Mechanical Engineering Undergraduate Education in the United States

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Abstract

The first part of the paper provides an overview of the current state of higher education in mechanical engineering-related undergraduate degree programs in the United States by examining the number, types, and availability of these programs in different states in the United States. The second part of the paper provides a summary of the examination of the curricular structure and requirements of the Bachelor of Science degree in mechanical engineering (BSME) degree programs in the United States. For ease of comparison, only sample curricula from 201 public universities on semester systems are considered. A total number of 125 BSME degree programs are selected for the present study. In particular, the total number of units requirement as well as the curricular component of the degree requirements in mathematics and science, major core requirements, technical electives, and general education are examined. This paper also addresses how each BSME program designs and implements its curriculum to prepare students in either mechanical or thermal systems. This paper is also intended to discuss how each program incorporates first-year experience, hands-on laboratory experience, and capstone design experience in the curriculum. In summary, a map of higher education in mechanical engineering-related programs is provided in the first part of this paper, while the latter part will be helpful for educators to learn of the current mechanical engineering curriculum trends in the United States.

Introduction

The bachelor's degrees awarded in mechanical engineering has increased by 84% from 17,375 in 2009 to 31,936 in 2018 [1]. Most mechanical engineering programs have experienced first-hand the enrollment growth over the last ten years. Take our own BSME degree program, for example. The number of degrees awarded has increased from 34 students in AY 2010-2011 to 219 students in 2018-2019. The number of 2-year associate's degrees in engineering technology typically awarded by 2-year community colleges was on the decline from 38,483 in AY 2010-2011 to 27,918 in AY 2016-2017 while the 4-year bachelor's degrees in engineering technology awarded has increased from 5,811 to 7,779 in the same period of time [2]. The popularity of a degree major is typically driven by the demand for labor in the job market. Based on the U.S. Bureau of Labor Statistics (BLS) on the Occupational Employment Statistics in 2018, around 25% of mechanical engineering jobs in the United States were found in six metropolitan areas: Detroit, Chicago, Los Angeles-Anaheim, Boston, New York, and Houston [3]. There were 78,450 mechanical engineer jobs in these metros, and that represented 4.46 mechanical engineer jobs per 1,000 workers. The BLS also estimates that mechanical engineering technician jobs and mechanical engineer jobs will increase by 3% and 4% from 2018 to 2028, respectively [4]. Based on the statistics, most mechanical engineering programs in these metros will continue to have opportunities to achieve and sustain growth in enrollment. The first part of the paper thus identifies the availability of degree programs in mechanical engineering related fields in different states in the United States.

The next question to address is whether the current mechanical engineering curriculum is adequate to prepare the next generation of mechanical engineers for their profession in both traditional and emerging fields in mechanical engineering. The National Academy of

Engineering established a steering committee in 2001 to provide a vision for the engineers in 2020 [5]. The career aspirations and desired attributes for future engineers were presented in that report. Similarly, the American Society of Mechanical Engineers (ASME) also established ASME Vision 2030 Task Force in 2008 to assess the state of ME education and provide recommendations for improving the curricula [6]-[7]. Four of the recommendations more closely related to mechanical engineering curricula included were: (a) to provide increased curricular flexibility, (b) to motivate and engage students in practice-based engineering experience and high-impact practices, (c) to foster the innovation and creativity skills, and (d) to strengthen the professional skills (soft skills). The mechanical engineering programs must also ensure to meet the ABET Engineering Accreditation Commission (EAC) program criteria [8] and to address ABET EAC student outcomes (1) through (7) in the curricula [9]. Often, the desire for curriculum revision is also met by other constraints. For example, the California Code of Regulations Title 5 CCR §40508 mandates that no baccalaureate degree programs shall extend the unit requirement beyond 120-semester units. An exception can be authorized by the Chancellor with justification provided. More recently, the Graduation Initiative 2025 (GI 2025) was launched in 2016 with the objectives to increase the retention and graduation rates for all California State University students while eliminating opportunity and achievement gaps for underrepresented minorities and Pell-eligible students by 2025. Curriculum review and revision to remove potential barriers for timely graduation is one way to increase the graduation rate. The second part of the paper is intended to dissect the current structure and composition of the degree requirement for mechanical engineering bachelor's degree and examine them carefully to identify the current trends of the mechanical engineering curricula in the nation.

Mechanical Engineering Related Degree Programs

First, the current state of higher education in mechanical engineering in the United States, the availability of bachelor's degrees in various mechanical engineering-related fields are first examined, and a summary is provided in Table 1. The programs included in this study are all ABET-accredited programs as of October 01, 2019 [10]. There are currently 327 undergraduate programs offering a BSME degree program in the United States. From these, 217-degree programs are from public universities and 110 from private universities. Figure 1 presents a map of the distribution of the BSME offered in different states in the United States. California, Texas, New York, Pennsylvania, and Michigan are the five states offering the most number of BSME

Table 1: Number of Bachelor of Science degree programs in mechanical engineering related fields in the United States.

