. Black students of both genders are underrepresented in choosing CE and in completing the degree. Among Asian, Hispanic, and White students, those who start in CE and leave are replaced by those who transfer or switch in, but Black students entering CE later do not make up for the large losses of Blacks who start in CE. The work suggests a range of qualitative questions to better understand CE students.

Dissemination

Results have been presented at key engineering education conferences such as Frontiers in Education (FIE) and the Annual Conference of the American Society for Engineering Education (ASEE). Manuscripts have appeared in the *International Journal of Mechanical Engineering Education,*[2] the IEEE *Transactions on Education,*[4] and *Chemical Engineering Education.*[3] A manuscript is in press at the *Journal of Professional Issues in Engineering Education and Practice.*[5] These journals were chosen because they target the appropriate audiences of Mechanical Engineering, Electrical and Computer Engineering, Chemical Engineering, and Civil Engineering educators, respectively.

A panel was presented to the ASEE Electrical and Computer Engineering (ECE) Division at ASEE 2014 in June to discuss our data and results with stakeholders in the ECE community, particularly faculty and administrators.[8]

A presentation in the ASEE Mechanical Engineering Division at ASEE 2014 in June allowed us to discuss our data and results with stakeholders in the ME and Aero communities, particularly faculty and administrators. [2]

Future Work

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

1-As this work 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 another one focused on Aero. To determine an appropriate venue for this work, we contacted the Editor-in-Chief of the AIAA Journal of Aerospace Information Systems (JAIS). The Editor-in-Chief was excited about our work. Dr. Marisa Orr, Assistant Professor of Mechanical Engineering at Louisiana Tech led this paper. Nichole Ramirez, currently an Engineering Education PhD student at Purdue, who has an undergraduate degree in Aerospace Engineering also joined the team for this paper. The paper was accepted in January 2015 subject to minor revisions.

2-Work has begun on a manuscript focusing on Industrial Engineering. Dr. Mary Pilotte, Professor of Practice in Engineering Education at Purdue, with significant industry experience in Industrial Engineering is leading this effort. Target venues: *Institute for Industrial Engineers (IIE) Transactions, Institute for Industrial Engineering (IIE) Industrial Engineer,* or the *Journal of Engineering Education.*

3- Work is underway on another manuscript that combines quantitative and qualitative analyses of students in Chemical Engineering. Because many themes which emerged may be of interest beyond Chemical Engineering, we plan to submit this to the *International Journal of Engineering Education*.

4- Work has begun on an overview paper comparing many engineering disciplines. The target venue for this is the *Journal of Engineering Education*. Our conference paper presented at FIE 2014 is a preliminary step in this progress.[9] This gave us an opportunity to explore data displays and identify most interesting results. Based on the emergence of multi-disciplinary stories related to access, pathways, and persistence, it seems likely that this work will need to be published in multiple papers.

Conference Presentations
To reach key stakeholders who teach subdisciplines of engineering, we have had our proposals to present panels sessions at ASEE 15 accepted for Chemical Engineering, Mechanical Engineering, and Industrial Engineering.

Publications Related to this Grant

Journal Publications

1. Ohland, M. W., S. M. Lord, and R. A. Layton, "Student Demographics and Outcomes in Civil Engineering in the U.S.," *Journal of Professional Issues in Engineering Education and Practice*, accepted January 2015, in press.

2. Lord, S. M., R. A. Layton, and M. W. Ohland, "Multi-institution Study of Student Demographics and Outcomes in Electrical and Computer Engineering in the U.S.A.," *IEEE Transactions on Education*, Available in Early Access as of Aug 21, 2014, DOI: 10.1109/TE.2014.2344622.

3. Lord, S. M., R. A. Layton, M. W. Ohland, C. E. Brawner, and R. A. Long, "A Multi-institution Study of Student Demographics and Outcomes in Chemical Engineering," *Chemical Engineering Education*, **48**(4), 223-230 (2014).

4. Orr, M. K., S. M. Lord, R. A. Layton, and M. W. Ohland, "Student Demographics and Outcomes in Mechanical Engineering in the U.S.," *International Journal of Mechanical Engineering Education*, **42**(1), 48-60 (2014).

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

6. Brawner, C. E., M. M. Camacho, S. M. Lord, R. A. Long, and M. W. Ohland, "Women in Industrial Engineering: Stereotypes, Persistence, and Perspectives," *Journal of Engineering Education*, **101**(2), 288-318 (2012).

7. Camacho, M. M. and S. M. Lord, "*Quebrando Fronteras:* Trends among Latino and Latina Undergraduate Engineers," *Journal of Hispanic Higher Education*, **10**(2), 134-146 (2011).

8. Lord, S. M., R. A. Layton, and M. W. Ohland, "Trajectories of Electrical Engineering and Computer Engineering Students by Race and Gender," *IEEE Transactions on Education*, **54**(4), November 2011, pp. 610-618. [received the IEEE Education Society Best Paper award as the best paper published in the journal in 2011]

9. Ohland, M. W., C. E. Brawner, M. M. Camacho, R. A. Layton, R. A. Long, S. M. Lord, and M. H. Wasburn. "Race, Gender, and Measures of Success in Engineering Education," *Journal of Engineering Education*, **100**(2), 225-252 (2011). [Received the William Elgin Wickenden Award recognizing the best paper published in the journal in 2011, selected to be featured in "JEE Selects" in ASEE *Prism*]

10. Lord, S. M., M. M. Camacho, R. A. Layton, R. A. Long, M. W. Ohland, and M. H. Wasburn. "Who's persisting in engineering? A comparative analysis of female and male Asian, Black, Hispanic, Native American and White students," *Journal of Women and Minorities in Science and Engineering,* **15**(2), 167-190 (2009).

Conference Presentations with Proceedings (Peer reviewed)

1. Lord, S. M., M. W. Ohland, and R. A. Layton, "A Disciplinary Comparison of Trajectories of U.S.A. Engineering Students," *Proceedings of the 2014 Frontiers in Education Conference*, Madrid, Spain, October 2014.

2. Lord, S. M., M. W. Ohland, and R. A. Layton, "Understanding Diverse Pathways: Disciplinary Trajectories of Engineering Students," *Proceedings of the 2014 ASEE Conference*, Indianapolis, IN, June 2014. (Poster in NSF Grantees Session and Proceedings Paper)

3. Orr, M. K, S. M. Lord, M. W. Ohland, and R. A. Layton, "Student Demographics and Outcomes in Mechanical and Aerospace Engineering including Migration between the Disciplines," *Proceedings of the 2014 ASEE Conference*, Indianapolis, IN, June 2014.

4. Lord, S. M., M. W. Ohland, R. A. Layton, and M. K. Orr, "Student Demographics and Outcomes in Electrical and Mechanical Engineering," *Proceedings of the 2013 Frontiers in Education Conference*, Oklahoma City, OK, October 2013.

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

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

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. 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.

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.[10] 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.

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

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 are an important population in higher education and potentially draw from a more diverse pool.

Impact on information resources that form infrastructure

Our methodological innovations affect diverse fields. Our "stickiness" metric has application to all disciplines.[11] The methodological conclusions we have drawn are of particular interest, since these affect persistence studies in all disciplines.

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7 Orr, M. K, S. M. Lord, M. W. Ohland, and R. A. Layton, "Student Demographics and Outcomes in Mechanical and Aerospace Engineering including Migration between the Disciplines," *Proceedings of the 2014 ASEE Conference*, Indianapolis, IN, June 2014.

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