STEM Retention: A Retrospective of Three Civil Engineers

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Abstract

This paper addresses the subject of retention in undergraduate engineering programs through the lens of three civil engineers in the same family. Although anecdotal, the divergent careers of each provide the framework for retrospection on what attracts students to STEM careers, why they persist, and what their ultimate career and life goals are. The experiences are placed in context with material from recent references on STEM education, and then observations and lessons are presented. The personal stories are not intended as evidence to prove national trends, but merely to put them into the context of experience of one family. The ability of curricula to help students envision broad and diverse career paths is an important issue that was crucial for this family.

Keywords Career Choices; Civil Engineering; Engineering Education; Persistence; Retention

Introduction

Crucial to encouraging more young people into STEM careers is of course secondary education (Moulding et al, 2018). Also, the higher education experience is important, where attrition rates in STEM fields match many other fields (National Science Board, 2018). This paper will review some of the issues facing STEM higher education, and give context to these with the personal stories of three civil engineers from one family. This family, as with any particular family, cannot be taken as representative of the larger population in general. Indeed, this is a traditional nuclear family, with all the advantages of access, motivation, resources and convention that implies, and therefore are not characteristic of the general student population. But the experiences of this family, including the fact that the father was a first generation college student, provide interesting insight and identity with the issues. The most recent statistics available (National Science Board, 2018) indicate that the three-year retention rate in science and engineering fields is about 75%, similar to other fields. Although the study did not elaborate, they apparently chose the three-year statistic as an indicator of those persisting into their final year, where changes would be expected to be uncommon. On the other hand, data from a few years earlier indicated that across all STEM fields the actual graduation rate is closer 50% (Chen and Soldner, 2013). About half of those failing to graduate with a STEM degree changed to a non-STEM field, and the other half dropped out of college. While attrition rates are about the same as those in business and the social/behavioral sciences, and actually slightly better than those in humanities, education and health sciences (about 60% attrition), the loss of about half of the students from STEM careers is important to society. While there are many reasons for leaving STEM fields, such as demographic characteristics, precollege preparation and course performance, the type of courses taken in the first year appear to have a key role on whether people leave STEM fields. A rigorous first year set of courses and commensurate good performance are strong indicators of retention (Chen and Soldner 2013).

This paper presents the experiences of three career professionals who entered civil engineering departments at three different universities over two different generations. Each story is unique, but there are some commonalities that offer implications and suggestions for retention efforts. And each had a very different first year experience in terms of courses and projects. The examples of these three individuals are not meant to explain retention and career trends, but to put them into the context of actual experience.

Each of the three subsequently pursued significantly different career paths. This preparation and ability to follow differing trajectories may have a beneficial effect on enhancing one's decision to remain in a STEM educational track. The first author knows many students whose preparation in civil engineering led them to choose very rewarding careers in the legal profession, commercial sales and policy areas. Indeed, the breadth associated with civil engineering may make it particularly well suited with respect to this aspect. In every engineering field perhaps this breadth can be emphasized more in the undergraduate curriculum. Commonalities across fields can be emphasized so that undergraduates can appreciate that their selected field is part of a larger picture addressing societal issues, and that there is a relation across the different fields of engineering. A curriculum that makes room for diverse aspects of solutions and melds science, mathematics, engineering and social concepts together in addressing issues could be an important aspect of retention for some students. These might include the analogies of probability and statistics with different aspects of mechanics (Peterson et al, 1974), and focusing on societal issues (Corotis et al, 2005). It is clear that envisioning breadth of career is not the only factor regarding retention. One cannot overemphasize the importance of diverse role models, effective pedagogy, a sense of belonging, and multiple pathways through the curriculum. And these issues are undoubtedly especially important for the success of traditionally marginalized students.

