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A Rose by Any Other Name: An Analysis of Agricultural and Biological Engineering Undergraduate Curricula

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Abstract

The objective of this study was to assess the extent to which a common thread exists among all of the ag-based biological systems engineering programs across the U.S. through a course-by-course analysis of individual program curricula. Publically available curricula were used to determine the coursework requirements for 88 unique curricula in the U.S. Due to the lack of standardization of course titles in the discipline, disciplinary courses were grouped into themes, and summary tables showing the distribution of courses by theme in the different curricula were made. In addition, a self-organizing map was made using the categorized data to provide visual mapping of curricular similarity among programs. Results indicate that although all programs require similar basic math, science, and engineering fundamentals, there is wide variety in the discipline-specific requirements. For example, the two most common discipline-specific themes are required by only 61% and 75% of programs (basic engineering applied to agricultural and biological systems, and instrumentation and controls, respectively). Furthermore, results show that the name of the program and/or option generally conveys limited information about the content of the curriculum, although some differentiation between agricultural engineering programs and biological engineering programs is evident.

Keywords

Agricultural engineering, Biological engineering, Biological systems engineering, Biosystems engineering, Calculus, Core subjects, Education, Physics, Self-organizing map

Disciplines

Agriculture | Bioresource and Agricultural Engineering | Engineering Education

Comments

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A ROSE BY ANY OTHER NAME: AN ANALYSIS OF AGRICULTURAL AND BIOLOGICAL ENGINEERING UNDERGRADUATE CURRICULA

A. L. Kaleita, D. R. Raman

ABSTRACT. *The objective of this study was to assess the extent to which a common thread exists among all of the ag-based biological systems engineering programs across the U.S. through a course-by-course analysis of individual program curricula. Publically available curricula were used to determine the coursework requirements for 88 unique curricula in the U.S. Due to the lack of standardization of course titles in the discipline, disciplinary courses were grouped into themes, and summary tables showing the distribution of courses by theme in the different curricula were made. In addition, a self-organizing map was made using the categorized data to provide visual mapping of curricular similarity among programs. Results indicate that although all programs require similar basic math, science, and engineering fundamentals, there is wide variety in the discipline-specific requirements. For example, the two most common discipline-specific themes are required by only 61% and 75% of programs (basic engineering applied to agricultural and biological systems, and instrumentation and controls, respectively). Furthermore, results show that the name of the program and/or option generally conveys limited information about the content of the curriculum, although some differentiation between agricultural engineering programs and biological engineering programs is evident.*

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Perhaps as befits engineering disciplines rooted in biology, curricula in agricultural engineering, biological systems engineering, biological engineering, and similarly named programs are extremely diverse. They are diverse in name: the 45 degree programs studied here have 14 distinct names, with the most common name occurring only 24% of the time. They are also diverse in content: whereas the curricular expectations for disciplines such as aerospace engineering are extremely prescriptive (ABET, 2011), presumably leading to a homogeneity in the knowledge base of the graduates of these programs, the curricular expectations for agricultural engineering, biological engineering, and similar programs (hereafter referred to as ASABE-umbrella programs) are broad and subject to local interpretation (ABET, 2011). This diversity may reflect the historical roots of the discipline at land-grant institutions where experiment station needs were critical in faculty hiring. The flexibility may also have been crucial to the survival of many programs, as it allowed them to meet the needs of regional employers and the available student base. For example, Johnson et al. (2006) argued that "change is necessary in a biological engineering curriculum" and used the University of Maryland Biological Resources Engineering program as a model. The changes they outline in their article were driven by shifts in local industries, state support, and student interest. Johnson et al. (2006) concluded that programs must adapt to survive. The flexibility provided in the ABET criteria has allowed programs to have room for this adaptation.

The beauty of this flexibility is precisely the diversity it engenders. Some programs focus on biological engineering including biomedical topics, others focus on food, and still others maintain a focus on topics organized around agricultural production. The challenge presented by this diversity is the dissolution of disciplinary identity that has characterized the past three decades: when asked what an agricultural or biological engineer does, a correct answer might well be "what state are we in?"

As the discipline evolves to face the significant challenges of the 21st century, it seems timely to have a discipline-wide discussion about curricula. The objective of this study, broadly, was to inform such a discussion by conducting a comprehensive analysis of ASABE-umbrella program curricula. Specific goals were to assess the extent to which a common thread exists through a course-by-course analysis of individual curricula, and to provide a visual mapping of curricular similarity among programs.

