Are there curricular differences between biology-based and application-based "bio" engineering disciplines?

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ABSTRACT

Several authors have previously promoted the transformation of the application-based agricultural engineering discipline into a biology-based biological engineering discipline. A systematic analysis of titles for courses being taught by ASABE-umbrella programs across North America was undertaken to identify curricular differences between biology-based and application-based "bio" engineering disciplines. Based on 44 ASABE-umbrella programs analyzed, the four most commonly used program names were biological engineering (25%), biosystems engineering (20%), biological systems engineering (15.9%) and agricultural engineering (13.6%). Definitions of these four program names were reviewed; biosystems, biological systems and agricultural engineering are typically defined such that they are best described as application-based "bio" engineering disciplines while biological engineering is best described as a biology-based engineering discipline. Based on statistical analysis of the frequency of words in course titles, there was a significant increase in the usage of the word "food" and a lack of the word "project" in the course titles within biological engineering programs. Over half of the unique options were found in biological engineering programs suggesting that they do offer unique course content compared with biosystems, biological systems and agricultural engineering degree programs, however, it is noteworthy that four options appear across all four degrees. It is concluded that there are curricular differences between biology-based and application-based "bio" engineering disciplines, however, the curricular differences are not as substantive as one might conclude from the philosophical discussions in the literature. Alternatively, it may simply not be possible to detect curricular differences solely from an analysis of the course titles.

RÉSUMÉ

Plusieurs auteurs ont déjà fait la promotion de la transformation de la discipline du génie agricole basée sur les applications en une discipline de génie biologique basée sur la biologie. Une analyse systématique des titres des cours enseignés par les programmes-cadres de l'ASABE en Amérique du Nord a été entreprise afin de cerner les différences entre les programmes d'études entre les disciplines de génie biologique fondées sur la biologie et les disciplines de génie « biologique » fondées sur les applications. D'après les 44 programmes-cadres ASABE analysés, les quatre noms de programme les plus couramment utilisés étaient génie biologique (25 %), génie des biosystèmes (20 %), génie des systèmes biologiques (15,9 %) et génie agricole (13,6 %). Les définitions de ces quatre noms de programme ont été examinées; les biosystèmes, les systèmes biologiques et le génie agricole sont généralement définis de telle sorte qu'ils sont mieux décrits comme des disciplines de génie « bio » basées sur les applications, tandis que le génie biologique est mieux décrit comme une discipline de génie basée sur la biologie. D'après l'analyse statistique de la fréquence des mots dans les titres de cours, il y a eu une augmentation significative de l'utilisation du mot « aliments » et un manque du mot « projet » dans les titres de cours des programmes de génie biologique. Plus de la moitié des options uniques ont été trouvées dans les programmes de génie biologique, ce qui suggère qu'ils offrent un contenu de cours unique par rapport aux biosystèmes, aux systèmes biologiques et aux programmes de diplôme en génie agricole, cependant, il convient de noter que quatre options apparaissent dans les quatre degrés. Il est conclu qu'il existe des différences entre les disciplines du programme d'études fondées sur la biologie et les disciplines de génie « biologique » fondées sur l'application, mais que les différences entre les programmes d'études ne sont pas aussi substantielles qu'on pourrait le conclure des discussions philosophiques dans la littérature. Par ailleurs, il peut tout simplement ne pas être possible de détecter les différences entre les programmes d'études uniquement à partir d'une analyse des titres de cours.

KEYWORDS

Curriculum, biology-based engineering discipline, application-based engineering discipline

MOTS CLÉS

Programme d'études, discipline de l'ingénierie fondée sur la biologie, discipline de l'ingénierie fondée sur les applications

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INTRODUCTION

More than a century ago, engineers trained in traditional disciplines (mechanical, civil and electrical engineering) and a core group interested in agriculture formed the American Society of Agricultural Engineers. Founding members of this technical society used their engineering education to remove manual drudgery associated with food production. Stewart (1977) provided a comprehensive overview of the creation of the discipline of agricultural engineering. Not surprisingly, the subjects taught in the established mechanical, civil, and electrical engineering disciplines influenced the agricultural engineering curriculum – leading to broad and interdisciplinary engineering education. Including biological science content, such as plant and animal physiology, was essential to enable an agricultural engineer to design livestock barns and controlled-environment production systems like greenhouses. The faculties developed agricultural engineering curricula to provide the fundamental knowledge necessary to solve production agriculture problems. Thus, from its inception, agricultural engineering was an application-based discipline (i.e., engineers ***apply*** fundamentals to problems with production agriculture).