	Bachelor of Science Degree Program					
	Mechanical Engineering	Mechanical Engineering Technology	Aerospace Engineering Related	Materials Engineering Related	Manufacturing Engineering Related	Systems Engineering Related
Public University	217	52	49	57	19	10
Private University	110	8	18	14	3	4
Total	327	60	67	71	22	14

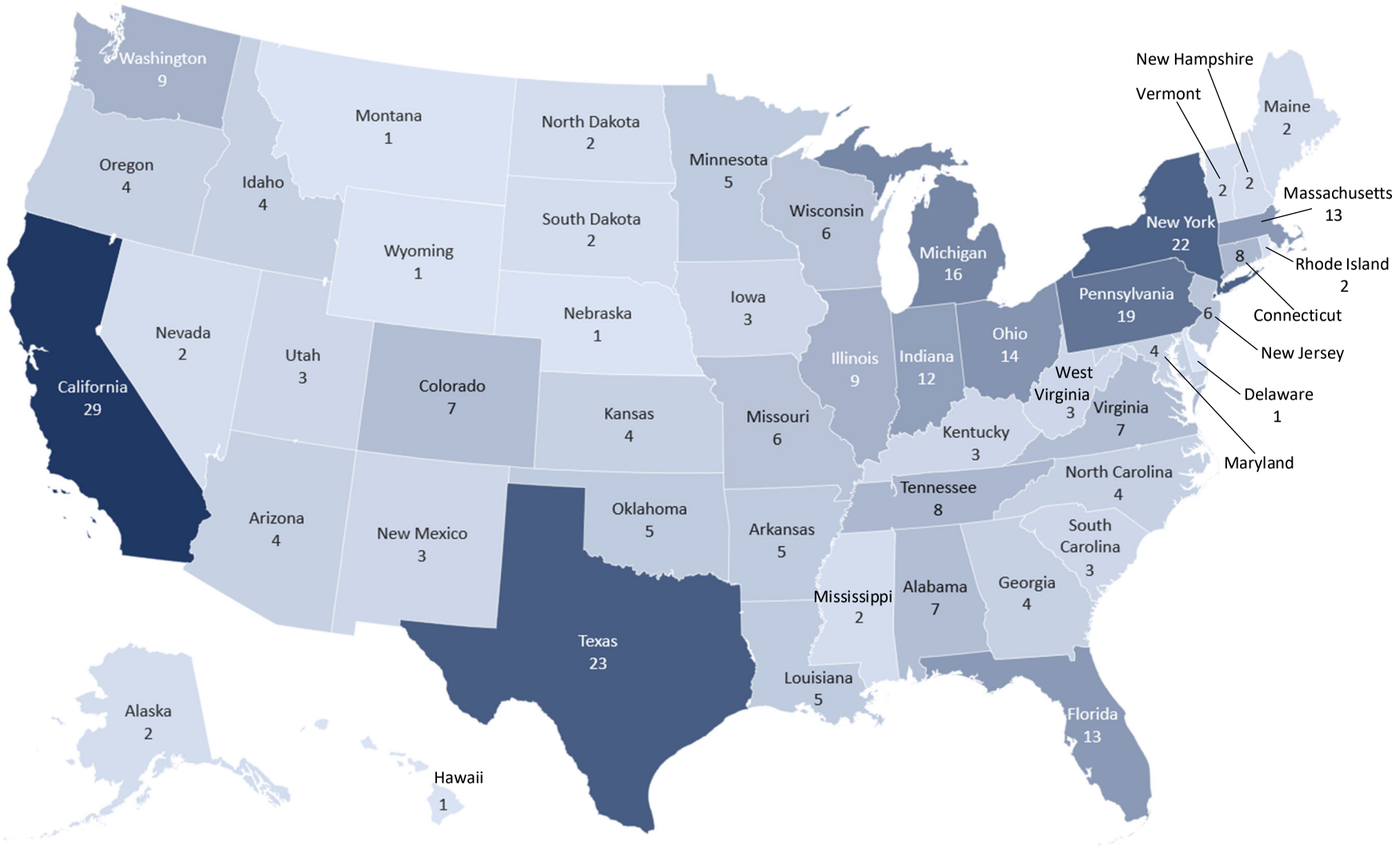

Figure 1: The availability of the Bachelor of Science degree programs in mechanical engineering in the United States.

degree programs. Corresponding to the one-quarter of all mechanical engineering jobs in the United States found in the six aforementioned metro areas, around 35% of the BSME degree programs are available in the respective states. Among the BSME degree programs, Georgia Institute of Technology, Pennsylvania State University, Iowa State University, Purdue University at West Lafayette, and Virginia Tech are among the largest mechanical engineering programs in the country [1]. As for four-year undergraduate degree programs in mechanical engineering technology, there are currently 60 programs in the United States: 52 from public and eight from private universities. As shown in Figure 2, the majority of the mechanical engineering technology programs are offered in the Great Lakes region, including states of New York, Ohio, Michigan, Indiana, and Pennsylvania. The number of four-year mechanical engineering technology programs in these five states accounts for 47% of programs in the United States. The red dots in Figure 2 represent the location of the institutions offering the program.

In addition to mechanical engineering and mechanical engineering technology programs, other degrees closely related to mechanical engineering being offered include degrees in aerospace engineering, materials science and engineering, manufacturing engineering, and systems engineering, as summarized in Table 1. Most aerospace engineering degree programs reside in the mechanical engineering department, or there is a joint mechanical and aerospace engineering department. The core curriculum requirement for an aerospace engineering degree is similar to that of the mechanical engineering degree program. 67 programs (49 public and 18