Seminal work in this area was reported by Young (2006a), who outlined the history of bio-type engineering as it emerged from agricultural, medical, and chemical type programs and compared bio-type programs from each of these origins. Young's analysis focused on 20 selected topics common across all the bio-type engineering programs and identified similarities and differences in these require-

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ments across those three origins of bio-type engineering. While Young's analysis was excellent, the scope of that project was somewhat different. In the work presented here, we include all topics in required coursework in any of the ASABE-umbrella curricula but do not consider curricula in other types of programs. As such, our analysis included courses like machine power, natural resources conservation, and food engineering, which were not among the 20 selected topics in Young's analysis, as well as any and all courses required by any ASABE-umbrella curriculum. We also limit our work to only ASABE-umbrella curricula, as described below.

Materials and Methods

Overall Approach

Our overall approach was to build a spreadsheet-based inventory of required courses in all curricula and then to assess the inventory to understand the frequency of occurrence of different subject matter. Additionally, the inventory was subjected to a neural-network based technique to visualize how similar individual curricula are to one another.

Organization and Coding of Data

The inventory was organized into a single large worksheet. The leftmost column contained a list of all the unique topics identified in the survey (e.g., Calculus II, General Chemistry, Physics I, Statics, Thermodynamics, Microbiology, Engineering Properties of Biological Materials). Each subsequent column to the right represented the contents of a specific curriculum, using a binary coding: 1 for required topics; 0 for those not required. Course catalog descriptions, rather than course titles, were used to determine the coding because some course titles were ambiguous. In some cases, topic names were taken verbatim from course names, but in cases where the course descriptions indicated that the content was sufficiently similar, we provided a generic topic name to facilitate the subsequent analysis (e.g., Natural Resource Conservation Engineering, Design of Soil and Water Conservation Systems, and Soil and Water Conservation Engineering were all coded as the topic Natural Resource Engineering). Seminar courses were not included unless the catalog description clearly indicated focused, specific content, such as ethics. Several programs have freshmen- or sophomore-level survey courses that cover multiple diverse topics. These courses were not considered comparable to focused course coverage on a single topic (e.g., Biological Reactors, Machine Systems, Structures, Natural Resource Engineering). Therefore, a survey course covering multiple topics did not trigger a "1" in each of the multiple topics it covered. At the project outset, general education requirements were included but lumped into broad topic categories. However, a large number of programs referred to general university requirements without including those requirements explicitly in the curricula, which caused us to ultimately exclude general education requirements from the inventory.

Data Collection

To populate the spreadsheet, we searched institution web pages of all the Morrill Act Land-Grant and 1890 institutions, looking for programs at those schools with names that included engineering and the words agricultural, biological, or other similar names or prefixes. Programs that appeared to have evolved from chemical engineering, or that were exclusively biomedically focused, were not included in this analysis. To ensure completeness, we also reviewed the ASABE listing of schools with student chapters of ASABE, and membership on the ASABE ED-210 Academic Program Administrators Committee.

All but two curricula and course descriptions were obtained from institutional websites from February to August 2011; two additional programs were added in spring 2012, and one in fall 2012. Within 45 degree programs at 38 institutions, 88 unique curricula were identified. There are more programs than institutions because some schools offer more than one degree; for instance, several schools offer both an Agricultural Engineering degree and a Biological Systems Engineering degree. There are more curricula than programs because a single degree program often has multiple options, each with a unique curriculum; these curricula were included separately regardless of the level of similarity between options. However, options that did not provide a unique list of specific required courses, i.e., that simply provided a listing of option electives, were not included separately in this analysis. The rationale for this is that when students select a small number of courses from a large list of sufficiently broad electives, the student knowledge outcomes are highly unpredictable. We did not include numbers for student enrollment; thus, this analysis is programmatic, not weighted by numbers of graduates.

Analysis Methods

Once completed, the spreadsheet contained a binary coding of course topics for each of the 88 curricula (see table 1 for a subsection of the spreadsheet). A total of 119 topics were identified; these are listed in the Appendix. Summative tabulations were generated to determine the frequency of occurrence of each topic (also provided in the Appendix).

Significant overlap in some topics exists even though the courses are, strictly speaking, unique. For instance, some curricula require a course in Machine Systems while others require a course in Machine Design. These topics were coded separately in the spreadsheet when the course descriptions suggested they were distinct. To better discern patterns in curricula, groupings of similar advanced disciplinary topics, termed "themes," were created, as follow: Biological Processing, Soil and Water Conservation, Machine Systems, Agricultural Structures, Instrumentation and Control, and Engineering Properties of Biological Materials. An additional theme was also created to capture basic engineering principles applied specifically to agricultural and biological systems (e.g., courses in engineering analysis of biological systems, and mass and energy balances of agricultural and biological systems). Summative tabulations of frequency of required themes were also generated.