Although the global need to produce food has not disappeared (and is increasing), finding "agricultural" engineers in North America is becoming increasingly difficult. Due to declining enrolments in the 1980s and 1990s, university departments faced the choice of changing or perishing. Change may be uncomfortable, but it is infinitely better than vanishing! I (regarding the first author) was an undergraduate agricultural engineering student at the University of Manitoba when these "name change" discussions occurred. A few years later, the University of Manitoba program officially changed from agricultural engineering to biosystems engineering. Presumably, similar discussions were happening on campuses across North America. Many departments arrived at a similar conclusion, as was the case at the University of Manitoba, and name changes occurred. Some programs resisted the change and have continued to deliver traditional agricultural engineering programs. Unfortunately, some departments at Canadian universities were permanently closed due to low enrolments (and perhaps other reasons). There is no disputing that the name "agricultural engineering" is now less common than it was in decades past.

Although there was reasonably widespread consensus that programs were required to change, there has been no consensus regarding the destination. A sufficiently large proportion of the programs affiliated with the American Society of Agricultural & Biological Engineers (hereafter referred to as ASABE-umbrella programs) have abandoned the word "agricultural" altogether or chosen to use it together with another word employing the "bio" prefix. In recent work, Kaleita and Raman (2012) reported that U.S. universities were using 14 unique degree names (compared with 17 unique degree names reported six years earlier by Young (2006)). The degree name "biological engineering" was the most common but appeared in only 24% of the degree names. The next most-common names were "biosystems engineering" (13%), "agricultural engineering" (11%), and "biological systems engineering" (11%). Many other degree names were combinations of the top four. The remaining names were unique and included: "ecological engineering," "bioenvironmental engineering," "bioengineering," and "food engineering. "Young (2006) provided numerical evidence to confirm that enrolment increases were associated with the renaming of curricula from "agricultural" engineering to some versions incorporating "bio" in the name. Thus, the name change seems to have reversed the trend of declining enrolment.

NAMES AND DEFINITIONS – WHAT DO THEY REALLY TELL US?

Table 1 provides a compilation of definitions associated with the various types of "bio" engineering disciplines and the definition for the originating discipline of agricultural engineering. Several observations are evident. First, two terms (bioengineering and biomedical engineering) can be equated with engineering applied to medicine for healthcare purposes. These two terms describe an application-based engineering discipline – specifically engineering applied to medicine and healthcare. Bioengineering and biomedical engineering do not seem to have originated from the ASABE-umbrella programs; Kaleita and Raman (2012) reported only one ASABE-umbrella program that used the degree name of bioengineering. The second observation is that the definitions found for biosystems engineering, biological systems engineering, and biological engineering have many similarities and based on these definitions, would seem to be interchangeable.

It should be recognized, however, that the definition of biological engineering provided by the Institute for Biological Engineering (ibe.org) seems to reverse the order between biology and engineering compared with the definitions provided for biosystems engineering and biological systems engineering. Rather than applying engineering principles to biological systems, the definition states that "biological engineers study biological processes and integrate them with engineering principles …" – intentionally seeming to place greater emphasis on knowledge of biology than on engineering fundamentals. This appears to be consistent with the definition provided by Tao et al. (2006), for example, who stated that

> "*… biological engineering should fundamentally require more than just the application of external stimuli to living systems to affect how they act. Rather it should involve the changing of the biological system itself, invoking a controllable change that becomes a self-sustaining integral part of the identity of the living system*."

The definition quoted from Tao et al. (2006) clearly describes biological engineering as a science-based engineering discipline where the engineer must, first and foremost, have a thorough understanding of biological principles and processes. Several other authors (Cuello 2006; Johnson 2006; Scott 2006) have also promoted the

Table 1. Definitions of various engineering disciplines that employ the "bio" prefix.

Engineering Discipline	Definition	Source
Agricultural Engineering	The branch of engineering involved with the design of farm machinery, with soil management, land development, and mechanization and automation of livestock farming, and with the efficient planting, harvesting, storage, and processing of farm commodities.	dictionary.com
Biosystems Engineering (or Biological Systems Engineering)	A field of engineering which integrates engineering science and design with applied biological, environmental, and agricultural sciences. It represents an evolution of the agricultural engineering discipline applied to all living organisms (but generally not including biomedical applications, which is the realm of biomedical engineering).	wikipedia.org
Biological Engineering	An interdisciplinary area focusing on the application of engineering principles to analyze biological systems and to solve problems in the interfacing of such systems with human-designed machines, structures, processes, and instrumentation.	bee.cals.cornell.edu
	Biological engineers study biological processes and integrate them with engineering principles to develop solutions for a wide variety of technical problems.	ibe.org
Bioengineering	The application of engineering principles and techniques to the field of biology, especially biomedicine, as in the development of prostheses, biomaterials, and medical devices and instruments.	thefreedictionary.com
	The application of engineering principles, practices, and technologies to the fields of medicine and biology, especially in solving problems and improving care. The application of biological techniques to create modified versions of organisms.	Merriam-webster.com
Bioenvironmental Engineering	Using engineering principles to reduce and solve environmental health risks and dangers caused by human activity.	wikipedia.org
	Having to do with the relationship between the environment and living organisms.	thefreedictionary.com
Biomedical Engineering	The application of engineering principles and design concepts to medicine and biology for healthcare purposes.	wikipedia.org
	The application of scientific and mathematical principles to useful ends, such as in the development of mechanical devices, systems, or processes.	thefreedictionary.com
Ecological Engineering	Uses ecology and engineering to predict, design, construct or restore, and manage ecosystems that integrate human society with its natural environment for the benefit of both.	wikipedia.org
	Blends engineering and science and focuses on the design of sustainable systems (natural, urban, and agricultural) that integrate human activities into the natural environment for the benefit of both.	bee.oregonstate.edu