Familial Experience

The Father

Since the age of three Ross wanted to be an engineer. When he became old enough to distinguish, he knew this meant a structural engineer. Architecture also had attraction, but the math and science foundation of structural engineering won out over the creative aspects of architecture. The second student in the history of his 178-year old Quaker school to attend MIT, he took the 1960's standard first-year, two-semester schedule of calculus, chemistry (with lab), physics (with lab) and of course humanities. The second year was devoted to engineering science, but with the advantage of breadth of exposure with mechanics taught by the mechanical engineering department, dynamics by the aerospace department, and materials by the material science department. Finally, in the third year came a mixture of fundamental and applied civil engineering courses, and the final year with more specialized and design courses (with a concentration in structural engineering), including the team-based, project-oriented senior design class.

This sequence worked fine, but partly because back then one took on faith the importance of building up knowledge from the basics, and the assurance that applications would come eventually. Inspiration and reward came from understanding the basics. Senior design was an important step to the working world; perhaps so realistic that it convinced him to stay for a master's degree rather than join that working world, and then a doctorate, and to be a professor for his whole professional career.

The Son

Also displaying interest in architecture and structural engineering, Benjamin took courses during high school from the Maryland Institute College of Art, worked one summer for an architecture firm, and followed their advice to go to college in civil engineering unless he was definite about a career in architecture. He enrolled at Northwestern University, and followed the mid-1990's standard civil engineering curriculum, which really deviated from the one thirty years earlier only in that there was a first-year applied projects course to introduce and interest the first-year students in solving a real world engineering problem. In this case that experience was to build a robot to maneuver an obstacle course. And the course enticed his mother to attend the competition day. The remainder of the curriculum followed the same pattern as that of the father, including a concentration in structural engineering, and led to the recognition that a graduate degree was now becoming more standard. Completion of a graduate degree in structural engineering at the University of California Berkeley led to the realization that his future lay not in the more advanced structures path of a doctorate, but instead in a master's of architecture at Berkeley. Several years at a small cross disciplinary architectural-structural engineering firm led eventually to his own firm.

The Daughter

Having been moved for her last year of high school from a small private girls' school in Baltimore to a large public school in Boulder, Colorado, Lindsay was unsure of her career direction, but associated best with the students who were serious about math and science. She decided that engineering fit her model better than science, and that civil engineering, with its broad interest in societal projects and team-oriented approaches to problems, was the best fit. The University of Colorado at Boulder, where she matriculated, pioneered an Integrated Teaching and Learning paradigm, with a new laboratory devoted primarily to first-year project-based learning. Each team of four to five students was matched with a real-world problem defined by a practitioner, which in her case was a special education teacher who needed a device for a cerebral palsy student to be able to mimic the click of his mouse. Constraints of time, money, constructability, reliability and practicality were part of the project. The rest of the curriculum was little changed from that of the father, but this time with the chosen specialization of construction engineering management. A master's in that chosen field then led to positions in construction management in the San Francisco Bay area.

The Lessons

So are there lessons to be learned here? Based purely on statistics (and ignoring intra-family correlation), there was less than a 15% probability that all three would remain in and graduate in a STEM field (50% cubed). They persisted, with the probability for the son and daughter very likely enhanced by the strong engineering role model in the family and the financial resources to support their educational choices. It is instructive at this point to examine context.