Table 1. Subsample of the spreadsheet indicating program names at top, and binary coding of course requirements in the column below. The full dataset, not shown here, included 86 unique curricula and 119 course topics. Course topics are given in the Appendix.

ID	9	10	11	12	13
Institution	Iowa State University	Iowa State University	Iowa State University	Iowa State University	Iowa State University
Degree	Agricultural Engineering	Agricultural Engineering	Biological Systems Engineering	Biological Systems Engineering	Biological Systems Engineering
Option (if any)	Agricultural and Environmental Systems	Power and Machinery	Bio-environmental	Biorenewable Resources	Food
Courses Required					
Differential calculus	1	1	1	1	1
Physics I (work, momentum, energy)	1	1	1	1	1
CAD or engineering graphics	1	1	0	0	0
Organic chemistry	0	0	1	1	1
Dynamics	0	1	0	0	0
Environmental engineering	0	0	1	0	0

To provide a visual illustration of the similarities and differences between curricula, we used the self-organizing map technique (Kohonen, 1990). Self-organizing maps (SOMs) arrange a high-dimensional problem space of empirical data into a two-dimensional neuron lattice. This approach, rooted in neural network theory, is particularly good at identifying patterns in highly noisy data and has been successfully applied in widely ranging fields such as linguistics and robotics (Kohonen, 2001). Input vectors of data for each observation or individual are presented one by one to the SOM algorithm, which then organizes the vectors into a two-dimensional lattice map. As each input vector is in turn compared to nodes on the output lattice, the closest matching node is identified. The nodes on the map are updated and re-organized after the introduction of each new vector, so that the node arrangement of the final map indicates similarities in the patterns within the input vectors in the entire data set.

In our application, the high-dimensional space is the set of 119-element vectors representing the individual curricula. We used the SOM Toolbox 2.0 (Vesanto et al., 2000) for MATLAB, with default parameters for distance formulae and neighborhood functions. We experimented with several different map shapes (these are arbitrary and can be selected for optimal visualization), settling on a 10×10 rectilinear format. The resulting SOM is a two-dimensional arrangement of the original multi-dimensional curricula vectors, displaying the results in a lattice where each node represents a single curriculum or a group of similar curricula (empty nodes also correspond to a "curriculum" in the sense that there is a 119-element vector for each node, but empty nodes had no such curricula vector in the inventory). The proximity between nodes in the lattice indicates the similarity between individual clusters, however, the distance is non-linear; some adjacent nodes are more similar than others Node distances are summarized in a unified distance matrix, which is not presented in this article but did not indicate any major breaks between nodes.

RESULTS AND DISCUSSION

WHAT ARE STUDENTS BEING REQUIRED TO LEARN?

Some course content areas, such as calculus, were required by all 88 curricula. Others, such as limnology or vibrations, were required by only one program. Table 2 shows the 24 topics required by 50% or more of the 88 curricula studied. Clearly, ASABE-umbrella programs are consistent in their valuing fundamental math and science subjects, as well as core engineering topics such as thermodynamics and engineering design. It is at the next level, i.e., that of discipline-specific engineering topics, that the diversity in our discipline becomes apparent. Table 3 illustrates this by listing the seven discipline-specific themes that emerged in the survey, along with their frequency of occurrence. One defining topic is that of instrumentation; this theme is required by nearly three-quarters of all of the curricula surveyed. This suggests a rebound from the trend reported by Young (2006a), who found that instrumentation was required by 72% of agricultural engineering-origin curricula in 1997 but by only 53% by 2002.

Following instrumentation, the frequency of common required themes drops dramatically: basic engineering principles applied to agricultural and/or biological systems is required by 60% of curricula, biological processing is required at nearly the same rate but with a broad array of course

Table 2. Topics occurring in more than 50% of the programs studied.

Course Topic	Programs Requiring
Calculus I	100%
Calculus II	100%
General chemistry I	100%
Statics	99%
Physics I	97%
Thermodynamics	94%
Capstone design	94%
Physics II	93%
Differential equations	92%
Calculus III	91%
Fluid mechanics	89%
Electricity, electronics, or circuits	77%
Programming	73%
Mechanics of materials	73%
Instrumentation and controls	74%
Biology I	70%
Heat and mass transfer (transport phenomena)	67%
Statistics	67%
CAD or engineering graphics	64%
Introductory engineering design	64%
Dynamics (kinematics)	62%
Organic chemistry	55%
General chemistry II	53%
Engineering properties of biological materials	51%

Table 3. Listing of seven discipline-specific themes, the subtopics that constituted them, and their frequency of occurrence.