term biological engineering and have indicated that this should be a biology-based engineering discipline.

So, what does the degree name really tell us? There seems to be a consensus on what is meant by the originating discipline of agricultural engineering. It is an application-based engineering discipline that applies fundamental engineering knowledge and principles to production agriculture problems. Although not closely related to agricultural engineering, bioengineering and biomedical engineering seem to fit the definition of application-based engineering disciplines that apply fundamental engineering knowledge and principles to problems involving medicine and healthcare. Although the view does not necessarily seem uniformly held, there are proponents that the best transformation from agricultural engineering is to the biology-based discipline, biological engineering. The definition provided by Tao et al. (2006) clearly expresses their view of how a biological engineer should be trained – seemingly emphasizing biology more than engineering knowledge and principles. Finally, based on the definition provided, biosystems engineering and biological systems engineering should be described as application-based engineering disciplines that apply fundamental engineering knowledge and principles to problems involving living systems. Just as with the originating discipline of agricultural engineering, knowledge of biology is used to complement engineering fundamentals. In summary, one might expect the curriculum of a biological engineering program to look different than that of a program in agricultural, biosystems, or biological systems engineering based on the fundamental difference in approach (i.e., biology-based perspective vs. application-based perspective).

MOVING BEYOND THE PROGRAM NAME - DELVING INTO THE CURRICULUM

It is evident that the engineering discipline formerly referred to as "agricultural" engineering is still in the process of transformation. There are differences in program names from institution to institution, but there are also curricular differences. Kaleita and Raman (2012) conducted a thorough analysis of ASABE-umbrella programs to initiate a discipline-wide discussion about curricula. More specifically, they attempted to identify the typical course types across all curricula. A total of 88 unique curricula from the 45 ASABE-umbrella programs were analyzed. As would be expected, Kaleita and Raman (2012) found that these ASABE-umbrella programs all included fundamental math and science subjects and engineering topics such as thermodynamics and engineering design. Due to inconsistency in course titles, Kaleita and Raman (2012) were required to sort courses by themes; the following seven discipline-specific themes were used:

1. Instrumentation, measurement, controls, and microelectronics (frequency = 75%)
2. Basic engineering applied to agricultural and/or biological systems (frequency = 61%)
3. Biological processing (frequency = 56%)
4. Engineering properties of biological materials (frequency = 51%)
5. Soil and water engineering (frequency = 49%)
6. Power and machinery engineering (frequency = 33%)
7. Structures (frequency = 20%)

Of these seven themes, only the first four were present in at least 50% of the ASABE-umbrella programs, with the theme of "instrumentation" being found in the highest proportion of programs (i.e., 75% of ASABE-umbrella programs included an "instrumentation" course). Kaleita and Raman (2012) presented a histogram displaying the distribution of the number of required theme areas among the ASABE-umbrella programs surveyed. No programs required courses from all seven discipline-specific themes, and less than 20% of programs included five or six discipline-specific themes. Approximately 25% of the programs required only one or two discipline-specific themes, with the remaining 55% of programs requiring three or four discipline-specific themes. Given the large diversity in the degree names, it is not surprising that such diversity in courses was also observed. A somewhat troubling conclusion from their work was 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*" (Kaleita and Raman 2012).

A review of the literature has identified three papers that have provided suggestions to those intending to develop an engineering program in biological engineering. Johnson (2006) provided some historical context in his article entitled "*The making of a new discipline*" and identified a need for new textbooks to be developed to support the core courses in biological engineering; he identified transport phenomenon, instrumentation, physical and biological properties of materials, control systems, and biology as examples of these core courses. In a later paper, Johnson (2010) described 25 essential concepts that should be taught to biological engineers (Table 2). However, the central premise of his article was that these essential concepts should be covered in a single, upper-year course, and he has subsequently written a textbook entitled "*Biology for Engineers*" (Johnson 2011) that can be used to teach these 25 fundamental concepts.

