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When Am I (N)ever Going to Use This? How Engineers Use Algebra (NSF DRL)

Prof. Brooke Istas, Southern Methodist University

Brooke Istas, consultant, adult education mathematics subject matter expert, Cowley College Mathematics Faculty, and a Ph.D. student at Southern Methodist University is recognized nationally for her knowledge of mathematics and mathematical instruction. She has shown herself to be an asset to adult education and the greater mathematics community. She has given several presentations at state, national, and international conferences on enhancing mathematical instruction, understanding higher-level mathematical content, teaching math at a distance, contextualizing mathematics for engagement, and is always willing to share her learning with others. She understands that adult education is enhanced through collaboration with other adult education programs. Brooke is also devoted to understanding adult learners' perceptions about mathematics to identify the moment that mathematics anxiety is born. Her research focuses on collecting mathematical journeys through qualitative methods. She is also the Subject Matter Expert (SME) for the LINCS (Literacy Information and Communication System), serving at the moderator for both the Math and Numeracy and Science Community of Practice. She is also a reviewer for the Math/Numeracy online resource collection, a part of the Basic Skills Collection of LINCS.

Dr. Candace Walkington, Southern Methodist University

Candace Walkington is an Associate Professor in Mathematics Education and Learning Sciences at Southern Methodist University. She studies personalizing math learning to students' career and personal interests.

Dr. Elizabeth Leyva, Texas A&M University San Antonio

Dr. Elizabeth Leyva is currently serving as the Director of Entry-Level Mathematics at Texas A&M University San Antonio. Her role focuses on student access and success in freshman level mathematics courses, including the implementation of corequisite and supplemental instruction models to support student learning.

Dr. Matthew L. Bernacki, University of North Carolina - Chapel Hill

Matthew Bernacki is an Assistant Professor who joined the UNC-Chapel Hill School of Education faculty in 2018. He earned his Ph.D. in educational psychology in 2010 from Temple University in Philadelphia and also holds master's degrees in Experimental Psychology from Saint Joseph's University and Social Work from Temple University. He worked at the Learning Research & Development Center (University of Pittsburgh) and the Human Computer Interaction Institute (Carnegie Mellon University) as a postdoctoral researcher at LearnLab, and was previously a member of the faculty at the University of Nevada, Las Vegas College of Education. Matt's research focuses on (1) the roles motivations and metacognitive processes play when learners use technologies like hypertext, intelligent tutoring systems, and learning management systems, (2) the development of interventions and software to promote effective learning strategies, and motivation to learn and (3) the development of learning materials and environments that personalize learning to students' interests.

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Brooke Istas, Southern Methodist University, bistas@smu.edu
Candace Walkington, Southern Methodist Univeristy,cwalkington@smu.edu
Matthew Bernacki, University of North Carolina, mlb@unc.edu
Min Wang, Southern Methodist University, minwang@smu.edu
Elizabeth Howell Leyva, Texas A & M University, eleyva@tamusa.edu

Advanced mathematics is required for all engineering degrees, however there have been relatively few research investigations of how engineers use specific math concepts they learn in college. In the present study, we interviewed 12 engineers, asking them a series of questions about how they use particular kinds of algebraic functions (e.g., linear, exponential, quadratic) in their work. The purpose of these interviews was to use the responses to create mathematical scenarios for College Algebra activities that would be personalized to community college students' career interests. This curriculum would represent how algebra is used in practice by STEM professionals. However, our results were not what we expected in that engineers did not typically use many of the concepts from College Algebra. In this paper, we discuss three major themes that arose from qualitative analyses of the interviews, and their implications for the field of engineering.

Keywords: STEM, algebra, career interest engineering

Mathematics has long been a stumbling block for undergraduate students seeking to pursue a variety of majors – including science and engineering (Harackiewicz et al., 2012). Mathematics is an important tool in engineering practice, as mathematical rules govern many designed systems (e.g., Nathan et al., 2013; Nathan et al., 2017). Investigations of structural engineers suggest that mathematical modeling is ubiquitous in their work, but the nature of the tasks they confront is not well-represented in the K-12 classroom (e.g., Gainsburg, 2008). This follows a larger literature base suggesting that school mathematics is often inauthentic and does not represent how mathematics is used in practice. At the same time, algebra is a persistent gatekeeper to careers in engineering (e.g., Harackiewicz et al., 2012; Olson & Riordan, 2012). An important question, then, is what kind of mathematics is actually used by practicing engineers.