Themes and Subtopics	Frequency
Instrumentation, measurement, controls, and microelectronics	**75%**
Instrumentation and controls	74%
Measurements of natural systems (forests, watersheds)	3%
Microcontrollers	2%
Basic engineering applied to agricultural and/or biological systems	**61%**
Applications of mass and energy balances in agricultural and biological systems	44%
Engineering analysis of biological systems	24%
Biological processing	**56%**
Process engineering (unit operations)	32%
Biological reactors (kinetics)	23%
Biological treatment engineering	9%
Microbial biotechnology or microbiological engineering	7%
Biochemical engineering	1%
Engineering properties of biological materials	**51%**
Engineering properties of biological materials (no subtopics identified)	51%
Soil and water engineering	**49%**
Natural resource engineering	36%
Hydrology	9%
Irrigation or irrigation and drainage	10%
Environmental hydraulics	9%
Power and machinery engineering	**33%**
Machine systems	19%
Machine design	10%
Energy and power	14%
Engine power	2%
Structures	**20%**
Structures	17%
Environmental modification/control	7%
Sustainable buildings	3%

quired by approximately half the surveyed curricula, and power and machinery engineering is required by just over a third of curricula. Structures, which included topics like environmental modification and control, was the lowest frequency theme identified, being required by a fifth of programs. As mentioned earlier, these percentages do not reflect student enrollment in various programs, so lower percentages cannot be interpreted to imply lower student impacts.

It was possible, with the data collected, to determine how many disciplinary theme areas were explicitly required by each of the curricula. Figure 1 is a histogram of these results, showing that approximately 10% of the surveyed programs require only a single theme area, and a similar number require five theme areas. Over a third of the surveyed programs require study in four theme areas, and this was the most common number of theme areas required. Arguably, programs requiring a high number of theme areas are providing the broadest training in the discipline.

One primary weaknesses of this analysis is that topics are sometimes embedded in curricula in ways that are not clear from a course title or description analysis. For example, math through differential equations is almost certainly required by 100% of the programs in this list (since it is a requirement for accreditation), but 8% of the programs did not show this in such a way that it was scored a "1" in the spreadsheet. Young's analysis (Young, 2006a) of curricula similarly identified that 95% of ag engineering-origin programs required differential equations in 2002. In the Biological Systems Engineering degree program at Iowa State University, with which we are intimately familiar, the topic of engineering economics is covered briefly in the required freshmen engineering course, then again in more detail in a 400-level analysis course within the department, but there is no explicit course requirement of engineering economics, and the program receives a "0" for the topic. Another weakness in this analysis is that several programs use a "choose *x* of *n* courses from the list below" approach for disciplinary core courses. Since none of the individual courses are required per se, they were coded as zeroes, despite students in these programs being taught multiple core courses. These inherent uncertainties in this analysis should be kept in mind when drawing conclusions from our results.

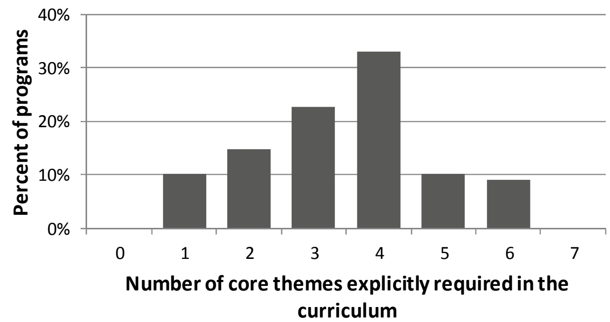

Figure 1. Distribution of the number of required theme areas among the surveyed programs.

Similarities and Differences among Programs

The self-organizing map (SOM) map generated from the 119-element binary vectors representing each curriculum is presented in figure 2. As we reviewed the SOM, we wondered about its veracity because some programs with which we were familiar were located in unexpected places. In approximately a dozen of such cases, we reviewed the original curricula to determine whether the program had somehow been misclassified by the procedure. In all these reviews, we verified that the curricula were in fact similar to those nearby on the SOM. While not a validation of all 88 curricula on the map, this process increased our confidence that the map reflects the nature of the curricular differences between programs.