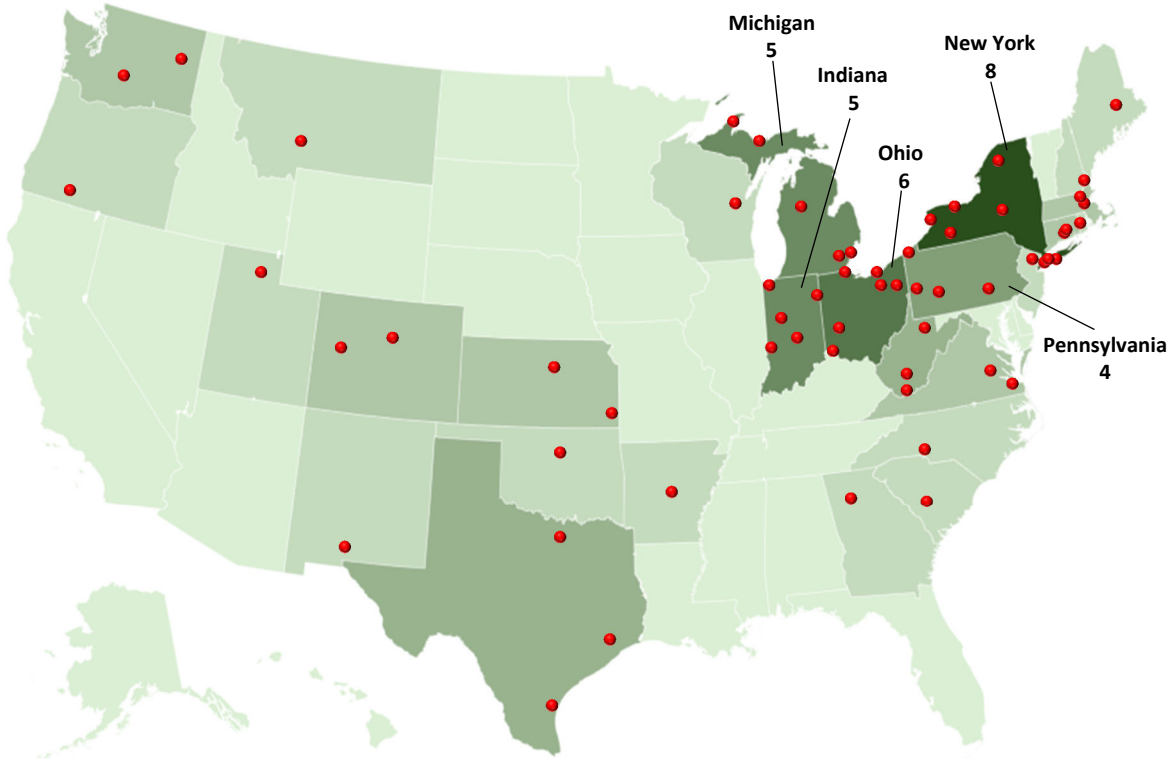

Figure 2: The availability of the Bachelor of Science degree programs in mechanical engineering technology in the United States.

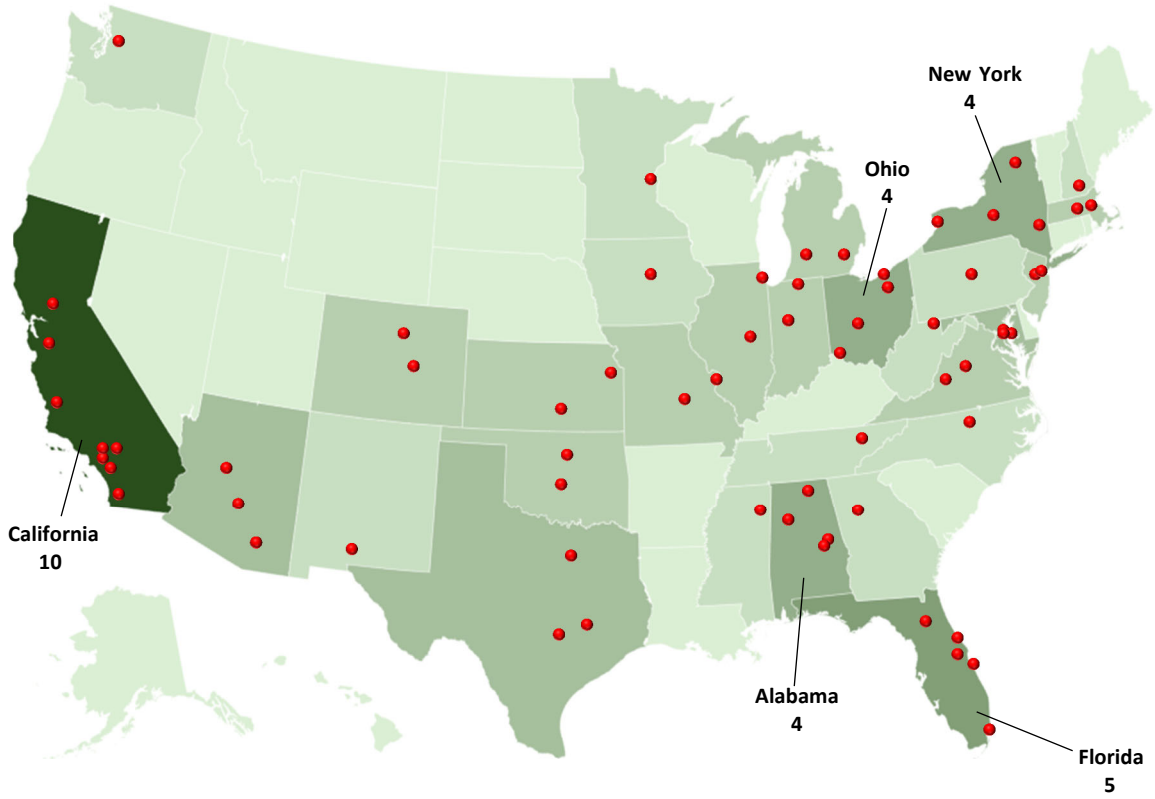

Figure 3: The availability of the Bachelor of Science in aerospace engineering-related degree programs in the United States.

private) are available in 29 states with California, Florida, New York, and Alabama has the most number of programs in the aerospace engineering-related areas, as shown in Figure 3. The data presented here include degrees such as the aeronautical/astronautical engineering, aerospace science engineering and aerospace systems engineering.