Some National Trends and Some Local Observations

The retention of all three members of the family in the STEM field stands in contradiction to national trends, and motivates a look at those challenges facing the field. Some associated interesting statistics are that men tend to drop out of STEM degree programs at a higher rate than women (50% for women versus 54% for men), that students from lower incomes tend to drop out at a higher rate, and that the less selective the institution the higher the dropout rate. (Chen and Soldner, 2013). This first statistic was investigated by the father when he was Dean of the College of Engineering and Applied Science at the University of Colorado at Boulder. Women were leaving the college without degrees at the same rate as men, so on the surface it appeared that there was no gender gap. But instituting exit interviews delved deeper and found some interesting observations. In summary, the men said they were leaving because they had lost interest in a STEM career, but the work was not too difficult; their grades were C's and D's. The women said they were still interested in STEM, but they were having trouble with the courses; their grades were A's and B's. There apparently was a gender gap; one of expectation and self-evaluation. A concomitant observation was that while women made up about 20% of the undergraduate student body, they garnered over 50% of the merit-based scholarships and were student leaders in half of the student organizations. Again, the initial observation was one of joy over the success of the women students. But further consideration, along with those exit interviews, suggest that only highly motivated women students were proceeding from high school into STEM college curricula. These women were highly motivated and demanding of themselves. We had plenty of borderline men, but where were the comparable women? They didn't seem to overcome the societal imageries of a male-dominated field to venture into a STEM program. The stigma ran deeper than we had suspected. A recent Canadian study (Sithole et al, 2017) notes with respect to some STEM careers that, "Why there are still only a few women… [indicates] a culturally structured social pattern resulting from specific historical experiences such as patriarchy and other parameters of social inequality." While such social patterns did not discourage the daughter from pursuing an engineering education, they are likely an important aspect for many women.

Nationally, the percentages of men and women who persist through engineering education are similar (Chen and Soldner, 2013; National Science Board, 2018), but these percentages (about 61% for engineering) are lower for both genders than in related STEM fields (about 71% in biological science fields and 62% in social and behavioral science fields. These numbers are better than non-STEM fields, where retention to undergraduate degree is about 55%. It is interesting that across all STEM fields, about half of the males who do not complete a STEM degree drop out of college, while only about a third of the females drop out, with the rest switching to another field (Chen and Soldner, 2013).

Return to the Family

So moving from statistics, what about the anecdotal university experience and professional paths of the family.

The Father

Lack of perseverance was never an option. Partly due to the early desire to be an engineer, and partly to family expectations, one persisted. Through the first years of fundamental theory into the applied subjects, the plan simply evolved. Certainly an element of the success was due to the father feeling he had an excellent advisor, and to role models. The lack of such role models for female and underrepresented minority engineering students could impact the future persistence of those students. But midway through the senior year, the thought of narrowing perspectives to apprentice in a firm became less glamorous and exciting and university life was beginning to exhibit more attractiveness. So armed with a graduate fellowship from the National Science Foundation, a master's degree definitely seemed the way to go. A year later, inspired by a master's thesis and a wonderful advisor, C. Allin Cornell, the idea of research and further learning presented an even more attractive alternative than "the real engineering world". So it was on to doctoral study. Perhaps learning about great engineering works and delving into new theories in focused aspects was the right career choice, not the day-to-day practice of engineering. Fifty years later, through three institutions, one department-founding, one deanship, and one yearlong fellowship with the federal government, simply being a professor was the right career after all.

The Son

Benjamin attended both undergraduate and graduate schools with fairly traditional civil engineering programs, heavily emphasizing the engineering curriculum and not providing many opportunities for electives outside of engineering. There were a couple of opportunities as an undergraduate student for art and music electives and participating in band. These classes and activities outside of the core curriculum were crucial in broadening his interest beyond the engineering fields (and he had to work them into rather limited flexibility in terms of engineering class times, and sometimes with lower enrollment priority as a non-major in those fields). The diversity of these classes not only broadened his education but provided an important balance to his engineering major. Thinking through problems and reasoning from different perspectives gave fresh perspective on engineering classes, allowing him to approach the engineering design problems thinking not only as an engineer but as how an artist or musician might approach the problem. Having the opportunity to move outside of one's comfort zone forces one to reflect on engineering with a new/fresh perspective. History has shown that all the great thinkers can reason outside of their field, bringing new ideas and perspectives that often lead to change in their field, something that can only be nurtured through a diverse education. While at the time the move to the architecture degree was to get a "break" from engineering, in retrospect the study of architecture provided a new way of looking and participating in the engineering field that would not have been possible without the broader educational background. Today in his office, the practice of engineering and architecture are developed together during the design process, and result in opportunities and projects that would not easily happen with a degree in only one field.

