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Reshaping curriculum and education for engineering in agriculture
——For the Centennial Anniversary of China Agricultural University

Zhang Yuanhui
(Department of Agricultural and Biological Engineering University of Illinois at Urbana-Champaign, Urbana, IL, 61801, USA)

Abstract Agricultural engineering profession has played a vital role in mechanizing agriculture, from farm machinery to rural electrification, from designing clear span wood trusses to protecting surface and ground water. To gain further efficiency and maintain sustainability, agricultural engineering will need to rethink the basics of production agriculture. The agricultural engineering discipline has already evolved into a number of different dimensions beyond mechanization for production, addressing such issues as precision agriculture, optimizing food production processes, improving air quality in buildings and vehicles, utilizing biomass and bioenergy, and reducing water contamination through biofiltration and runoff control. The result is an increasing biological science and application emphasis. Rapid advances in technology allow us to take advantage of developments in global positioning systems by, distributed power supply, nanotechnology, biosensors and robotics to develop precision agriculture, where each plant or animal can be treated as an entity to maximize profitability and to minimize environmental impact. Other constant challenges, such as biomass and bioenergy, are revitalized in our research and economic domains. To meet these challenges, we must educate our students, and the profession, to be able to adapt changes, that is, to be able to learn.

Key words agricultural engineering; curriculum; biological engineering; profession

农业工程类学科教育与课程整合
——庆祝中国农业大学百年校庆

张 源 辉
(美国 Illinois 大学 农业与生物工程系,Illinois, Urbana, 61801)

摘 要 农业工程类专业在从农业机械化到农村电气化、从净跨木屋架设计到地下和地表水保护等领域的机械化农业过程中发挥了至关重要的作用。为进一步提高其贡献率和维持其可持续性发展,农业教育工作者应该从农业生产基础的角度对农业工程进行再定位。目前:农业工程学科已涉及除机械化生产之外的很多其他方面,例如精准农业、食品加工过程优化、室内和运输车辆内空气质量改善、生物质与生物质能源利用、通过生物过滤与径流控制以减少水体污染等,这些成果正在逐渐成为生物科学及其应用的重点;飞速发展的科学技术已允许我们在全球定位系统中,利用诸如分布式电力供给、纳米技术、生物传感器以及机器人等技术发展精细农业,使得每个动植物个体都可以作为一个实体进行处理以使效益最大化并将环境的负影响降至最低;我们对一些持续的挑战已经有能力应对 ——例如生物质和生物质能源在科学研究和经济领域内已经获得了新生。为适应那些更加广泛的挑战,我们需要培养相适应的学生和专业人士并使他们学会学习,把不断优化的专业基础知识应用到生产和社会实践中去,做促其高效持续发展的积极推动者。

关键词 农业工程; 课程; 生物工程; 专业
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Introduction

This year marked the centennial birthday of China Agricultural University (CAU). It is also the centennial birthday of American Society of Agricultural Engineers (ASAE). Birthdays are a time of celebration but also of reflection.

Humankind has distinguished itself from other living species by emotions and the ability to think, but thrived by means of agriculture. Agriculture has been the mother of human society, responsible for its birth, growth and maturation. From an anthropological perspective and using a logarithmical time scale, human evolved from its primitive ancestors about one hundred thousand years ago. Agriculture was experi-

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About the author: (Dr. Yuanhui Zhang is a professor and the leader of Bioenvironmental Engineering Section, Department of Agricultural and Biological Engineering at the University of Illinois at Urbana-Champaign. Beside his teaching and research, Dr. Zhang has taken the leadership in the curricula reform in the newly named Agricultural and Biological Engineering Department. He is also a member of the Executive Committee of the College of Engineering at UIUC, and has accumulated considerable experiences in curricula development.
张源辉博士为我校客座教授。

mented with at about ten thousand years ago when some crops were domesticated, but was not widely practiced until about one thousand years ago, when agriculture developed systematic cropping and animal husbandry. Yet, the real growth of agriculture was observed only in the past one hundred years marked by its mechanization. At the turn of the 21st century and the centennial anniversary, we have many reasons to ask ourselves: Can we sustain such an exponentially growing trend in agriculture? Or has agriculture reached its plateau? Or is agriculture in decline? In searching for answers, I will focus on the trends of the past century-the same period since the birth of CAU and ASAE —and use the example of my profession: agricultural and biological engineering.