Another popular degree program often offered through the mechanical engineering department is the materials science and engineering program. There are 71 programs in the United States related to the materials field including degree programs such as materials science and engineering, metallurgical engineering, plastics engineering, paper engineering, composite materials engineering, polymer science and engineering, ceramic engineering, glass engineering science, textile engineering and materials science and nanoengineering. 22-degree programs in the manufacturing area are also offered through degree programs such as manufacturing engineering, manufacturing systems engineering, management, and engineering for manufacturing, manufacturing and design engineering, product design, and manufacturing and welding engineering. More engineering colleges are now offering a degree program related to systems engineering to prepare students to solve and design integrated solutions to complex interdisciplinary real-world problems. University of Arizona established the first systems engineering department in the nation in 1961. A total of 14 systems engineering degree programs are available from programs such as the United States Air Force Academy, United States Naval Academy, United States Military Academy, George Mason University, and the University of

Virginia. The University of Illinois at Urbana-Champaign offers a major in systems engineering and design; Case Western Reserve University offers a degree in systems and control engineering while both Washington University and University of Pennsylvania offer degree programs in systems science and engineering. Similar to systems engineering, Purdue University offers a major in multidisciplinary engineering while Grand Valley State University has a major in interdisciplinary engineering.

In recent years, more ABET-accredited programs are found in the following emerging fields. The examples of the institutions given in the list below are not intended to be an exhaustive list.

(a) Nanoengineering Fields: University of California, San Diego, has a Department of Nano-Engineering, and their Bachelor of Science degree in nanoengineering has been accredited by the Engineering Accreditation Commission of ABET since 2014. Louisiana Tech University has a B.S. in nanosystems engineering degree program while the State University of New York, Polytechnic Institute, offers a degree in nanoscale engineering.
(b) Renewable Energy Fields: Oregon Institute of Technology is the pioneer in offering a bachelor's degree in renewable energy engineering since 2005. Energy systems engineering programs are offered by Oregon State University, Massachusetts Maritime Academy, and University of Wyoming. Energy engineering degree programs are available at the Indiana University-Purdue University Indianapolis (IUPUI), Ohio University and Penn State University.
(c) Robotics Engineering Fields: Worcester Polytechnic Institute is the first institution in the nation to offer a bachelor's robotics engineering degree program. This robotics program has been accredited since 2009. More recently, an undergraduate robotics engineering degree is also available at the University of Michigan - Dearborn and Lawrence Technological University.
(d) Mechatronics Engineering Fields: The undergraduate major of mechatronics is available through programs such as the California State University Chico, Kennesaw State University in Georgia, Vaughn College of Aeronautics and Technology in New York and Middle Tennessee State University. Wentworth Institute of Technology offers a similar degree in electromechanical engineering.

Other unique degree programs in mechanical engineering related areas are also found throughout the nation. For example, Old Dominion University offers the nation's first and only bachelor's degree in modeling and simulation engineering. Driven by the motorsports and performance racing industry in Indianapolis, IUPUI is the first program offering a bachelor's degree in motorsports engineering. Penn State Altoona and University of Akron are the first and only program to offer a bachelor's degree in rail transportation engineering and corrosion engineering, respectively. Another interdisciplinary engineering program is the acoustical engineering and music program offered by University of Hartford in Connecticut.

Total Degree Units Requirement and Composition

The next part of the paper examines the curriculum structure and composition of mechanical engineering degree programs in the nation. In a recent study conducted to explore the current trends of mechanical engineering education in California [11], it is found that private

universities tend to allow more flexibility in the major curricula compared to the public universities. It is also challenging to compare the degree programs in the semester system with those in the quarter system. As such, the present study will consider public universities on the semester system only: 201 out of the 217 public universities offering BSME degree are on the semester system. A sample of 125 programs is then selected for this latter part of the study. Care is taken to ensure an unbiased selection of the programs included. The 125-program sample intends to include representation from every state, and the number of programs selected is corresponding to the state population. The selection of the programs within each state is then based on the number of graduates in AY2017-2018 [1] such that all the major programs in the nation are captured in the sample. It is noted that unfortunately none of the four Oregon programs offering BSME degree is included in this sample study as the three public universities in the state (e.g., Oregon Institute of Technology, Oregon State University, and Portland State University) are on a quarter system and University of Portland is a private university on a semester system. In addition, the degree programs such as United States Air Force Academy, United States Coast Guard Academy, United States Naval Academy, and United States Military Academy are excluded from the sample list as these program degree requirements are not all readily available from the websites. Also, these degree requirements include additional cadet requirements beyond the typical mechanical engineering degree requirements. Table 2 presents the list of 125 programs included in the present study with the total degree units requirement. The most updated degree requirements or flow charts were obtained from the online catalog [12]-[136]. As shown in Figure 4, 9.6 % of programs require 120 total units. It is noted that four