The Daughter

Lindsay's parents worked very hard to make sure she did not fall prey to traditional societal stereotypes that women were less capable of excelling in STEM fields. She does not take that blessing for granted. She always excelled at math and liked the physical aspects that came with applying mathematics in an engineering career. In her senior year she came to realize that that for her, the strictly structural aspect of engineering was not a broad enough picture of the physical product. A senior class in Engineering Management and an influential professor opened her eyes to the construction management field. She decided to continue with a Master's degree in construction management and take an internship with a local construction company over the summer and throughout the following year. Upon graduation she was driven to the beauty and diversity of the City by the Bay, San Francisco, and has resided there ever since, working for her second general contracting firm since graduating. While she rarely wears a hard hat on a daily basis anymore, the collaborative nature and daily changing environment of the construction world has proven to keep her entertained and challenged and validated her decision to enter the construction management field. While not utilizing much of her technical background anymore, the knowledge and skills learned in her undergraduate career help her every day.

A Role of Future Imagined Career Paths

So in general terms, there is a lot of commonality. Civil engineering undergraduate educational programs are required by ABET to prepare students to analyze and solve problems in at least four different technical areas of civil engineering (usually chosen from construction, environment, geotechnical, hydrology, structures and transportation), as well as conduct experiments and analyze results in two of the areas (ABET, accessed December 1, 2018). Each of us focused on the buildings side: vertical construction and structures. We continued this general focus for graduate school, as one went into structural engineering for a master's and then structural mechanics, one went into structural engineering and then architecture, and one into construction engineering and management. The subsequent career paths evolved very differently. The father into academia, with research focus on structural reliability, the son into his own business in architecture and engineering, and the daughter into construction management with large firms. Day to day life is very different for the three. It is hard to know how each imagined their eventual career paths, but perhaps this diversity played a role in retention during the undergraduate years.

Only about a third of graduates with undergraduate engineering degrees define themselves as working in engineering occupations as narrowly defined by the Standard Occupational Classification System used by the National Science Foundation and the Bureau of labor Statistics, but a full 80% define themselves as working "in occupations closely associated with engineering that draw heavily on their technical and professional engineering knowledge and skills (National Academy of Engineering, 2018). About a fifth of all graduates (a quarter of the 80%) report that they are in "management occupations associated with engineering" (ibid). Even many of the remaining 20% who report they are not in engineering-related fields indicate that they draw heavily on their problem-solving skills learned in engineering school. A recommendation of the recent National Academy of Engineering study is that professional societies and employers convey to students the wide range of occupations open to engineers, helping to "define and solve important problems for people and society" (ibid). Indeed, most curricula undoubtedly evolve through the guidance of ABET, with implied assumptions about preparation for the workforce and career trajectories, with little attention to the manner in which the curriculum influences student decisions.

It would be interesting to ask undergraduates to express their visions and dreams of how their careers will unfold, and then to reinforce those ideas throughout their undergraduate program. A prior paper considered the generally recognized image of engineers ("techie"), which inevitably influences how undergraduate students view themselves (Corotis and Scanlan, 1989). That paper proposed the following very different picture: "the image of the engineer as a wise and deeply trained intellectual counselor must be enhanced. Of course, this must be based on fact. The educational process that the engineer undergoes must warrant it." (Corotis and Scanlan, 1989). Indeed, improved retention could be an obvious outcome if the undergraduate engineering curriculum worked to replace the image of the engineer as a "high-tech tool" with a "much broader view of engineers as inheritors of the culture of society and guardians and projectors of it toward the clearly technological future" (Corotis and Scanlan, 1989). Possibly this is a call for a diverse education, one that truly prepares them for this broader role, not just for being the number crunchers. Perhaps a new lexicon in the United States is needed, replacing the word "engineer", whose etymological basis derives from "one who operates an engine", to "ingénieur", the French word, which has the same basis as ingenious, ingenuity, and simply genius.