1 A continuous changing profession

In 2001, the U. S. National Academy of Engineering ranked agricultural mechanization as the 7th greatest engineering achievement in the 20th century, ahead of inventions such as computers, telephones, air conditioning and refrigeration, and spacecraft. At the beginning of 20th century, more than 60 % of the population of the United States worked on farms. By the turn of the 21st century, only 1.5 % of the population worked on farms, producing plentiful and high quality food and fiber for the nation and helping the United States to become a dominant exporter to the world food market. Additionally, approximately 25 % of the U. S. population is now involved in industries related to agriculture (including production, processing and service), with increasing emphasis on quality in addition to quantity, and augmenting productivity with sustainability. To adapt to this phylogenic progress and to better serve society, mechanization-based agricultural engineering is evolving into a biologically based agricultural engineering.

This evolution was initially gradual, beginning in the 1980s, but it accelerated rapidly in the 1990s. The American Society of Agricultural Engineers (ASAE) has approved its name change to The American Society of Agricultural and biological Engineers (ASABE) in 2005 to reflect this transformation of the profession. Accreditation for agricultural engineering and biological engineering has been combined and is administered by ASABE. The name change is only one visible sign of the transition that has begun.

All of the traditional agricultural engineering departments in the U. S. now have a name with some variation of "bio" included. It is the current perception that many of the curricula in these departments include "bio" subject matter, but it is largely added to the curricula, either as additional or modified courses, or as a separate degree track in biological engineering within a department offering other engineering degrees. The 'add-on' biological courses or programs may be distracting as the existing engineering curricula are already rigorous and demanding for many engineering undergraduate students. It is important for these programs to integrate biological content completely throughout agricultural engineering in order to create a degree program that is truly "agricultural and biological engineering."

The transition to an integrated curriculum of agricultural and biological engineering requires a paradigm shift in thinking and a higher order of scholarship in teaching and learning among faculty and students. Agricultural and biological engineering should be to the science of biology what mechanical engineering is to mechanics and what chemical engineering is to chemistry. Significant progress has been made in the past several decades to shift the biology phylogeny from descriptive to quantitative, and with more precise control in some areas. Yet the existing biological science is still very much inductive, depending on the accumulation of knowledge to define general laws. In contrast, agricultural engineering is very much deductive, applying a few laws to solve specific problems related to food and agriculture. As a result, the teaching and learning of biology and agricultural engineering have been distinctly different. Current teaching methods emphasize craft, whereas fully integrated curricula will need a concept-based teaching method. This shift will require continuing education in pedagogies for the faculty.

2 Current status

2.1 Integrating biology and engineering

A number of resources are helpful in considering how to integrate the content and ways of thinking of biology and engineering. Hall and Lima[1] compared traditional engineering systems with their interpretation of biological engineering systems. They identified three specific issues concerning the complexity of living systems: non-linearities in system properties and dynamics, temporal and spatial variation within biological systems, and emergent properties of combinations of systems. They also advocated a paradigm change with fundamental biological engineering in which the focus shifted from a primarily physical science emphasis to the biology of the system. They suggested letting the biology of the system lead the design process while considering the unique properties of a biology system. They also believed that cultural, social, and ethical issues must be central to the design process for biological engineering to be successful as a discipline. This holistic approach was regarded as critically important as it took into account all aspects of a biological system (humans) and how that system interacted with other systems (other species and the ecosystem).

Hughes and Kristy[2] propose two potential methods of defining important biological concepts for biological engineering. One involves examining the biological engineering fields and then defining the biological knowledge that students need to become proficient in these fields, and the other relies on examining modern biology, defining key concepts of biology, and then assessing their applicability to biological engineering. The second method is regarded as having a major advantage as it provides a platform for the definition of a biological engineering curriculum that, regardless of specialization, would enable communication among all biological engineers.

Johnson and Phillips[3] proposed philosophical foundations for biological engineering. As biology and engineering are in their different phylogenic stages, their teaching philosophies and methods are inevitably different. In general, biology is primarily inductive - accumulating more knowledge and trying to find fundamental laws; yet engineering is primarily deductive - conceptualizing many facts then utilizing a few well-known laws. For example, Newton's Law and Fick's Law are used to solve several problems. Such a fundamental difference in biology and engineering inevitably leads to conflicts, and makes them difficult to combine. With the advances in biology, some biology subject areas have entered the phylogenic stage of quantification. These advances help to quickly bridge the gaps between biology and engineering.

