

Connecting Specific Knowledge Areas Throughout Core Courses in Biological and Agricultural Engineering

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Abstract

Biological and Agricultural Engineering (BAE) programs across the U.S. are aimed at teaching engineering principles and concepts of biology as they apply to both agricultural and biological systems. There is a clear definition of what the undergraduate curricula should instill in students prior to entering into the workforce as defined by the Accreditation Board for Engineering and Technology, Inc. However, individual institutions determine the exact knowledge concepts within the coursework offered for students to be successful and prepared for their careers. This research project was motivated by the need to differentiate between the BAE program knowledge areas and a newly formed Environmental Engineering program in a southwestern University's Civil Engineering Department. Understanding and classifying the knowledge gaps in the progression of BAE courses can lead to applying the proper integrating techniques in order to balance and equilibrate the prospective teaching modules.

Therefore, in this work we examined specific knowledge concepts considered essential within the curriculum at a large southwestern University's Bio-based engineering program. The research aimed to understand the level of students' exposure to essential knowledge and suggest recommendations for an improved comprehensive degree plan. The study used a survey in order to evaluate knowledge areas required for discipline specific core courses by a program based assessment of faculty who have taught through at least one academic year. The survey results identified the level of understanding for each specific knowledge area students must have or will gain during a particular core course.

A survey was developed based on knowledge levels from previously mapped knowledge areas. From the survey results, the knowledge level for each specific knowledge area (KAs) was averaged for all courses, the top, middle and bottom knowledge areas and ranked. Knowledge level averages were divided into three overarching areas, 1) knowledge completely taught in the course, 2) previous knowledge that we expect students to know and use, but they will learn at some level within the course and 3) information that students should know and is heavily used during the course. Rankings of the level of knowledge were used to as assessment methods to connect courses and knowledge areas.

It was determined that specific knowledge areas, such as physical properties of biological materials, were found throughout the core courses. Conversely, there were other specific knowledge areas that we expected students to have previous knowledge of but they were not being taught in any of the core courses. A previously identified specific learning concept of aeration, which is important for understanding physical properties of agricultural commodities, grain drying, and storage systems, ranked zero in all of the core course. This means that students are not receiving this knowledge in any of the course curriculum courses. Overall the highest ranked knowledge area was for students to be able to identify, formulate, and solve BAEN related problems. These results will guide and assist in the development of future supplemental trainings for students.

The research project's results are expected to enhance faculty, researchers, and administrators' in the understanding of the role their course plays in education of the students. Likewise, this will allow us to draw connections between classes and help students understand why they need to know the information being taught.

Introduction

The Accreditation Board of Engineering and Technology (ABET) describes Biological and Agricultural Engineering separately. Agricultural Engineering is described as applying engineering to agriculture, aquaculture, forestry, human or natural resources [1]. Biological engineering is described as applying engineering to biological systems [1]. The culmination of the two definitions of what a Biological and Agricultural Engineer might be is up to the engineering program's interpretation.

Design of engineering courses in the curriculum of the engineering programs is major oriented that direct each program for the specialty. This design can be strongly instructed to help students to choose proper courses that enable them in partnering with different industries, academia, and service-learning projects. Biological and Agricultural Engineering (BAE) departments have a wide range of concentrations instructed through the agricultural engineering modules including energy policy, precision agriculture, food and bioprocessing, biomaterials, and water quality [2], [3], [4]

The rapid advancement of BAE and its development in a variety of agricultural fields as an interconnected major between different disciplines has increasingly attracted many students in a variety of concentrations. However, this fast development along with university policy to increase the number of undergraduate students has made some voids in understanding the knowledge gap in designed courses.

Integration of different modules for each concentration needs deliberate educational planning to comprehensively cover all dimensions of science and engineering for an undergraduate student [5], [6].

A well-designed curriculum will challenge students to apply the skills and gained knowledge during their undergraduate career to address complex problems. Knowledge levels (Ks) can be identified in each module course that is taught throughout the curriculum [7], [8]. BAE core course in the curriculum across the top ranked Biological and Agricultural type engineering programs always include the following courses: Introduction to BAE, Heat and Mass Transfer, Bioprocessing, Sensors & Controls/Machine Systems, and Properties of Biological Materials. Curriculum also includes more general engineering courses such as Thermodynamics, Circuits, Dynamics, Fluid Mechanics and Economics to name a few [9], [10], [11].