In Fall 2018, we began to identify and interview engineers about how they use College Algebra concepts in their careers. First, surveys were given asking about the importance of College Algebra to their field and asking them to identify where specific kinds of algebra would be used in their work. Next, a more in-depth interview was conducted using the same questions from the survey but pushing for a clearer understanding of the use of algebra in their work. Twelve engineers were identified and interviewed for this study. The purpose of these interviews was to use the responses to create mathematical situations for College Algebra activities that would be personalized to community college students' career interests. For example, a student interested in engineering would get to view a video of an engineer describing a situation where the algebraic concept the student is learning is applicable. Thus, the curriculum would represent how algebra is used in practice by STEM professionals. During these one-on-one interviews, many of the engineers would share with the researcher their perspectives and opinions. One female mechanical/biomedical engineer described how they felt about the relevance of their math classes, and our approach of personalizing math to career pathways: "I wish I had that growing up…because I think math classes are my least favorite. They felt the least relevant." This response was not atypical, especially when explicitly asked about topics beyond linear (e.g., y=mx+b) relationships. One female industrial engineer described how "In my specific field, I rarely had the need for advanced calculations - however, I'm confident I was adequately prepared during my college coursework, had the need arisen." These results were not what we expected. In this paper, we discuss three major themes that arose from qualitative analyses of the interviews.

First, we found that engineers resoundingly endorsed the importance of College Algebra concepts for their day-to-day work and often stated that math was vital to engineering. One of the newest male engineers we interviewed, who had just finished college, said, "College Algebra is used heavily in almost every Mechanical Engineering discipline. All of the relationships that show up in functions in college algebra apply to engineering work. Exponential, logarithmic, polynomial, linear, quadratic, and even piecewise functions show up constantly when engineers analyze systems in any domain (hydraulic, electrical, mechanical, etc.). In fact, most of the methods used in Mechanical Engineering can utilize all different types of functions to represent relationships between different parameters in any system."

This juxtaposition of usage in their day-to-day operations as engineers and ability to do algebraic processes for a deeper understanding of their college coursework lead us to the second theme. Engineers struggled to describe how they used functions more complex than linear functions (i.e., y=mx+b) in their work. Students typically learn about linear functions prior to College Algebra, and in College Algebra, explore more complex functions like polynomial, logarithmic, and exponential. Some engineers drew on contexts outside of engineering to describe the application of polynomial, logarithmic, and exponential functions, if they could find a situation at all. Our survey results showed that only 25% of engineers could describe how functions other than linear functions are utilized in their field of engineering. When the researcher asked for specific examples of quadratics, many engineers were familiar with the terminology and could identify that it was used in projectile calculations but struggled with identifying specific examples from their work. One of the primary outcomes of College Algebra is to solve quadratics, and a get deal of time is spent teaching students how to factor, complete the square, factor, and use the quadratic equation. A mechanical engineer revealed the following when asked about the use of exponential and logarithmic functions, "I can't say we do too many exponential or logarithmic functions in my job…it brought back nightmares from my professional engineering exam. I think that was the last time I hit "e" to the some power or log. I don't even know what log does anymore other than taking up space on my calculator."

Third, we found that engineers rarely use the explicit algebraic form of an algebraic function (e.g., y=3x+5) in their work, and instead rely on tables, graphs, informal arithmetic, and computerized computation systems where the equation is invisible. One mechanical engineer commented about the importance to his job of, "…the interpretation and continued iteration of graphs, charts, and even the products/prototypes/projects themselves." Another mechanical engineer described how he used tables: "We look at volume calculations [in a table] associated with tank capacities, product flow rates through piping, pressure measurements related to thermal expansion."

Other engineers accentuated the importance of statistics rather than algebra. An aerospace engineer explained how, "Regression analysis can also be used to mathematically sort out which variables in the data sets have an impact on increasing items such as revenue, program effectiveness and product flow in production in a manufacturing facility." She also described how "Data analytics is very important. You are required to use data sets to find correlations between independent and dependent variables and trends including identifying outliers." Another aerospace engineer described how "We use a lot of relationship analysis - sequential, regression, year over year(s) and yes, there are a lot of cross-relationships." We were surprised by these statements that described an ability to analyze data, given that the bulk of the College Algebra course involves learning how to use and manipulate these formal expressions, learning skills like factoring, simplifying, solving, and interpreting parameters. We also found that these trends for engineers followed trends we saw in our larger sample where we interviewed professionals from across STEM fields.

This study calls into question the gatekeeping role of formal algebraic courses like College Algebra for STEM careers. There are certainly a limited number of people in any field of workwho do need to know advanced mathematics – to program the software that other use, for example. But if most engineers don't actually use 75% of the content in these courses, and do not also seem to be using more advanced content, why are these courses required? One reason might be that the courses are simply outdated, or arguments might be made that learning mathematics builds more general modelling and problem-solving skills. However, research from educational psychology on the difficulty of transfer would strongly refute this point – people tend to learn things that are very specific. Another reason to consider is that formal mathematics courses like advanced algebra have emerged as a very convenient mechanism to filter people by race, gender, and socioeconomic background, and to promote the maintenance of the "status quo" inequality in STEM fields. This is a critical issue to investigate for the future of the field of engineering as a whole.

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