2.2 New approaches to teaching and learning

In order to prepare students for this new integration, a reconsideration of pedagogy is essential. A paradigm shift is occurring in higher education in which institutions are "thinking less about providing instruction and more about producing learning"[4]. In their seminal article, Barr and Tagg[5] discuss key components of this paradigm shift; the following are most relevant to this paper:

1) *Mission and purposes: from 'improving the quality of instruction' to 'improving the quality of learning.'* Ideas behind this statement include eliciting students' discovery and production of knowledge, creating powerful learning environments, and planning for success for diverse students[5]. The Gateway Coalition, funded by the U.S. National Science Foundation, is a useful resource for our project in this regard, as it models the "changing engineering education paradigm." The coalition addressed a range of topics and issues including institutionalizing outcome-based assessment and continuous improvement processes, the innovative use of technology, and outreach to underrepresented groups so that they were integrated into plans for each project from the beginning[6]. In Gateway Coalition programs, students learn the basics of science and engineering "in context and concurrent with open-ended engineering inquiry and engineering experimental methods". These new programs also allow students to integrate communication skills, teaming and interpersonal skills, and the ethical dilemmas faced by engineers[6]. Fromm[6] also indicated that the coalition's innovations such as engineering up-front, student professional development, and mentoring resulted in increased retention rates as well as increased graduation rates.

2) *Criteria for success: from 'quality of entering students' to 'quality of exiting students.'* If we are thinking differently about the discipline, an important consideration will be the changes in the knowledge, skills, and attributes of the agricultural and biological engineers whom we are preparing for the profession. Of course, the "*a* through *k*" competencies described by the U.S. Accreditation Board of Engineering Technology (ABET) will be foundational in this consideration. In addition, the U.S. National Academy for Engineering[7] has offered further insights into their vision for the "Engineer of 2020." While many of their characteristics overlap with the "*a* through *k*" competencies, additional attributes more explicitly expressed include creativity, a background in the principles of business and management, leadership skills, and "dynamism, agility, resilience, and flexibility"[7]. Fromm[6] predicted the need for even more global and cross-institutional linkages in the years ahead with programs becoming more technically intensive while intellectually broadening. Such changes would require new approaches and taking advantage of new tools, developed by engineers. Engineers will need to be able to function on teams across many geographical boundaries, thus requiring intellectual maturity and broader cultural understandings, much of which will be facilitated through technology.

3) *Learning theory: from 'learning is cumulative and linear' to 'learning is a nesting and in-*

teraction of frameworks.' New developments in cognitivist and constructivist learning theory[8-9] will inform our redesign process. Of particular relevance are matters such as how learning transfers to new contexts[9], metacognition[10], and how expert thinkers differ from novice thinkers[11-13]. A central cognitive process in engineering is problem-solving. Fogler and LeBlanc[14] describe a variety of strategies within a problem-solving heuristic comprising five building blocks that are aimed at helping engineers solve problems. Both creative and critical thinking capabilities are addressed. Lumsdaine and Lumsdaine[15] provide a more detailed text addressing numerous aspects of problem-solving in the engineering discipline. The department has introduced generic problem-solving heuristics in a freshman class. However, a more sustained approach to developing problem-solving skills is required that exercises all thinking skills, particularly creative and critical thinking through all four years of the degree program.

4) *Nature of roles: from 'faculty being primarily lecturers' to 'faculty being primarily designers of learning methods and environments.'* Engineering education must avoid the cliché of teaching more and more about less and less, until it teaches everything about nothing. Addressing this problem may involve reconsideration of the basic structure of engineering departments and the infrastructure for evaluating the performance of professors as much as it does selecting the coursework students should be taught"[7]. Our goal is to move towards a curriculum that promotes conceptual learning and problem-solving, and thus gears students towards life-long learning.

3 Contemporary issues

Although significant advances have been made to the present, substantially larger advances are still possible because we are well below the genetic potential of most biological systems. Compared to past achievements, there are some major shifts of research and teaching areas and concerns in agricultural and biological engineering. Production efficiency may be a lesser concern compared with food safety and quality. Environmental protection and sustainability has become a major issue in agriculture. Animal welfare has become an increasing concern in livestock production and consumers (with many food chains such as McDonald promoting 'happy animals make happy meals'). There are also, one should not neglect, noticeable differences between research issues in developed and in developing countries. The following update may overlap many present issues for developed countries with future issues for developing countries:

1) Current ABE systems allow higher quantities, better quality, and more reliable sources of food relative to previous production systems. At present, ABE systems have had positive and some negative effects on human society and the natural environment.