The contribution of engineering courses to the professional component of the BAE curriculum can be satisfied through a course evaluation by the instructors who have a better understanding of the required material and student's potentials to learn. Evaluating the knowledge gap provides many benefits for student education in BAE [12]. For instance, students may be challenged with a real-world problem in agricultural post harvesting issues; if the design of the curriculum has covered a balance between undergraduate core modules and supplementary courses, students will be able to easily propose an idea to solve the problem involving multiple knowledge areas (KAs).

An additional advantage is given to the students who balance their knowledge gap and improve the voids in their understanding [12], [13]. This study aims to evaluate the knowledge gaps that exist through the curriculum of the BAE to better understand and plan for undergraduate students and exchange students joining the program from a different background. This study further shed light on essentials such as project management, engineering education and ethical principles which were not discussed expansively during undergraduate coursework.

This paper will report the knowledge gap analysis conducted via survey forms which were evaluated by professional instructors. Study objectives include: (1) assessment of each form which evaluators perceived students' knowledge gap of course material of BAE course and program outcomes, (2) Correlating the evaluated data on knowledge gap with the common core subjects.

Methodology:

A survey was created based off of the knowledge levels from a previous mapping of knowledge areas. This survey was given to faculty at a single institution and covers a four-year Bachelor's of Science curriculum. This survey ranked each skill from zero to three shown below in Table 1. This survey was distributed throughout the faculty members to rank each specific knowledge area based off of the core BAE course they taught.

Knowledge not required = 0	Knowledge they will acquire during the course = 1	Previous knowledge only mentioned = 2	Previous knowledge – heavily used = 3
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Table 1. Arrangement of knowledge levels given to Faculty for course Knowledge areas in BAE and the value associated with them for ranking

The evaluation sheets for each core BAE course were collected, and all the data was assessed in excel sheets. From the results, the knowledge level for each specific knowledge area was averaged for all courses, the top, middle and bottom knowledge areas.

Assessment of data was done to find the knowledge gaps based on these surveys. The quantitative analysis of this research developed a graphical based system to see how the knowledge areas contributed to five major areas (chemistry, biology, math, software-based, and social science). These five groups were then broken down further into 3 specific knowledge levels 1) fully covered knowledge, 2) background knowledge, and 3) fundamental knowledge. This provided as educational flowchart to inter-connect prerequisites.

Results & Discussion:

Ranking Specific Knowledge Areas for Required Biological and Agricultural Engineering major courses

Faculty considered each of the SKAs (Table 2) and selected at which level it is taught in their course [14]. The averages came out developed five distinct areas after evaluation and were put into Table 2 shown below (1-1.49) was determined as knowledge completely taught in the course, (1.5 – 1.749) as knowledge taught during the course and that students are moderately

expected to have some knowledge in. (1.75 – 2.249) is previous knowledge expected for students to know and use, but are also reviewed briefly in class. (2.25 – 2.49) is information that previous knowledge that is mostly mentioned but may also be used. (2.5 – 3) was labeled previous knowledge heavily used in the courses.

Ranking from (Author, 2018)	Specific Knowledge Area	Knowledge Level Average
22	Identify, formulate, and solve BAEN related problems	2.11
21	Apply computational skills to solve problems	1.56
2	Heat and mass transfer (not mass balance), thermal props, Fundamentals of energy transfer	1.50
3	Physical properties of biological materials (prediction and measurement), Materials testing & handling (raw materials through storage including packaging), Mixing-bulk fluid transport, Moisture content and water activity	1.30
20	Algorithms, basic computer programming	0.89
8	Basic control theory, controllers, Basic electricity, Computer programming, measurement science, sensors and transducers, Process control	0.80
4	Psychrometrics	0.70
1	Fluid mechanics	0.50
11	Crop production, harvest, transport, Plant and animal materials from dedicated cultivation and process waste (BIOMASS), Simple machines, kinematics, agricultural field processes, agricultural machinery, Refrigeration cycle	0.50
6	Kinetics, Reaction kinetics, Factors affecting food quality, Microbial kinetics “ thermal destruction	0.50
10	Inorganic chemistry, mass balance, heat and mass transfer, thermal conversion of materials, Fate processes: advection, dispersion, decay, growth, Metabolic pathways and bioenergetics	0.50
5	Soil science, soil texture classification, soil structure, soil mineralogy, soil chemistry, Stoichiometry	0.40
17	Wind erosion, control practices	0.30
19	GIS	0.30
7	Hydrology	0.20
16	Cleaning and sanitation	0.20
9	Microbiology	0.10
18	Esterification, etc.	0.10
14	Aeration	0.00