In the third paper mentioned earlier, Scott (2006) began his article with the question of whether biological engineering will become a science-based engineering discipline or an applied area where engineering is applied to biological systems. He did not directly answer this question but concluded that biological engineering has the "*DNA or rational structure to be a well-grounded engineering discipline"* – the implication seems to be that biological engineering should develop as a science-based (specifically biology-based) engineering discipline. His paper suggested the body of knowledge that should be taught within a biological engineering curriculum. Beyond the core sciences (physics, chemistry), mathematics, and core engineering subjects that are fundamental for all engineers, he suggested seven core biological engineering courses and four concentration areas in which electives are offered (Table 3). Scott (2006) admitted that the program at Cornell has "*evolved dramatically from its roots in agricultural engineering*." He said, "*we are committed to a path of being among the pioneering departments which define and develop the discipline of biological engineering*."

Table 2. Twenty-five essential concepts for biological engineers identified by Johnson (2010).

Essential Concepts for Biological Engineers
Survival and reproduction of the genes
Modularity and incremental change
Form is related to function
Environment influences outcomes
Physical limits cannot be exceeded
Energy, order, entropy and information
Reversible chemical reactions
Molecular shapes and chemical mass action
Osmosis
Redundancy and alternative pathways
Adaptation requires energy and resources
Competition for limited resources
Antagonistic mechanisms give precise control
Optimization saves energy
Directed evolution
Analogical thinking
Looping and successive approximation
Reliability curves
Circulation proves immediate availability
Proportional plus derivative sensors
Weber-Fetchner Law
Young's Principle
Hägen-Poiseuille Formula
The Law of Laplace
Class 3 levers

RESEARCH HYPOTHESIS

Though there have been strong proponents for the application-based discipline of agricultural engineering to transform into the biology-based discipline of biological engineering, the evidence seems to suggest that there are still a substantial number of departments who remain committed to the concept of an application-based engineering discipline that applies fundamental engineering knowledge and principles to problems involving living systems based on the names that have been selected for departments and programs. It is hypothesized that an in-depth review of the courses taught by ASABE-umbrella departments should identify fundamental differences between those that deliver their programs in departments named "biological engineering" and those that deliver their programs in departments with names that align with the application-based engineering disciplines (i.e., agricultural engineering, biosystems engineering, and biological systems engineering).

MATERIALS AND METHODS

Source of Information for Study

The website (asabe.org) of the American Society of Agricultural and Biological Engineers (ASABE) has a page that lists all of the ASABE student engineering branches. This resource was used to identify ASABE-umbrella programs to be included in the study. A total of 40 university departments were identified as offering ASABE-umbrella engineering programs (37 programs in the U.S. and three in Canada). There was a total of 4 of these departments offering two distinct programs, yielding a total of 44 ASABE-umbrella engineering programs considered in this analysis. The programs sorted by degree name are provided below in Table 4. The four most common degree names are biological (n=11), biosystems (n=9), biological systems (n=7) and agricultural (n=6). A total of 11 other distinct degree names were used at only one institution.

At the beginning of the study, an email was sent to department heads of the ASABE-umbrella programs requesting access to program lists. Some department heads responded with electronic files showing lists of courses or the program sequence, while others provided links to their department's website. Using information received from department heads in response to this request and information publicly available from the websites of the 44 ASABE-umbrella programs, an Excel spreadsheet was populated using the following five column headings: i) university, ii) degree, iii) options, iv) course type (core or technical elective), and v) course title. For this analysis, the emphasis was focused on undergraduate-level courses taught by the department. In other words, we did not include course titles for basic engineering topics (i.e., calculus, chemistry, physics, statistics, etc.) that are essential to the engineering program but taught by other university departments. For many programs, it was possible to fully populate the spreadsheet based on program scheduling information and/or official course lists available from

Table 3. Core biological engineering courses and concentration areas for a model biological engineering curriculum (Scott 2006).

Core Biological Engineering Courses	Concentration Areas
Bio-kinetics and thermodynamics	Biomedical engineering
Biotransport (heat and mass)	Bioprocess engineering
Biofluids	Bioenvironmental engineering
Biomaterials	Computational biological engineering
Bioinstrumentation	
Physiological engineering	
Molecular and cellular bioengineering	

Table 4. ASABE-umbrella programs included in the current study.