For example, Iowa State University (ISU) offers two degree programs: an Agricultural Engineering degree with two options (machinery, and environmental-structural), and a Biological Systems Engineering degree with three options (food, environmental, and biorenewables). One difference between these two degree programs is that the AE program contains more advanced engineering mechanics types of courses, while the BSE program contains more advanced science courses, such as organic chemistry and microbiology. In the SOM, these two degree programs split apart, so that the biological systems engineering programs (ISU-B-B, ISU-B-E, and ISU-B-F) are in the bottom row, and the agricultural engineering programs (ISU-A-M and ISU-A-A) are towards the top of the map. The ISU-A-A option, with a focus on environmental and structural systems, occupies the same node as two options in the University of Georgia's Agricultural Engineering degree: structural systems and natural resource management. The two degree

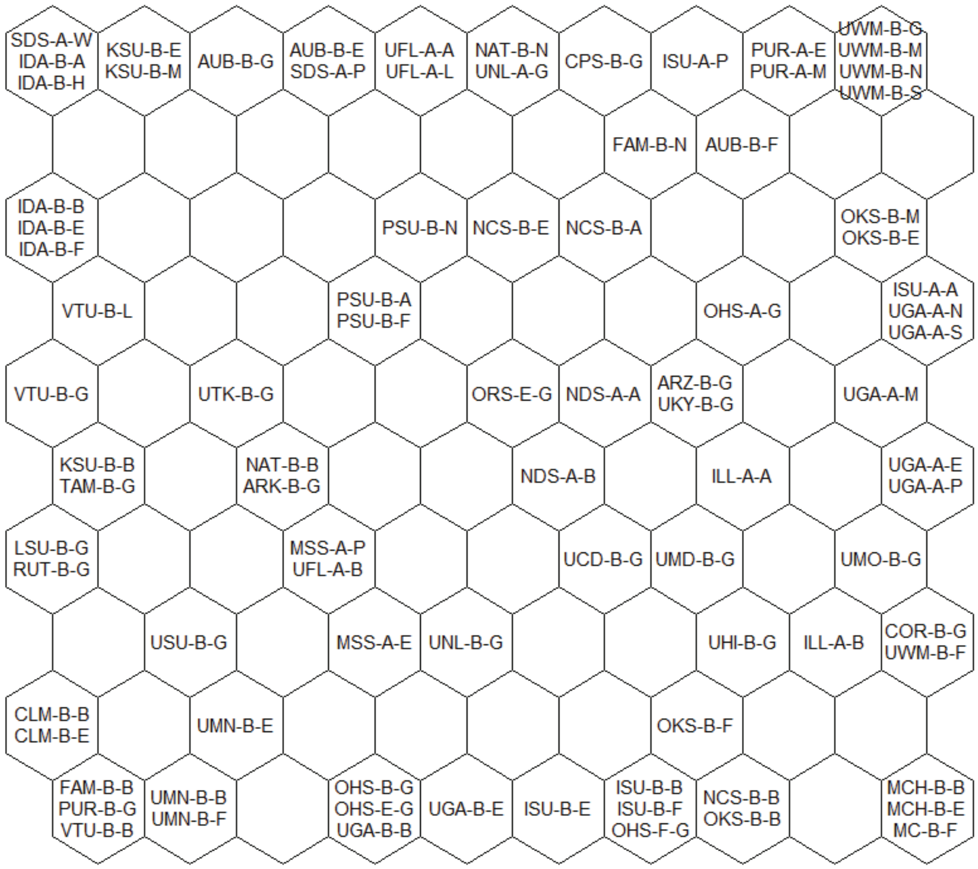

Figure 2. Visual representation of curricular similarities by self-organizing map. Each string represents an individual curriculum, per table 4.

programs at the University of Georgia (Agricultural Engineering and Biological Engineering) are similar to those at ISU in that the Agricultural Engineering program has a higher number of advanced engineering topics, while the biological engineering program has a higher number of advanced biology and chemistry topics. The BE programs at UGA appear towards the bottom of the map.

Figure 2 shows that programs with agricultural or similar names as first billing are predominantly in the upper half of the map (65% above midline, 35% below), while programs with biological or similar names as first billing are more evenly distributed (47% above midline, 53% below). Despite the broader distribution of bio-named programs over the entire map, the bottom tier of the map is completely filled by bio-named programs. In contrast, the top tier of the map has the highest number of ag-named programs. The inconsistency between name and curricular content that appears to emerge from this map has implications for employing our students: if the same recruiters go to more than one university, they may encounter degree programs that are similarly named but are quite different in terms of the content the students may have been exposed to during their academic preparation. This is not an indictment of any particular program; it is instead a wake-up call that we may be able to better communicate our program competencies to stakeholders (employers, prospective students, and colleagues at a minimum) if we look seriously at how program names map to curricular requirements. For example, we have struggled to distinguish between the "environmental" options in the AE and BSE degree programs at ISU. The map illustrates what we know to be true: these curricula are significantly different from one another. Yet the map shows that not only do we have "environmental" options at either edge of the map, but that environmental options are distributed evenly, left and right and up and down, on the map. This suggests a lack of clear identity even among curricula that might seem by name to be very similar.