Table 2. Average of knowledge levels required for the specific knowledge areas in the core BAE required courses

The lowest ranked knowledge area is aeration (14) which is extremely important, but does not show up in any core curriculum courses (Table 2). One must ask why is this KA ranked as zero, ‘knowledge not required’ as noted in Table 1? It is possible that aeration showed up as a KA but is being taught in upper level elective courses and not any core curriculum. Table 3 provides raw data from each core course and how each KA was use in that course [actual course number

hidden]. From Table 3, knowledge areas of heat and mass transfer (2), basic control theory (8), and formulating and solving BAEN related problems (22) were being taught later in the curriculum as if they were being taught these concepts for the first time. In theory knowledge areas should build as students progress through the curriculum. These courses should fill in the gap and correlate the concepts in order. This will ensure the KA being focused on make more sense to students. From Table 3 we note that the knowledge area of cleaning and sanitation (16) was ranked as 2- being previously mentioned, but is not acknowledged in any other courses before it. We have to assume that students gain knowledge from a non BAEN course at some time before they take this course. In addition to cleaning and sanitation, algorithms (20), applying computational skills to solve problems (21), and solving BAEN related problems (22) were shown to be 3-heavily used with no previous knowledge taught but are not taught before this course. This means that if students have not been exposed to these KAs before they take this course they will need some scaffolding to help them build up the knowledge level.

Table 3: Rankings of knowledge level (0-3) according to the 10 core BAEN courses.

Lastly, we notice in Table 3 that there are KAs which are 1-knowledge they will acquire during the course in the earlier stages of the curriculum and then are emphasized as 3-previous

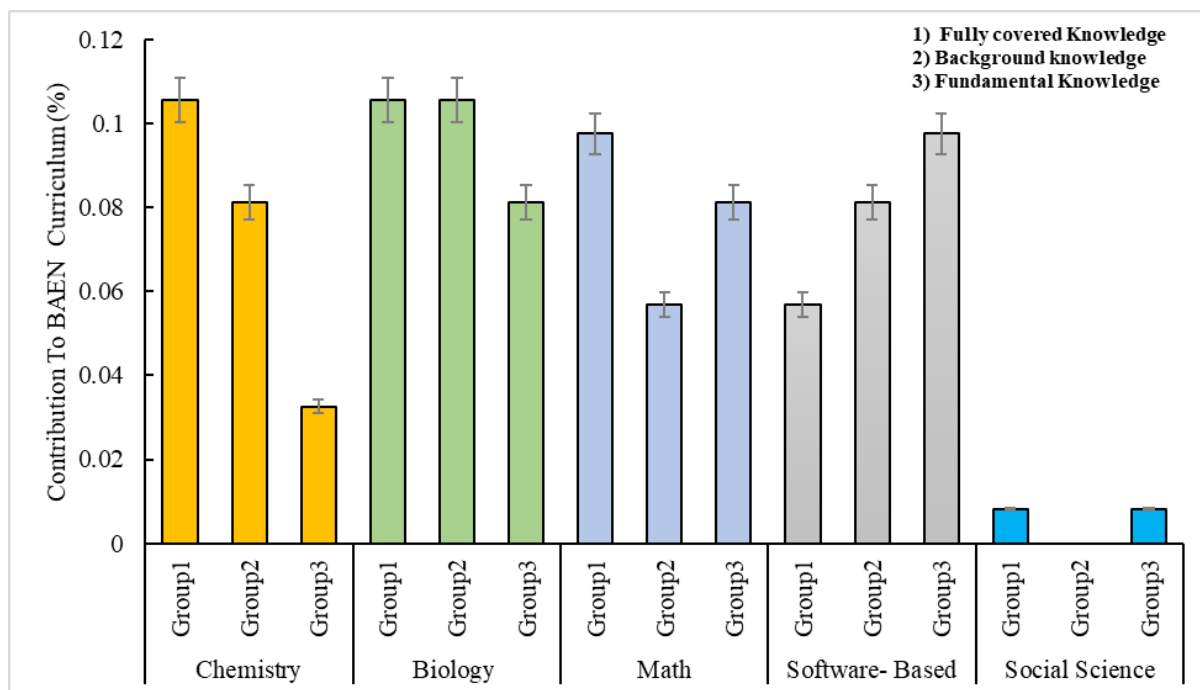
	Knowledge areas																	
Course number	1	2	7	3	4	9	11	18	5	6	14	16	10	8	19	20	21	22
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	n/a	n/a	n/a
2	1	1	1	1	1	0	1	1	1	0	0	0	1	0	0	3	3	3
3	0	2	0	2	0	1	0	0	1	1	0	2	1	0	0	0	0	1
4	0	3	0	2	2	0	0	0	0	2	0	0	0	3	3	2	3	3
5	1	2	1	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
6	0	1	0	1	1	0	0	0	0	1	0	0	0	0	0	0	2	3
7	3	3	0	3	1	0	2	0	0	0	0	0	0	0	0	0	0	3
8	0	1	0	0	0	0	0	0	0	1	0	0	1	3	0	0	3	3
9	0	0	0	2	2	0	0	0	0	0	0	0	0	1	0	3	3	1
10	0	2	0	2	0	0	2	0	2	0	0	0	0	0	0	0	0	1