Observations

For economic, entrepreneurial and intellectual reasons, the United States should work to increase the number of young people selecting education and careers in STEM fields, which has remained steady around one-third for the past two decades, although most recent indications are that entering students have shown increased interest in STEM fields (National Science Board, 2018). The particular challenge, and yet opportunity, for engineering, is that the percentage of women enrolled in undergraduate engineering degrees has remained unchanged around 20% (varying less than 1%) since the year 2000 (National Science Board, 2018).

The percentage of underrepresented minorities at U.S. universities across all fields has increased to about a third, almost exclusively due to a significant increase in the number of Hispanic students over this same period (the number essentially doubled since the year 2000) (National Science Board, 2018). The percentage of Hispanics at American universities increased from 10% to 17% over the 15-year period shown, while that of Black or African American only increased from 11% to 13%. If Science and Engineering degrees are to grow to more than about a third of all undergraduate university degrees, there must be increased attractiveness across all demographics. The demographics carry an important enough message that Figure 1 is reproduced here from the National Science Board (2018) report Science and Engineering Indicators. "Science and Engineering Indicators and other titles published by the National Science Board are works of the U.S. federal government and carry no claim to copyright. Thus material from these reports may be freely used as in the public domain." The attractiveness to the engineering field for women must be moved from the 20%, where it has been for almost two decades, and minority groups including the growing Hispanic population must be attracted to the fields (NASEM, 2018). As referenced earlier, excellent studies have been conducted on the broadening of diversity among engineering undergraduates (e.g., Chen and Soldner, 2013; Sithole et al, 2017). The limited experiences of three individuals from a rather traditional family that are discussed in this paper do not form a sufficient scientific study to allow one to draw conclusions from