Degree Name	University	Total Number
Agricultural	Georgia; Purdue; Iowa State; Nebraska; North Dakota State; Wisconsin-River Falls	6
Agricultural & Biological	Illinois	1
Agricultural & Biosystems	South Dakota State	1
Bioengineering	Maryland	1
Bioenvironmental	Rutgers	1
Biological	Florida; Hawaii; Idaho; Purdue; Louisiana State; Mississippi State; Missouri; Cornell; North Carolina State; Penn State; Guelph	11
Biological Systems	California; Florida A&M; Iowa State; Kansas State; Nebraska; Virginia Tech; Wisconsin-Madison	7
Biological & Agricultural	Texas A&M	1
Biomedical	Maine	1
Bioproducts & Biosystems	Minnesota	1
Bioresource	McGill	1
Bioresource & Agricultural	Cal Poly	1
Biosystems	Auburn; Arizona; Kentucky; Michigan State; North Dakota State; Oklahoma State; Clemson; Tennessee; Manitoba	9
Ecological	Oregon State	1
Food, Agricultural & Biological	Ohio State	1

websites. However, there were a small number of instances where we could not locate all the required details. For example, there were a few instances where only a program overview was available – it is not known whether the program overview listed all courses. The intent was to record the complete course title. However, there were a few instances where only abbreviated course titles could be located. Finally, it was not always possible to determine whether specific courses were core to the program or whether they were technical electives. This was complicated because some courses were core to a given option, but technical electives were in other options. We did not omit any data, but most likely did not accurately classify all the incomplete information – introducing a small amount of error to the results.

Data Mining & Analysis

The course titles accumulated for the four most common umbrella programs (agricultural, biological, biological systems and biosystems) were analyzed as a representation of course content. Specifically, we answered the research question: are course titles different between the differently named programs? We began by removing spelling mistakes that occurred during data entry. We then removed words from the course titles that are connective or convey relationships (i.e., *a*, *and*, *in*, *for*, *on*, *the*, and *to* were removed). Roman and Arabic numerals were removed from course titles to highlight content words. Finally, all words that begin with *bio* (except biology, biological, bioengineering and biotechnology) were replaced with the hyphenated *bio-* to ensure we could count *bio* as a course title word and count the root word (e.g., process from bioprocess.)

We proceeded with the analysis using a custom-written script in R (v.4.0.3), tokenizer, xpetrial. The first action is to count the frequency of each word in the titles abbreviated above and rank the frequencies by program name. We then filtered the words to include only those that appeared in the top 10 for any programs. Due to the commonality between the lists, this left only 15 words: (agricultural, bio, biological, biosystems, design, energy, engineering, environmental, food, introduction, management, materials, process, project, and systems). We then posed the following statistical question: Given the frequencies of these 15 words for each program, is it possible that the occurrence rate for one program type is a random recombination of another program type?

RESULTS AND DISCUSSION

Observations Related to Degree Names

Before proceeding with the results of the completed qualitative analysis of course titles, we would first like to discuss a couple of interesting observations that became evident from tabulating information in Table 4. Four universities currently offer two distinct degrees (Table 5). These four departments view their agricultural degree program as fundamentally different from alternate programs named biological engineering, biological systems engineering or biosystems engineering. This seems to align partially with the information presented earlier in the paper – specifically, an application-based agricultural engineering program is fundamentally different from a biology-based biological engineering program. The second observation is that a total of six degrees combine multiple keywords in the degree title (i.e., Agricultural & Biological; Agricultural &

Table 5. Degree names used by departments offering two distinct programs.

University	Degree Name #1	Degree Name #2
Purdue	Agricultural	Biological
Iowa State	Agricultural	Biological Systems
Nebraska	Agricultural	Biological Systems
North Dakota State	Agricultural	Biosystems

Biosystems; Biological & Agricultural; Bioproducts & Biosystems; Bioresource & Agricultural; Food, Agricultural and Biological). It is somewhat unexpected that three-degree names combine the application-based "agricultural" engineering and the biology-based "biological" engineering in the same degree name. This mixing of keywords in the degree name would suggest no fundamental or philosophical differences associated with agricultural or biological engineering courses.

Observations Related to Options

Names of the options available to students in the four most named programs are listed in Table 6. There are many names used to define options. The complete list of options was sorted alphabetically using Excel to identify duplicates and similarly named options. In some instances, discretion was used in grouping these options (i.e., power & machinery was grouped with machinery systems options). A total of 20 unique options were identified (shown in bold in Table 6), with 11 of the 20 unique options associated with the biological engineering degree. This observation suggests that biological engineering programs do offer unique course content. Some of the options seem a bit strange. For example, a student in a biological engineering program can obtain an option in biosystems. Or a student in a biological system engineering program can get an option in biological. Presumably, in the minds of the administrators at these institutions, there is sufficient difference between these terms that they warrant the status of an option within the degree program.