The Name Game Revisited

Young (2006a) identified 48 institutions offering biological engineering from agricultural origins in 1997 and 46 in 2002. This analysis identified only 38 institutions (and one of them discontinued the program shortly after the curricula were collected). Young (2006b) identified 17 different degree names in 2002; we identified 14, as shown in table 5. Among the 14 unique names, Biological Engineering is the most common, with 24% of degree programs named so; 82% of degree programs have bio- in some form in their name, 38% include the word agriculture, and 7% of programs use neither bio- nor agriculture in the name. As discussed above, examination of the self-organizing map suggests that names are not necessarily predictive of curricula. This finding may have implications for how we as a profession market our degree programs.

Table 4. Curricula included in this analysis, as coded in figure 2 (continued on next page).

Code	University	Program	Option (if any)
ARK-B-G	University of Arkansas	Biological engineering	-
ARZ-B-G	University of Arizona	Biosystems engineering	-
AUB-B-E	Auburn University	Biosystems engineering	Ecological
AUB-B-F	Auburn University	Biosystems engineering	Forest
AUB-B-G	Auburn University	Biosystems engineering	General
CLM-B-B	Clemson University	Biosystems engineering	Bioprocess
CLM-B-E	Clemson University	Biosystems engineering	Ecological
COR-B-G	Cornell University	Biological engineering	-
CPS-B-G	Cal Poly San Louis Obispo	Bioresource and agricultural engineering	-
FAM-B-B	Florida A&M	Biological and agricultural engineering	Bioproccesing and food
FAM-B-N	Florida A&M	Biological and agricultural engineering	Natural resource conservation
IDA-B-A	University of Idaho	Biosystems and agricultural engineering	Agricultural engineering
IDA-B-B	University of Idaho	Biosystems and agricultural engineering	Biological systems engineering
IDA-B-E	University of Idaho	Biosystems and agricultural engineering	Environmental engineering
IDA-B-F	University of Idaho	Biosystems and agricultural engineering	Food and bioprocess engineering
IDA-B-H	University of Idaho	Biosystems and agricultural engineering	Ecohydrological engineering
ILL-A-A	University of Illinois	Agricultural and biological engineering	Agricultural engineering
ILL-A-B	University of Illinois	Agricultural and biological engineering	Biological engineering
ISU-A-A	Iowa State University	Agricultural engineering	Agricultural and environmental systems
ISU-A-P	Iowa State University	Agricultural engineering	Power and machinery
ISU-B-B	Iowa State University	Biological systems engineering	Biorenewable resources
ISU-B-E	Iowa State University	Biological systems engineering	Bioenvironmental
ISU-B-F	Iowa State University	Biological systems engineering	Food
KSU-B-B	Kansas State University	Biological and agricultural engineering	Biological
KSU-B-E	Kansas State University	Biological and agricultural engineering	Environmental
KSU-B-M	Kansas State University	Biological and agricultural engineering	Machine systems
LSU-B-G	Louisiana State University	Biological and agricultural engineering	-
MCH-B-F	Michigan State University	Biosystems engineering	Food
MCH-B-B	Michigan State University	Biosystems engineering	Bioenergy
MCH-B-E	Michigan State University	Biosystems engineering	Ecosystems
MSS-A-E	Mississippi State University	Agricultural and biological engineering	Environmental
MSS-A-P	Mississippi State University	Agricultural and biological engineering	Precision ag and ag systems
NAT-B-B	North Carolina A&T	Biological engineering	Bioprocess
NAT-B-N	North Carolina A&T	Biological engineering	Natural resources
NCS-B-A	North Carolina State University	Biological engineering	Agricultural engineering
NCS-B-B	North Carolina State University	Biological engineering	Bioprocessing
NCS-B-E	North Carolina State University	Biological engineering	Environmental
NDS-A-A	North Dakota State University	Agricultural and biosystems engineering	Agricultural engineering
NDS-A-B	North Dakota State University	Agricultural and biosystems engineering	Biosystems engineering
OHS-A-G	Ohio State University	Agricultural engineering	-
OHS-B-G	Ohio State University	Biological engineering	-
OHS-E-G	Ohio State University	Ecological engineering	-
OHS-F-G	Ohio State University	Food engineering	-
OKS-B-B	Oklahoma State University	Biosystems engineering	Bioprocessing and biotechnology
OKS-B-E	Oklahoma State University	Biosystems engineering	Environment and natural resources
OKS-B-F	Oklahoma State University	Biosystems engineering	Food processing
OKS-B-M	Oklahoma State University	Biosystems engineering	Biomechanical
ORS-E-G	Oregon State University	Ecological engineering	-
PSU-B-A	Pennsylvania State University	Biological engineering	Agricultural engineering
PSU-B-F	Pennsylvania State University	Biological engineering	Food and bioprocessing engineering
PSU-B-N	Pennsylvania State University	Biological engineering	Natural resource engineering
PUR-A-E	Purdue University	Agricultural engineering	Environmental and natural resource engineering
PUR-A-M	Purdue University	Agricultural engineering	Machine systems engineering
PUR-B-G	Purdue University	Biological engineering	-
RUT-B-G	Rutgers University	Bioenvironmental engineering	-
SDS-A-P	South Dakota State University	Agricultural and biosystems engineering	Power and machinery
SDS-A-W	South Dakota State University	Agricultural and biosystems engineering	Water and natural resources engineering
TAM-B-G	Texas A&M University	Biological and agricultural engineering	-