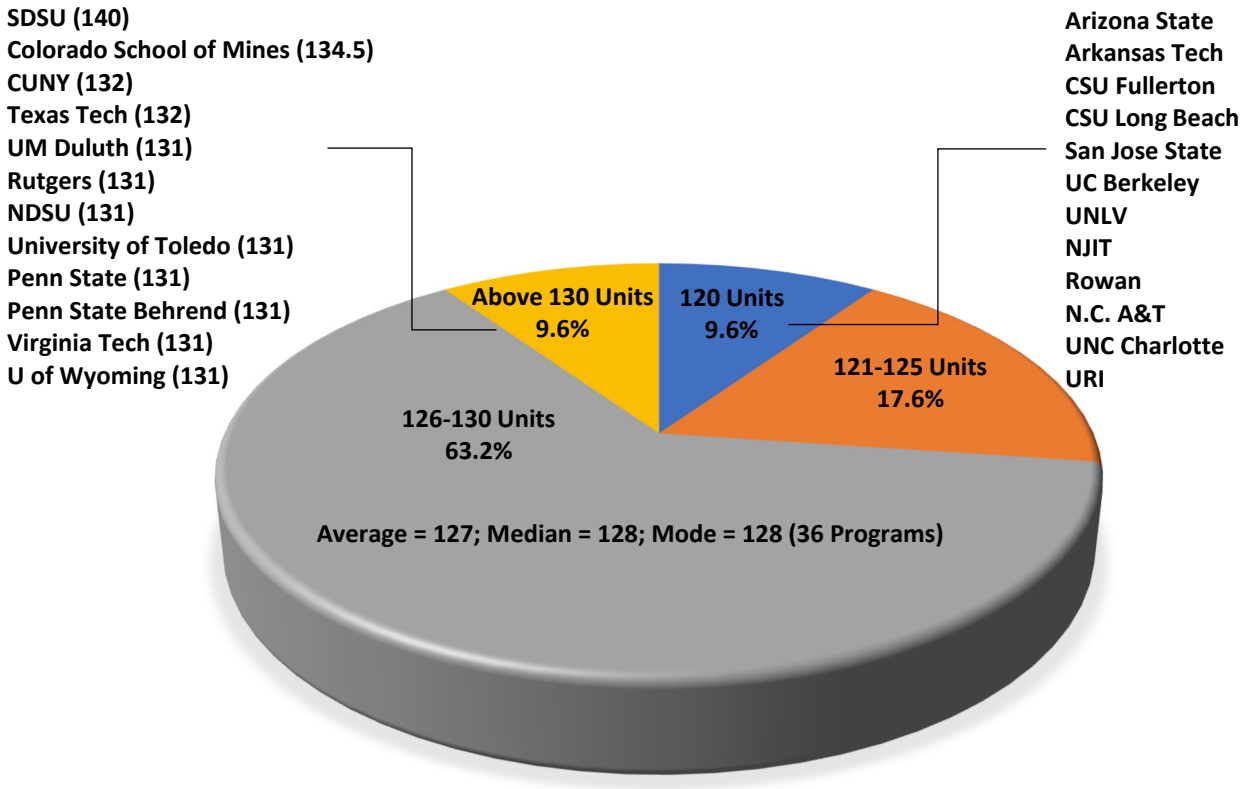

Figure 4: Categorization of mechanical engineering programs based on the total degree unit requirement.

Table 2: Total degree unit requirements for 125 mechanical engineering programs [12]-[136].

State	University	Unit	State	University	Unit
AL	Auburn University	122	**MS**	Mississippi State University	128
	The University of Alabama in Huntsville	129		The University of Mississippi	128
	The University of Alabama	126	**MO**	Missouri University of Science and Technology	128
AK	University of Alaska, Fairbanks	130		University of Missouri, Columbia	127
AZ	Arizona State University	120		University of Missouri, Kansas City	130
	University of Arizona, Tucson	128	**MT**	Montana State University, Bozeman	128
AR	Arkansas Tech University*	120	**NE**	University of Nebraska, Lincoln	128
	University of Arkansas, Fayetteville	124	**NV**	University of Nevada, Las Vegas	120
CA	Cal Poly Pomona*	127		University of Nevada, Reno	126
	California State University, Fullerton*	120	**NH**	University of New Hampshire	129
	California State University, Long Beach	120	**NJ**	New Jersey Institute of Technology	120
	California State University, Los Angeles*	122		Rowan University	120
	California State University, Northridge*	126		Rutgers, The State University of New Jersey	131
	California State University, Sacramento*	122	**NM**	University of New Mexico	125
	San Diego State University	140	**NY**	The City University of New York, City College	132
	San Jose State University*	120		State University of New York at Binghamton	128
	University of California, Berkeley	120		Stony Brook University	130
	University of California, Merced	121		University at Buffalo, The State U. of New York	128
CO	Colorado School of Mines	134.5	**NC**	North Carolina Agricultural and Technical State U.	120
	Colorado State University, Fort Collins	129		North Carolina State University	126
	University of Colorado Boulder	128		University of North Carolina at Charlotte	120
CT	University of Connecticut, Storrs CT	128	**ND**	North Dakota State University	131
DE	University of Delaware	125	**OH**	Cleveland State University	128
FL	Florida International University	128		Ohio University	127.5
	Florida State University	128		The Ohio State University	130
	University of Central Florida	128		The University of Toledo	131
	University of Florida	128		University of Cincinnati	126
	University of South Florida	128	**OK**	Oklahoma State University	121
GA	Georgia Institute of Technology	129		The University of Oklahoma	123
	Georgia Southern University*	130	**PA**	Pennsylvania State University	131
	Kennesaw State University*	130		Pennsylvania State University, Behrend College*	131
	University of Georgia	130		Temple University	128
HI	University of Hawaii at Manoa	125		University of Pittsburgh	128
ID	Boise State University	125	**RI**	The University of Rhode Island	120
IL	Northern Illinois University	126	**SC**	Clemson University	125
	Southern Illinois University Carbondale	126		University of South Carolina	125
	Southern Illinois University Edwardsville*	126	**SD**	South Dakota School of Mines and Technology	130
	The University of Illinois at Chicago	128	**TN**	Tennessee Technological University	129
	University of Illinois at Urbana-Champaign	128		The University of Tennessee Knoxville	128
IN	Indiana University – Purdue U. Indianapolis	128	**TX**	Texas A&M University	129
	Purdue University at West Lafayette	128		Texas Tech University	132
	Purdue University Northwest*	122		University of Houston	128
IA	Iowa State University	129		University of North Texas	127
	University of Iowa	129		The University of Texas at Arlington	130
KS	Kansas State University	125		The University of Texas at Austin	126
	The University of Kansas	128		The University of Texas at Dallas	127
	Wichita State University	128		The University of Texas at El Paso	128
KY	University of Kentucky	127		The University of Texas at Rio Grande Valley*	129
	University of Louisville	125		The University of Texas at San Antonio	128
LA	Louisiana State University	127	**UT**	University of Utah	127
	University of Louisiana at Lafayette	130		Utah State University	127
ME	University of Maine	129	**VT**	The University of Vermont	126
MD	University of Maryland Baltimore County	126	**VA**	Old Dominion University	128
	University of Maryland College Park	124		University of Virginia	128
MA	University of Massachusetts Amherst	124		Virginia Commonwealth University	130
	University of Massachusetts Dartmouth	123		Virginia Polytechnic Institute and State University	131
	University of Massachusetts Lowell	127	**WA**	Washington State University	127
MI	Michigan State University	128	**WV**	West Virginia University	124
	Michigan Technological University	128	**WI**	University of Wisconsin – Madison	128
	Oakland University	128		University of Wisconsin – Milwaukee	128
	University of Michigan, Ann Arbor	128		University of Wisconsin – Platteville*	124
MN	University of Minnesota, Twin Cities	125	**WY**	University of Wyoming	131
	University of Minnesota, Duluth*	131			