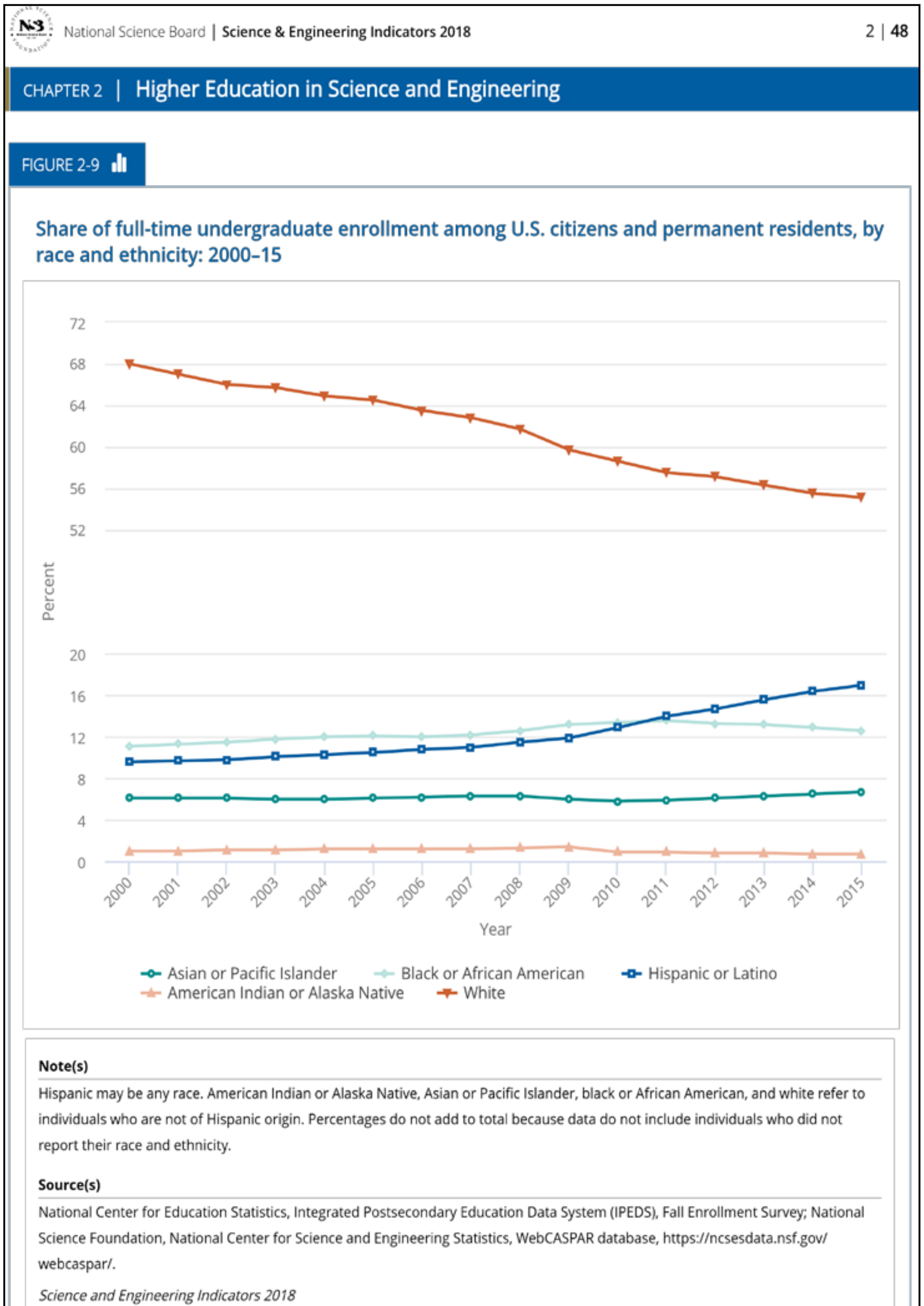

Figure 1. STEM undergraduate enrollment of citizens and permanent residents by race and ethnicity: 2000-2015. (The National Science Board (2018) *Science and Engineering Indicators*)

those experiences in this important area.

The actual numbers for science and engineering are somewhat more encouraging. The number of undergraduate degrees in engineering essentially doubled, increasing from about 50,000 in 2000 to 100,000 in 2015 (the physical sciences and mathematics saw an increase of about one-third during this same period) (National Science Board, 2018). Undergraduate enrollment in all science and engineering fields reached a peak of around 600,000 during this period. This is driven by the fact that entering first-year students indicating interest in science and engineering increased from about one-third in 2000 to 45% in 2016 (about one-quarter of these indicated engineering).

Actual degrees granted in STEM fields reflect continued movement out of those fields during the undergraduate years. For instance, in 2016 the percentage of STEM undergraduate degrees awarded (including social science) was 26% (National Center for Education Statistics, 2019). This percentage has decreased only slightly since 1971, when it was 33%. During this same period, undergraduate degrees in business rose from 14% to 19%, those in communication from 1% to 5%, and those in health and related fields from 3% to 12%. It is also interesting that during that period the degrees in education dropped from 21% of the total to 5%, and those in the social sciences dropped from 18% to 8%.

This attractiveness to engineering, in particular, need not and should not necessarily come from dramatic changes in the undergraduate curriculum. Rather it can come from an increased awareness of the importance in recognizing different learning styles and different reasons why students make the leap from a high school introduction to science (in most school districts) to a commitment to a career in engineering. With an increased awareness of broader career paths, it can be expected that should attract students with wider self-images and career aspirations than it is doing now. Introductory classes could excite them about the array of career paths that are possible for those with engineering degrees.