It is noteworthy that some options appear across all four degrees. For example, some programs offer environmental options in all four degrees. Likewise, within all four degrees, options related to food and processing (sometimes appearing as bioprocessing) can be found. Biomedical or premedical options are present in three of the four degrees (no agricultural engineering program offers a biomedical or premedical option), suggesting that administrators in ASABE-umbrella programs are interested in taking advantage of the attraction by engineering students to biomedical engineering even though ASABE purposefully separates itself from the discipline of biomedical engineering. Machinery systems (or similarly named) options are present in three of the four degrees (no biological engineering program offers this option, although this is the only degree that provides an option in precision agriculture). Overall, there seems to be a reasonable consensus that engineering students in ASABE-umbrella programs are interested in environmental issues, food engineering and/or bioprocessing, biomedical engineering, and machinery systems. There continue to be some options that refer to the historical divisions within agricultural engineering (i.e., structural, controlled environment, machinery systems, land & water resources, and animal production systems). Some options seem to reflect emerging interest areas (i.e., bioenergy, sustainability, biotechnology, biorenewable resources, precision agriculture, and ecological engineering).

Table 6. Names of options available to students in programs named Agricultural Engineering, Biological Engineering, Biological Systems Engineering and Biosystems Engineering.

Degree Name	Options Available to Students
Agricultural	**Animal Production Systems**; **Electronic**; Food & Process Systems; Land & Water Resource; Machine Systems; Machinery Systems; Mechanical Systems; Natural Resource Management; Natural Resources & Environmental Systems; Power & Machinery; Process Operations; Processing Systems; Soil & Water Resources; **Structural**
Biological	Agricultural; Agricultural Production; Bioenvironmental; **Biomaterials**; Biomedical; Bioprocessing; **Biosystems**; **Cellular & Biomolecular**; **Computational Biological Engineering**; Ecological; Ecological & Microbial Systems; Environmental; Food & Biological Processing; Land & Water Resources; **Molecular & Cellular Systems**; **Nanobiotechnology**; Natural Resources; **Packaging**; **Pharmaceutical Process**; **Precision Agriculture**; Premedical; **Sustainability**; **Synthetic Biology**
Biological Systems	Agricultural & Natural Resources; Bioenvironmental; **Biological**; Biomedical; Bioprocess; Bioprocessing & Food; Biorenewable Resources; **Biotechnology**; Environmental; Environmental & Water Resources; Food; Food & Bioprocess; Machine Systems; Machinery Systems; Natural Resources Conservation; Natural Resources & Environment
Biosystems	**Bioenergy & Bioproduct**; Bioenvironmental; Biomedical; Bioprocess; Bioprocessing & Food; **Bioresource**; **Controlled Environment**; Ecological; Ecosystems; Environmental; Environmental & Natural Resources; Food; **Forest**; Machine Systems; Machine Systems in Agricultural Engineering; Premedical

Observations Related to Course Titles

An initial sort of the titles of core courses offered some interesting insights. Many courses use the word "introduction" in the course title – many of which are "introduction to ______ engineering," where the blank is populated by the program name. Without reviewing the course description or outline, it is difficult to know what content is covered in these courses. Not surprisingly, numerous course titles include words such as design, project, or capstone; all engineering programs are expected to emphasize design across the curriculum, culminating with a capstone experience. Other typical course titles were those referring to instrumentation, engineering properties of biological materials, transport processes (or phenomena), and heat & mass transfer. This observation aligns with the findings presented by Kaleita and Raman (2012). There appear to be several subject areas that continue to be core for ASABE-umbrella engineering programs. Several programs included stand-alone courses dedicated to the development of various professional skills. This included courses on career development, project management, and leadership skills. As a profession, if we want our graduates to stand out among their peers from other engineering disciplines, there seems to be much merit in helping our students learn how to develop their careers and teaching them how to be engineering leaders.

Regarding technical electives offered by ASABE-umbrella programs, it was initially hoped that a review of the course titles would identify emerging subject areas that could be used to update the elective offerings for departments wishing to embark upon program renewal. After sorting the course titles alphabetically, it becomes apparent that there is no consensus on the engineering content to be offered in technical electives across ASABE-umbrella programs because many subjects are represented in the list. Furthermore, it is difficult to determine which subject areas (if any) should be considered emerging areas because the titles do not convey any information associated with the year of introduction of the course. It was noted that a reasonable number of programs now offer courses in ecological engineering, biocomposites engineering, and biomass and bioenergy engineering. Bioenvironmental engineering is another subject area noted with one program named bioenvironmental engineering. Another interesting observation was the number of courses that employed the words "sustainable" or "sustainability" in their titles. Finally, a couple of programs offered courses covering "appropriate technology for developing countries."

Curriculum Differences Between Biology-Based and Application-Based "Bio" Engineering Disciplines

The statistical analysis of the frequency of words in course titles led to 15 words. We used the *rstatix* package with R v4.0.3 to run a multinomial test on word frequencies and yield a pairwise binomial comparison on the counts versus expected frequencies, adjusting the p-values with Bonferroni's adjustment for multiple comparisons. This test determines if the word frequencies occurring in the four programs could occur by random chance from the word frequency of each of the other three program types. The alternative is that some words occur with a higher or lower frequency than random chance would expect. Tables 7-10 show that the names of the programs are highly represented in the course titles, and the program name differences are reflected in the program names. While the word biosystems is infrequent outside of that program, the word agricultural is more frequent in biological systems courses.