*Non-Ph.D. Granting Programs

out of twelve of those programs are from California: California State University, Fullerton, California State University, Long Beach, San Jose State University and the University of California, Berkeley; two from New Jersey: New Jersey Institute of Technology and Rowan University; and two from North Carolina: North Carolina A&T University and University of North Carolina, Charlotte. The remaining four programs at 120 units are Arizona State University, Arkansas Tech University, University of Nevada Las Vegas, and University of Rhode Island. On the other hand, 9.6% of the programs require more than 130 units. San Diego State University has the highest total unit requirement at 140, followed by Colorado School of Mines at 134.5. The majority of the programs, with 63.2% has between 126 and 130 units. The average total unit requirement is 127, with a median of 128, and 36 programs out of 125 programs are at 128 units (mode). The composition of mechanical engineering degree programs in different categories is discussed next.

Mathematics and Sciences

A typical engineering curriculum is structured around a sequence of mathematics and science courses in the first two years of college. Many mechanical engineering programs place four courses in the mathematics sequence: differential calculus, integral calculus, multivariable calculus, followed by differential equations, and or linear algebra. For sciences, a common list of courses includes two physics courses in mechanics followed by electricity and magnetism with laboratories. Some mechanical engineering programs require a third-semester physics (commonly optics, waves, and thermodynamics). Almost all mechanical engineering programs require at least one course in chemistry. In 125 mechanical engineering programs studied in this paper, 14 programs are requiring at least one course in life science.

There is no doubt that mathematics and science courses serve as the foundation, as well as an early predictor for success in upper-division mechanical engineering courses. Despite critical importance placed in mathematics and sciences in the mechanical engineering curriculum, little has changed over the years, for a variety of reasons. Many times, when a mechanical engineering curriculum goes through a revision, the changes often take place outside of mathematics and science courses. Changes in the first two years occur with modifications only in courses, such as Introduction to Engineering, Academic Success Skills, Global and Social Issues in Engineering. These courses help students see a holistic picture of engineering at an earlier stage of their academic career.

Although continuous pedagogical improvements have taken place in mathematics and science courses over the years, many times, the changes occur without much input from faculty in engineering programs. Often, there is a disconnect between faculty in engineering and mathematics/science colleges. Many engineering professors have an inadequate understanding of mathematics classes, often unaware of where and how the specific knowledge is obtained in the mathematics sequence. On the other hand, mathematics professors usually have a limited understanding of how their mathematics courses apply in downstream engineering classes [137]. The issues surrounding science courses are similar as well. Table 3a indicates the range and average percentage of mathematics and science courses in comparison to the total degree requirements. The average across 125 programs stands at 25.4%, with a standard deviation of

2.2%. The following are some of the notable characteristics observed from the curriculum data from 125 mechanical engineering programs:

- Michigan Technological University has the highest percentage of mathematics and science units in comparison to the total degree units at 32.0%, while University of South Carolina has the lowest at 20.0%.
- Seventeen programs require more science than mathematics course units.
- Seventy-nine programs have at least one mathematics course required after the four typical courses in mathematics (differential, integral, and multivariable calculus, along with ODE/linear algebra). It indicates that there is still a strong emphasis on mathematics in the mechanical engineering curriculum.
- Only six programs require a third-semester physics, and 15 require a second-semester chemistry course.
- The University of Oklahoma is the only program that requires modern physics (4^{th} - semester physics), while University of Houston is the only program that requires a course in partial differential equations.