Conclusions and Future Work

There is a common theme of courses in ASABE-umbrella programs: we are, in some sense, "general" engineering programs with emphasis in instrumentation and then one or more theme areas, including bioprocessing, physical properties of biological materials, soil and water engineering, power and machinery engineering, and structures. We continue to operate with a broad array of program titles, despite the hard work of many discipline leaders to try to standardize names. This likely reflects the various academic realities faced at different institutions (e.g., at some institutions, departments like Chemical Engineering are unwilling to have a Biological Engineering program per se), as well as accidents of history related to faculty composition at the time of new program formation. As shown in figure 1, programs vary greatly in the breadth of disciplinary exposure that they require. The implications of this for critical disciplinary issues such as recruitment, retention and taking the professional engineering examination in Agricultural Engineering are probably contradictory and diffi-

Table 4. Curricula included in this analysis, as coded in figure 2 (continued from previous page).

Code	University	Program	Option (if any)
UCD-B-G	University of California at Davis	Biological systems engineering	-
UFL-A-A	University of Florida	Agricultural and biological engineering	Agrisystems engineering
UFL-A-B	University of Florida	Agricultural and biological engineering	Biological engineering
UFL-A-L	University of Florida	Agricultural and biological engineering	Land and water resources engineering
UGA-A-E	University of Georgia	Agricultural engineering	Electrical and electronic systems
UGA-A-M	University of Georgia	Agricultural engineering	Mechanical systems
UGA-A-N	University of Georgia	Agricultural engineering	Natural resource management
UGA-A-P	University of Georgia	Agricultural engineering	Process operations
UGA-A-S	University of Georgia	Agricultural engineering	Structural systems
UGA-B-B	University of Georgia	Biological engineering	Biochemical
UGA-B-E	University of Georgia	Biological engineering	Environmental
UHI-B-G	University of Hawaii	Biological engineering	-
UKY-B-G	University of Kentucky	Biosystems and agricultural engineering	-
UMD-B-G	University of Maryland	Bioengineering	-
UMN-B-B	University of Minnesota	Bioproducts and biosystems engineering	Bioproducts engineering
UMN-B-E	University of Minnesota	Bioproducts and biosystems engineering	Environmental and ecological engineering
UMN-B-F	University of Minnesota	Bioproducts and biosystems engineering	Bioprocessing and food engineering
UMO-B-G	University of Missouri	Biological engineering	-
UNL-A-G	University of Nebraska - Lincoln	Agricultural engineering	-
UNL-B-G	University of Nebraska - Lincoln	Biological systems engineering	-
USU-B-G	Utah State University	Biological engineering	-
UTK-B-G	University of Tennessee	Biosystems engineering	-
UWM-B-F	University of Wisconsin-Madison	Biological systems engineering	Food and bioprocess engineering
UWM-B-G	University of Wisconsin-Madison	Biological systems engineering	-
UWM-B-M	University of Wisconsin-Madison	Biological systems engineering	Machinery systems engineering
UWM-B-N	University of Wisconsin-Madison	Biological systems engineering	Natural resource and environment engineering
UWM-B-S	University of Wisconsin-Madison	Biological systems engineering	Structural systems engineering
VTU-B-B	Virginia Tech	Biological systems engineering	Bioprocess engineering
VTU-B-G	Virginia Tech	Biological systems engineering	General
VTU-B-L	Virginia Tech	Biological systems engineering	Land and water resources

cult, to discern. Similarly, the lack of name standardization is hard to discern. On one hand, student placement may not be so heavily impacted since companies often build strong bilateral relationships with specific programs and thus are not confused by the differing program names used across the country. On the other hand, large companies with HR departments that recruit from multiple institutions will have a harder time classifying and understanding the capabilities of students coming from programs with slightly varying names and potentially significantly varying curricula.