The stand-out item is the lack of the word project in biological engineering course titles. This makes that program type noticeable for lack of project-oriented courses. When coupled with the significant increase in the usage of the word food in biological engineering compared with biosystems and agricultural engineering programs, application orientation has taken precedence over large-scope project courses. For brevity, the non-significant frequency differences for the words: bio, energy, engineering, management, materials, and process have been left out.

A View to the Future Curriculum

In preparation for this article, we came across an article entitled "*Engineering education: future trends and*

Table 7. Observed word frequencies in Agricultural Engineering course titles that are significantly different from the expected values from Biosystems, Biological and Biological Systems Engineering. Significance was adjusted for multiple comparison using Bonferroni (*p_{adj} <0.05, ** p_{adj} <0.01, * p_{adj} <0.001, **** p_{adj} <0.0001).**

Word	Observed Agricultural	Expected by Biosystems Freq.	Expected by Biological Freq.	Expected by Biological Systems Freq.
agricultural	23	2.0 ****	3.2 ****	10.0 **
biological	13	10.6	25.9	34.5***
biosystems	3	33.2 ****	1.6	3.0
systems	24	13.3	14.6	26.5
design	31	26.6	24.3	16.5**
environmental	8	1.3 **	3.8	3.5
project	4	6.6	0.0 ****	4.5

Table 8. Observed word frequencies in Biosystems Engineering course titles that are significantly different from the expected values from Agricultural, Biological and Biological Systems Engineering. Significance was adjusted for multiple comparison using Bonferroni.

Word	Observed Biosystems	Expected by Agricultural Freq	Expected by Biological Freq.	Expected by Biologica Systems Freq
agricultural	3	34.6****	4.8	15.1**
biological	16	19.6	38.5****	51.9****
biosystems	50	4.5****	2.4****	4.5****
systems	20	36.1*	21.6	39.9**
design	40	46.7	36.1	24.8*
environmental	2	12.0*	5.6	5.3
project	10	6	0.0****	6.8

(* p_{adj} <0.05, ** p_{adj} <0.01, *** p_{adj} <0.001, **** p_{adj} <0.0001)

Table 9. Observed word frequencies in Biological Systems Engineering course titles that are significantly different from the expected values from Agricultural, Biosystems and Biological Engineering. Significance was adjusted for multiple comparison using Bonferroni.

Word	Observed Biological Systems	Expected by Agricultural Freq	Expected by Biosystems Freq.	Expected by Biological Freq.
agricultural	20	46.0***	4.0****	6.5***
biological	69	26.0****	21.3****	51.7
biosystems	6	6.0	66.4****	3.2
systems	53	48.0	26.6****	29.1***
design	33	62.0***	53.1*	48.5
project	9	8.0	13.3	0.0****

(* p_{adj} <0.05, ** p_{adj} <0.01, *** p_{adj} <0.001, **** p_{adj} <0.0001).

Table 10. Observed word frequencies in Biological Engineering course titles that are significantly different from the expected values from Agricultural, Biosystems, and Biological Systems Engineering. Significance was adjusted for multiple comparison using Bonferroni.

Word	Observed Biological	Expected by Agricultural Freq	Expected by Biosystems Freq.	Expected by Biological Systems Freq
agricultural	6	41.6****	3.6	18.1*
biological	48	23.5****	19.2****	62.4
biosystems	3	5.4	60.1****	5.4
systems	27	43.4	24.0	48.0**
food	14	5.4*	4.8**	7.2
introduction	20	10.9	8.4**	12.7
project	0	7.2*	12.0***	8.1**

(* p_{adj} <0.05, ** p_{adj} <0.01, *** p_{adj} <0.001, **** p_{adj} <0.0001) *advances*" written by Marc Rosen (Rosen 2009). Rosen's article was not written specifically about the "bio" engineering discipline. It has been over a decade since his views on future trends in engineering education in the Canadian context were penned. Nevertheless, any view to a future "bio" engineering curriculum would be wise to consider Rosen's insights.