Table 3a: Summary of major curriculum composition based on 125 BSME degree programs.

Categories of Curriculum	Percentage Relative to the Total Degree Units				BSME Degree Program	
	High	Low	Average	Standard Deviation	Highest Percentage	Lowest Percentage
Mathematics & Sciences	32.0	20.0	25.4	2.2	Michigan Tech. University	University of South Carolina
Mechanical System Design	27.3	11.7	19.3	3.2	University of Wisconsin Milwaukee	Temple University
Thermal System Design	13.2	5.5	8.7	1.5	University of Iowa	Michigan Tech. University
Technical Electives	20.6	2.8	11.1	3.7	Florida International University	Tennessee Tech. University
General Education	27.9	9.4	17.1	3.6	San Diego State University	University of Nebraska Lincoln and University of Virginia

Table 3b: Categories of curriculum.

Categories of Curriculum	Examples of Courses Included
Mathematics & Sciences	**Calculus**: Differential, Integral, Multivariable; **Physics**: Mechanics, Electricity and Magnetism, Optics, Waves and Thermodynamics, Modern Physics; **Chemistry**: General Chemistry for Engineers, General Chemistry I, General Chemistry II; **Life Science**: Biology; **Other Math Classes**: Linear Algebra, Differential Equations, Probability and Statistics, Engineering Analysis Including Topics Such As Laplace/Fourier Transform
Mechanical System Design	**Mechanics**: Statics & Dynamics; **Materials**: Solid Mechanics, Material Science/Engineering Materials; **Machine Design**: Mechanical Design, Kinematics/Dynamics of Mechanisms; **Manufacturing**: Manufacturing Processes, Design and Manufacturing, Introduction to Engineering Design, Manufacturing Process Lab/Machine Shop; **Dynamics and Control**: Mechanical Vibrations, Mechatronics, Controls, System Dynamics
Thermal System Design	**Core Thermal Science Classes**: Thermodynamics, Fluid Mechanics, Heat Transfer; **Other Thermal Science Classes**: Thermodynamics II, Thermal Science, Thermal/Energy Systems, Propulsion, Nuclear Engineering

Core Major Courses in Mechanical Engineering

a) Mechanical System Design: The courses that fall under this category are noted in Table 3b. The average percentage of mechanical system design courses in comparison to the total degree requirements in 125 programs stands at 19.3% (standard deviation of 3.2%). University of Wisconsin Madison is the highest at 27.3%, and Temple University is the lowest at 11.7%. The following are some of the notable characteristics observed from the curriculum data of 125 mechanical engineering programs:

- Eleven programs have a one-semester engineering mechanics course (combined statics & dynamics), and the rest have separate independent statics & dynamics courses – more popular treatment of engineering mechanics topic.
- One hundred twelve programs have a standalone course in materials engineering/science course. This increase has been noticeable in mechanical engineering programs in the last 20 years – the importance of material science or engineering materials knowledge has become very noticeable in the current curriculum.
- There are only 23 schools without any manufacturing-related courses in the required courses. Again, the importance of manufacturing-related courses, such as manufacturing processes or design and manufacturing, has become a steady increase in the last 20 years.

The current ABET EAC's Mechanical Engineering Program Criteria require the curriculum to "prepare students to work professionally in either thermal or mechanical systems while requiring topics in each area." Typically, almost all mechanical engineering programs have courses allocated more units towards the mechanical systems than the thermal systems. The unit allocation for dynamics and control varies from program to program, but it is very clear that its importance is emphasized. Eighteen programs place seven units or more in this area. University of Illinois at Urbana Champaign has a course in signals and systems, coupled with a course in system dynamics, placing heavy emphasis in this area. University of California Berkeley also places a strong focus in this area with a sequence of hands-on mechatronics courses. On the other hand, there are seven schools without a course in the field of dynamics and control.

b) Thermal System Design: Typical courses in this section are listed in Table 3b. The average percentage of thermal system design courses in comparison to the total degree requirements in 125 programs stands at 8.7% (standard deviation of 1.5%). University of Iowa has the highest percentage at 13.2%, and Michigan Technological University has the lowest with 5.5%. The following are some of the notable characteristics observed from the curriculum data of 125 mechanical engineering programs:

- Forty-five programs have only the "minimal" traditional three courses sequence: thermodynamics-fluid mechanics-heat transfer.
- Kansas State University requires nuclear engineering as a required course. California State University Long Beach requires a course in power plant design. The University of Mississippi is the only program that requires propulsion. These three programs use a very specific course as part of additional thermal system courses unique to their program.

Typically, a mechanical engineering program is composed of two main branches: mechanical system and thermal system. It is interesting to note that the 125 mechanical engineering programs place, on average, 24.4 units in the mechanical system design compared to 11.0 units in the thermal system design – rather a significant difference.

c) Computing/CAD: Courses in this category can be any form of computer-aided design course (such as AutoCAD or SolidWorks), computer programming, and numerical methods or finite element methods type of courses. Here are some notable characteristics from the 125 programs:

- On average, 6.9 units (standard deviation of 2.7 units) are allocated for the computing and CAD category.
- Colorado School of Mines has the most with 16 units.
- Computer programming languages vary across all 125 engineering programs, but C and MATLAB are the most popular languages.
- Seventeen programs do not have a specific course in computer programming.
- Although a course such as numerical methods has been dropped from the mechanical engineering curriculum due to state legislature pressure in reducing the credit hour limits [138], there are still 74 programs that have at least one course addressing numerical methods or computational methods.