We recommend that future work in this area attempt to include data on student numbers, placement rates in industry and graduate school, primary employer types, FE participation and pass rates, sources of faculty (e.g., degrees and institutions from which terminal degree is earned), and size of faculty within the department or program. Weighting the results presented here by factors such as numbers of students in the program could allow us to better discern the topics and themes that make up the current bulk of the profession, and might assist those who are trying to understand the ongoing challenge of Professional Engineering licensure in Agricultural Engineering. Weighting the results by numbers of students going on to graduate or other professional school could similarly provide insight into how post-graduation plans vary by curricula. It would be particularly interesting to follow this work with a similar analysis of some of the other primary engineering disciplines, such chemical engineering, industrial engineering, and mechanical engineering. This would give an indication of the comparative variability of curricula between disciplines, and thus provide a better context for interpreting the results reported here.

Table 5. Degree names and number of degree programs (not curricula) with each name.

Degree Name	Number
Biological engineering	11
Biosystems engineering	6
Agricultural engineering	5
Biological systems engineering	5
Biological and agricultural engineering	4
Agricultural and biological engineering	3
Biosystems and agricultural engineering	2
Ecological engineering	2
Agricultural and biosystems engineering	2
Bioengineering	1
Bioenvironmental engineering	1
Bioproducts and biosystems engineering	1
Bioresource and agricultural engineering	1
Food engineering	1

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APPENDIX

Full list of course topics, with the frequency of occurrence of each topic in all the curricula in the inventory.

Course Topic	Frequency (%)	Course Topic	Frequency (%)
Calculus I	100	Physical chemistry	6
Calculus II	100	Fluid power	6
General chemistry	100	Ecological engineering	6
Statics	99	Material science engineering or metallurgy	5
Physics I	97	Food microbiology	5
Thermodynamics	94	Fluid dynamics	5
Capstone design	94	Life cycle analysis	5
Physics II	93	Physics III	3
Differential equations	92	Measurements of natural systems (forests, watersheds)	3
Calculus III	91	Finite element analysis	3
Fluid mechanics	89	Food processing (non-engineering)	3
Electricity, electronics, or circuits	77	Manufacturing	3
Instrumentation and controls	74	Quality engineering	3
Mechanics of materials	73	Renewable energy	3
Programming	73	Water resources management	3
Biology I	70	Sustainable buildings	3
Heat and mass transfer (transport phenomena)	67	Post-harvest operations	3
Statistics	67	Environmental science	2
CAD or engineering graphics	64	Food chemistry	2
Introductory engineering design	65	Fluids specifically for food/bio materials	2
Dynamics (kinematics)	63	Air pollution engineering	2
Organic chemistry	55	Engine power	2
General chemistry II	53	Watershed modeling	2
Engineering properties of biological materials	51	Separations engineering	2
Applications of mass and energy balances in agricultural and biological systems	44	Microcontrollers	2
		Sustainable engineering	2
Engineering economics	39	Industrial bioprocessing	2
Natural resource engineering	36	Nutrition	1
Microbiology	35	Industrial engineering	1
Process engineering (unit operations)	32	Quantitative biology	1
Soils or soil management	30	Environmental chemistry	1
General biology II	30	Plant chemistry	1
Systems modeling or numerical methods	28	Cell biology and physiology	1
Technical writing/communication	27	Environmental biology	1
Engineering analysis of biological systems	24	Forest or biological products	1
Biochemistry	23	Geotechnical engineering	1
Biological reactors (kinetics)	23	Wood science	1
Machine systems	19	Bioenergy feedstocks	1
Linear algebra	19	Biomass conversion engineering	1
Structures	17	Environmental chemical fate and transport	1
Analytical reasoning and logic or experimental methods	15	Environmental pollution and control	1
Surveying	15	Food engineering of fluids	1
Energy and power	14	Food engineering of solids	1
GIS or GIS/GPS or land CAD	11	Forest management	1
Advanced design and/or project management	10	Hazardous waste treatment	1
Environmental engineering	10	Microbial ecology	1
Machine design	10	Stormwater and erosion control	1
Irrigation or irrigation and drainage	10	Thermodynamics of chemical and phase equilibria	1
Nonpoint-source pollution	9	Vibrations	1
Biological treatment engineering	9	Geomatics	1
Hydrology	9	Open-channel hydraulics	1
Environmental hydraulics	9	Bioprocessing plant design	1
Organismal biology	8	Biochemical engineering	1
Biology in engineering	8	Building design	1
Food engineering	8	Limnology	1
Molecular biology	7	Human impacts on ecosystems	1
Ecology	7	Modeling physiological systems	1
Environmental modification/control	7	Biomechanics	1
Microbial biotechnology or microbiological engineering	7	Bioimaging	1
Optimization	7	Biomaterials (molecular and cellular)	1