Although not our intent to repeat all the points made by Rosen (2009), here are some key points that stood out. Engineering programs must "*continually improve to maintain relevance, effectiveness, and accreditation*." Although the intention is not to downplay the importance of maintaining accreditation, it seems likely that a program that ceased to be relevant would struggle to attract students long before accreditation would be jeopardized. Thus, we concur with Rosen in placing relevance at the beginning of the list. Rosen emphasized the need to develop problem-solving and lifelong learning skills among graduates and reminded us of the importance of a range of other professional skills (i.e., leadership skills, teamwork skills, communication skills) and an appreciation for topics such as environmental stewardship, sustainable development, socio-political & cultural implications of engineering, and responsibilities of professional engineering practice. Perhaps Rosen had a premonition of what would happen in 2020 – he stated that "*alternative modes of engineering education are growing, and the role of distance education will become particularly significant in supporting lifelong learning and continuing professional development*." Although not by choice, all our engineering educators have recently gained a wealth of experience in online/remote delivery of engineering courses because of the COVID-19 pandemic. While we may not see this as a long-term replacement for the in-person delivery of our engineering programs, we should be more receptive to the strategic use of online/remote delivery of engineering content.

In terms of future trends, Rosen (2009) acknowledged that emerging engineering fields may develop; he listed areas such as biomaterials and biotechnology engineering, health engineering, engineering for sustainable development, and sustainable energy. Although this is not the entire list of advancing fields mentioned by Rosen, it should be heart-warming to those of us in the "bio" engineering discipline to note that many of these so-called emerging fields have strong ties to what we are already teaching in our programs. Rosen (2009) warned the curriculum developer to resist the temptation to compress the curriculum with increasing discipline-specific details overly. He suggested " focusing *more on fundamentals and engineering methods and approaches, which tend to provide students with the tools they need to address discipline-specific tasks*." This will require a focus on independent learning during the engineering program so that graduates can undertake independent learning when they enter the workforce. Perhaps engineering students should be granted opportunities for independent learning within courses, with a requirement that students reflect on what they learned due to the independent learning activity. The idea of active learning and reflection was contributed by Shekar (2007). Rosen (2009) anticipated the enhancement of professionalism through increased use of co-op work terms and exposure to topics such as entrepreneurship and globalization. Finally, Rosen (2009) envisioned a greater use of virtual experimentation and computer simulation in laboratory activities – a trend that may be necessary to address the increasing costs of traditional laboratory equipment.

CONCLUSIONS

The discipline of agricultural engineering is disappearing in North America. A literature review has confirmed that only 11% of ASABE-umbrella programs used agricultural engineering to describe their program in 2012. What is perhaps most surprising, however, is that there is still no consistency in program names among those that have decided to abandon the name of agricultural engineering. Based on the current review conducted, the four most common degree names are biological engineering (25%), biosystems engineering (20%), biological systems engineering (15.9%), and agricultural engineering (13.6%). A review of the definitions for these four disciplines suggests that biosystems, biological systems, and agricultural engineering are typically viewed as application-based engineering disciplines. In contrast, biological engineering is often regarded as a biology-based engineering discipline. Following a review of literature related to the establishment of the discipline of biological engineering, it was hypothesized that there might be fundamental differences in curricula between those programs that deliver their programs in departments with names that align with the application-based engineering disciplines and those that align with biology-based engineering disciplines.

Based on a statistical analysis of the frequency of words in course titles, we identified some differences between biological engineering programs and those programs called biosystems engineering, biological systems engineering or agricultural engineering. Specifically, there was a significant increase in the usage of the word "food" in biological engineering course titles. Likewise, there was a complete lack of project-oriented courses that employed the word "project" in the course title within biological engineering programs. Further evidence of differences between biological engineering and other programs was found when examining the names of the options available to students in the various ASABE-umbrella programs. Over half of the unique options were in biological engineering programs suggesting that they offer unique course content compared with biosystems, biological systems and agricultural engineering degree programs. It is noteworthy that four options appear across all four degrees. There seems to be a consensus that engineering students in ASABE-umbrella programs are interested in i) environmental issues, iv) food engineering and/or bioprocessing, iii) biomedical engineering (even though ASABE purposefully separates itself from the discipline of biomedical engineering), and iv) machinery systems.

Considering all the information described in this paper, it is probably reasonable to conclude that there are some curricular differences between biology-based and application-based "bio" engineering disciplines. However, the curricular differences between biological engineering and the three application-based "bio" engineering disciplines (biosystems, biological systems and agricultural) are perhaps not as substantive as one might conclude from the philosophical discussions provided in the literature. Alternatively, it may be impossible to detect curricular differences solely from an analysis of the course titles as we have done in this study. A more thorough review of the programs may be required to investigate this hypothesis better.

Although 25% of the ASABE-umbrella programs analyzed in this study have adopted the degree name of biological engineering (and this is the most common degree name among ASABE-umbrella programs), it must be remembered that 50% of the ASABE-umbrella programs have adopted program names biosystems, biological systems or retained the title of agricultural engineering - all of which are best viewed as application-based engineering disciplines. Thus, there are still more engineering departments that seem to view themselves as offering an application-based engineering program than those that consider themselves as providing a biology-based engineering program.

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