d) Capstone Senior Design: Capstone senior design is a required element for all ABET-accredited engineering programs, and perhaps it is one of the most critical parts of the curriculum since it culminates all prior learning into one or two courses. Mechanical engineering programs use their capstone senior design courses to capture many of the ABET EAC Student Outcomes (SO) in the assessment. Because of its importance, almost all programs put continuous efforts in changing the course structure, pedagogy, laboratory environment, and assessment methodology related to capstone senior design courses. Here are notable characteristics observed from the 125 mechanical engineering programs:

- The average units allocated to senior design courses are 4.7 units (standard deviation of 1.5 units).
- Forty-one programs have a 1-semester course requirement, 83 programs have a two-course sequence, and 1 program has the three-course sequence (Cal Poly Pomona, 1 unit for each course).

e) Mechanical Engineering Labs: The courses in this section are standalone mechanical engineering laboratory courses, independent and separate from lecture courses. There are many programs blending lectures and laboratories in one course (typically three units of lecture with 1 unit laboratory). Here are notable characteristics from 125 mechanical engineering programs:

- Eleven programs do not have standalone mechanical engineering laboratory classes (they are blended with lecture classes).
- The average unit allocation for laboratory courses is 4.6 units.
- The majority of laboratory courses centers around the mechanics of materials and thermo-fluids laboratory courses.

f) Other Core Major Classes: Courses in this category are: 1) Introduction to Engineering or Mechanical Engineering (Non-CAD), 2) Engineering Economics, Professionalism, and Ethics, 3) Soft-Skill Development, and 4) Electrical Engineering Related Classes. Here are some notable observations from the 125 mechanical engineering curriculum:

- Forty-six programs have an electrical engineering or related course that is customized for non-electrical engineering majors, which has become a popular trend in the last ten years.
- Missouri University of Science and Technology, University of Nebraska-Lincoln, and Virginia Commonwealth University have a dedicated course in leadership, which is a skill that the engineering industry is seeking more from graduates.
- University of South Carolina has a course in project management, which helps students in capstone senior design classes. CSU Long Beach, University of Texas Arlington, and University at Buffalo have a course to develop academic success skills of students.
- Seventy-three mechanical engineering programs have a dedicated Introduction to Engineering or Mechanical Engineering (Non-CAD based) course during freshmen year. This course is dedicated to increase freshmen retention, and introduce global, social, economic, ethical issues in engineering or mechanical engineering, through practical problem solving and critical thinking.

Technical Electives

Technical electives provide students with some flexible choices within specific areas of mechanical engineering, helping them to gain a deeper understanding of areas that are otherwise not possible through required courses in the curriculum. Table 3a lists information about the percentage of total technical elective units in comparison to total degree units. On average, 125 mechanical engineering programs place 11.1% (standard deviation of 3.7%) of the total degree requirement for technical electives. Florida International University has the highest with 20.6%, while Tennessee Technological University has the lowest with 2.8%. It is interesting to note that San Diego State University (SDSU) requires only nine units of technical electives, despite the total degree requirement of 140 units (highest among 125 programs). The large degree unit requirement comes due to the large general education requirement of 39 units, which is the most among 125 programs.

General Education (GE)

The importance of General Education (GE) has increased in the last twenty years. Rather than having mechanical engineering students take GE courses in a randomly scattered pattern, many of the universities attempted to strategically integrate or blend GE courses as part of the engineering curriculum [139]-[140]. However, many of the mechanical engineering curriculum studied in this paper still have traditional ways of covering the breadth of topics in arts, social sciences, and humanities. This paper analyzes the unit patterns in 125 engineering programs regarding GE composition in comparison to total degree units. For the analysis, courses such as English Composition/Writing, Macroeconomics, and Microeconomics are included in the GE category. Technical writing and engineering economics courses are categorized separately for the analysis of this paper since many mechanical engineering programs treat these courses separately, outside of GE. The average GE percentage in the total mechanical engineering degree

requirement is 17.1% (standard deviation of 3.6%), across 125 engineering programs analyzed in this paper. San Diego State University has the highest GE composition (27.9% of the total degree units).

Other Course Requirements

The courses categorized in this section are technical writing/communication, co-op/internship, physical activities, and free electives. Here are the notable characteristics of the 125 mechanical engineering programs:

- Forty-one programs have a standalone course in technical writing/communication as a requirement.
- University of Louisville, University of Toledo, and the University of Cincinnati have co-op as the degree requirement.
- Colorado School of Mines and State University of New York at Binghamton require two units of Physical Activities course.
- There are 32 programs allowing free elective units within the degree requirement, allowing flexibility for students.

Concluding Remarks

The first part of the paper identifies the availability of mechanical engineering and its related fields across the United States. It then explores whether the current mechanical engineering curriculum is sufficient to prepare next-generation mechanical engineers in areas of both traditional and emerging fields such as nanoengineering, renewable energy, robotics, and mechatronics. The second part of the paper studies the current structure and composition of 125 ABET-accredited mechanical engineering programs that are from semester-based public institutions. Although many of the programs have their uniqueness in the curriculum in carrying out the mission of training the best mechanical engineers for the future, the majority of programs possess strikingly similar curriculum structure. The main objective of this paper was to provide a reflection of the current status of the mechanical engineering programs in the United States and provide a structural comparison for curricular improvement. The authors hope that this paper provides a basis of understanding for mechanical engineering programs in the US, and support universities to create a more innovative curriculum for future mechanical engineers.

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