The experience referenced earlier regarding retention characteristics by gender in the University of Colorado engineering program indicates that students who enter an engineering education do so with varying goals and aspirations. Appealing to a wider range of student individualities could make many more students feel welcome in an engineering program. These students then have to see an eventual career that respects, nourishes and rewards these varying aspirations. This probably should start with a change in mindset of the faculty. Careers in public policy, social service, secondary-level teaching (and even perhaps more importantly at the primary level), entrepreneurship, intellectual property, technical sales and service must be respected and engendered to the same degree as graduate engineering education and careers in research and higher education. Indeed, perhaps more universities should offer a degree in engineer that is not designed for people directly practicing engineering, but instead are product designers, astronauts, economists, toy designers, video game developers, creators of public policy etc. This might follow the templates of the Bachelor of Arts degree in General Engineering developed at The Johns Hopkins University (for which the first author of this paper was the founding academic advisor), and the four-year non-ABET accredited Bachelor of Arts degree at Dartmouth College (which can be followed by the ABET accredited Bachelor of Engineering degree if desired).

Conclusions

While no single family experience can represent all issues regarding engineering education (indeed, Bill Wulf, the former President of the National Academy of Engineering, used to say "data is not the plural of anecdote"), the experiences can help us reflect on why young people decide on a career in engineering, and what may lead to increased retention in that field. Indeed, it may be miraculous that as many people select engineering as they do when one reflects on a poll reported by Wulf a decade ago: two percent of the public associate the word "invents" with engineering, three percent associate "creative", and five percent associate "train operator" (Wulf, 2008). We need to attract a broader diversity into engineering: gender, race and especially people with a wide variety of creative interest and career dreams.

Declarations

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References

ABET Criteria for Accrediting Engineering Programs, 2018-2019. Accessed December 1, 2018. https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2018-2019/#3

Chen, Xianglei and Soldner, Matthew (2013, November). *STEM Attrition: College Students' Paths Into and Out of STEM Fields, Statistical Analysis Report.* U.S. Department of Education, Institute of Education, National Center for Education Statistics, Alexandria, Virginia, NCEA 2014-001.

Corotis, Ross and Scanlan, Robert (1989). Future of Civil Engineering Profession and Role of Education, *Journal of Professional Issues,* ASCE, 115(2), April, 117124.

Corotis, Ross, Frangopol, Dan, Diekmann, James, Molenaar, Keith and Hearn, George (2005). An Educational Experiment to Address Infrastructure Needs, *International Journal of Critical Infrastructures,* 1(2/3), 269-280.

Moulding, Brett, Songer, Nancy and Brenner, Kerry Editors (2018). *Science and Engineering for Grades 6-12: Investigation and Design at the Center*, The National Academies of Sciences, Engineering and Medicine, The National Academies Press. Doi: https://doi.org/10.17226/25216, Washington, DC.

NASEM (2018). National Academies of Sciences, Engineering, and Medicine. *Minority Serving Institutions: America's Underutilized Resource for Strengthening the STEM Workforce*. Washington, DC: The National Academies Press. doi: https://doi.org/10.17226/25257.

National Academy of Engineering (2018). *Understanding the Educational and Career Pathways of Engineers*. Washington, DC: The National Academies Press. https://doi.org/10.17226/25284.

National Center for Education Statistics (2019). Department of Education. Website https://nces.ed.gov/fastfacts/display.asp?id=37, accessed February 11, 2019.

National Science Board (2018). *Science and Engineering Indicators 2018*, Alexandria, Virginia, National Science Foundation (NSB-2018-1). Available at https://www.nsf.gov/statistics/indicators/.

Peterson, George, Wachs, Martin and Corotis, Ross (1974). "Teaching Through Analogy: Moment Theory in Statics and Statistics," *Mechanical Engineering News,* ASEE, Vol. 11, No. 3, August, 2429.

Sithole, Alec, Chiyaka, Edward, McCarthy, Peter, Mupinga, Davison, Bucklein Brian, and Kibirige, Joachim (2017, January). Student Attraction, Persistence and Retention in STEM Programs: Successes and Continuing Challenges, *Higher Education Studies,* (7:1), Canadian Center of Science and Education, Richmond Hill, Ontario, Canada, 46-59.

Wulf, William (2008). Diversity on Engineering, updated article from *The Bridge*, 28(1), National Academy of Engineering, Washington, DC.

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