knowledge heavily used later in courses. However, for KA (2) heat and mass transfer we notice that this KA is being taught again at an introductory level in later courses, after it has been previously utilized as a 3-previous knowledge heavily used. If faculty are able to streamline how the KAs are distributed throughout the curriculum they may reduce various levels of redundancy which sometimes cause courses to drag on. The curriculum should develop skills and consistently recall important learning concepts that BAE undergrads should indeed know. Each professor should be able to know what skills their BAE undergraduate students should know prior to their course and what new areas that will introduce new learning concepts.

Distribution of Knowledge in Common Core Areas for BAE Students

Specific knowledge areas which BAE students are expected to possess were divided into 5 common core areas. The common core areas included Chemistry, Biology, Math, Software-Based and Social Science knowledge areas. Figure 1 illustrates the overall distribution of the studied module in BAEN curriculum, which was driven based on the survey evaluation.

Figure 1. Analytical results of the knowledge gap as an indicator for the contribution of three mother sciences of chemistry, biology and mathematics as well as computational software courses and social science courses in BAEN curriculum.



The primary results proved that a good balance exists between knowledge levels in BAEN curriculum across the three main foundational subjects of chemistry, biology and mathematics. The information and the concepts in mother sciences are being fully covered, or student will learn through the semester. Therefore, undergraduate alumni could have adequate levels of knowledge based on their degree plan.

As was expected the weight of biology was more significant compared to other categorized disciplines. Because biological engineering students apply engineering techniques into biological systems, interest in revising or proposing novel biological engineering courses and curriculums is remarkably increasing. The interpretation of the results further lead to planning for the detail investigation through the conceptual framework of a specific, necessary, and integrative discipline which biological engineering students must attain [15].

The high-level graph bars of group three indicate that senior and junior students may have higher pressure to carry a high load of information to apply in certain courses which require a prerequisite (Fig. 1). Those students may need to review the essential materials before each class for better performance [16]. In this case, students may need tutors or extra classes. The courses which are covering social science such as relevant law, regulation, and engineering ethics were

assumed to be at an adequate level in the curriculum due to these classes being taught in additional elective course and learning ethics periodically in the curriculum.

The relatively low percentage in the math category is still alarming due to the availability of math courses through the K12 system. In the recent decade, the field of education has been seriously challenged teachers, researchers and educational systems to incorporate calculus as an essential key of K12 STEM education [17], [18], [19]. Integrating high-level education and extending the academic communication within K12 STEM supports learners of all ages and make them capable of applying computational thinking through the planned and targeted contexts [20], [21]. As results undergrad students can efficiently develop practices which are mathematically based. For example, if the academic relations between undergraduate, graduate, and K12 improves the math related issues can be balance [19]. This is more prominent when we consider the strong international community of graduate students with high GRE levels and strong math skills annually enter the educational system of the USA [22], [23].

The evaluation further determined that knowledge gaps play a key role in the adjustment of the student degree plan that could be equilibrated through the core courses. However, there were certain knowledge areas that were supposed to be known by students and have not been taught in any of the core courses. It is important to mention that basic engineering concepts and fundamentals of biology frameworks can be integrated into undergraduate courses [24], [25]. Though specific mandatory courses are different from university to university, all BAE curriculums must contain courses on engineering subjects, life sciences areas, and courses which integrate both areas.

In recent years, statistical and engineering software are regularly and extensively used for problem-solving in some of the core BAE engineering courses (for example the “watershed modeling” and “food processing” courses,) but in many of the courses, the computation software is still insufficient [26], [27], [28]. This fact has been reflected in the survey results of this study. This may result in some alumni engineers having to learn the software in post-graduation opportunities or internships. This underutilization of computer skills in some of the BAE courses have challenged the students with class examples and homework problems that require the use of the software practice based on today job market needs [29], [30]. Therefore, the need to invest in and investigate this knowledge gap is a critical issue that has been highlighted in this study.

The evaluation of results also indicates that many instructors seem to believe that fundamental knowledge in chemistry needs improvement. Most fundamental knowledge in chemistry is known by the student, but there are some fuzzy areas which students have not cleared adequately. Therefore, there is a call for integrating the K-12 system with academia at high educational systems to counter balance the gap of knowledge between chemistry teachers and academic professionals [31], [32]. In the current situation, the instructor should play a dual role to convey the design course and direct and clear certain fundamental knowledge of chemistry by integrating this subject throughout core courses.

The quantitative analysis of this research was expected to enhance the quality of knowledge communication between, students, faculty members, researchers, and administrators. Also, it could be applied to clarify the practical knowledge required for a student as a Biological and

Agricultural Engineer. The outcome will assist in better preparation and development of future supplemental training for prospective and enrolled students. Likewise, this will enable an educational flowchart to inter-connect prerequisites modules and essential courses in a rational manner. By filling the gap of knowledge, students in BAE should be capable of synthesizing their thoughts from many disparate sources as well as communicating with the alumni network from many distinct disciplines.

Conclusions

Overall, the survey technique gaps in the current BAE curriculum. The gaps can be fixed having a cohesive curriculum that have similar goals and accurate knowledge of what the students are learning during their undergraduate career in BAE. This can guide in having an ABET accreditation category that can accurately describe what skills and concepts a BAE should know throughout their post-secondary education curriculum. This study will allow for the creation of educational modules that can assist with bridging the gap between core courses taught at the undergraduate level.

The Fundamentals of Engineering (FE) exam requires BAE to know the following concepts: biomaterials processing, physical and chemical properties of biological materials, mass transfer between phases, hydrology, and erosion control (NCEES, 2015). The requirements of this exam identify some key knowledge areas specifically aeration involved in biomaterials processing is a specific learning concept an undergraduate student should know. Unfortunately, the curriculum used in this study does not support that the learning concept is being taught. At the same time, this research supports the importance of heat and mass transfer, biological materials and basic computer programming which is correlated with required knowledge needed for the BAE FE exam.

Other universities can benefit, for example, the BAEN department at University of Illinois can implement the mapping and survey technique to identify the learning outcomes of the program. A program describes a BAE student should be able to have a skill set in environmental protection and the biological interface of plants, animals, soils, and microorganisms (University of Illinois, 2018). This definition of a BAE differs from another university which is the focus of the program is to develop processes, products, and systems using biological and environmental science and engineering tools to solve solutions to societal problems (Cornell University, 2019). Mapping put potential knowledge areas and identifying knowledge gaps can lead to improvements of BAEN programs. This will lead to an improved definition of what a BAE can offer for post-graduation opportunities.

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