2) Newer biological systems need engineering in order to produce at higher levels.

3) We must analyze the issues and concerns with present ABE systems to provide us with a point of reference from which we can determine future research needs, to predict which research programs will have the most impact on our future food supply.

4) We must analyze external forces that will dictate future changes in food and fiber production. We need to develop sustainable ABE systems that minimize inputs and maximize recycling.

5) Societal constraints and consumer acceptability changes in products and management will alter facility design and management of ABE systems. Consumers demand fresh, safe, dependable, and consistent food supply with desirable characteristics such as taste, texture, and aroma. There is an increasing demand for organic and environmentally conscious foods.

6) Four key factors that may affect future needs in ABE research:

a) Environmental quality protection-Production outputs often pollute the natural environment and need to be controlled to acceptable levels. Outputs include wastes, nutrients, odor, particulates, undesirable gases, carcasses, noise, heat, etc.

b) Societal constraints and consumer acceptability-ABE systems need continuous improvement to remain competitive, based on consumer need and environment concerns.

c) Food production reliability, security and safety-Consumers are concerned that food supplies be safe and uncontaminated.

d) Improve economics of production - Must ensure good livelihood of the producers, and provide jobs for people in all economic groups and geographical regions.

7) We must address societal concerns of energy security. Organic wastes have been, and will continue to be used as feedstock for bioenergy production to reduce gaseous emissions (NH_3, CH_4, VOCs, and odors). The following biomass conversion technologies have been researched and are under continuous development: gasification, liquefication, other ther-

mochemical conversions, biodiesel production, combustion, ethanol fermentation, and anaerobic digestion.

8) Biofuels are at infant stage and need significant development. There is a need to assess the current status of technologies used for bioenergy production and usage. Small biogas digesters are well developed, however larger scale digesters are needed for concentrated livestock farms and other agricultural operations.

4 Future issues

Compared with some other industry sectors such as computer and information technology, ABE has a much longer cycle of technology advancement, largely because the infrastructure is expensive to replace or renovate. On the other hand, societal concerns and consumer driven economy will likely have a much greater impact on ABE, pushing for development and adaptation of new technologies. The future trends include:

1) Better measurement methods, monitoring systems, abatement technologies and decision-making process will improve the quality of air, water and biosystems. Many current information technologies such as global positioning systems (GPS) and geographical information system (GIS) will be adapted to agricultural production.

2) Vertically integrated animal & plant production and waste treatment systems to reduce or avoid the cost of transportation and become more efficient. The production of livestock and greeneries will likely be more integrated into larger scale.

3) Bioenergy supply will increase to reduce non-renewable energy dependency with the help of improved and newly developed technologies. Efforts will be made to achieve higher bioenergy conversion efficiency for digestion, fermentation, combustion, gasification and liquefaction.

4) Development of sustainable plant and animal production systems with controlled environment system platforms for management and troubleshooting. Better energy efficiency for building systems can be achieved through improved ventilation system design and control.

5) It is expected there will be fewer emissions from animal production facilities, less chemical application through organic and precision farming, improved facility design and management, abatement technologies, public consciousness and government regulations.

6) Working environment, indoor air quality and animal welfare will be further improved. The driving forces will be occupational health (for working conditions) and consumer demand (for well-being animals).

7) Nanoscience and nanotechnology will substantially affect new technology and ABE. These nano-size or bio-based technologies include:

a) Nano-biosensors for precision agriculture applications such as tracing pathogens, remote sensing, and nutrient mapping. For example, nano-sensors may be implanted into individual animals to monitor their health and performance, and centrally managed by a computer. Nano-sensors can be used in a distributed manner to monitor the field distribution of nutrient, moisture, pesticide/herbicide and yield for precision agriculture.

b) Biotechnology and new materials may alter many biological processes. Agricultural buildings may be built using new materials. Odor components may be manipulated or treated through new feed formulas or deodorants.

8) A hydrogen driven economy may gradually replace the petroleum economy:

a) Fuel cell combined with other conversion technologies may be the new economical engine for 21st century.

b) Modern societies including China may move away from a petroleum-based energy supply to an increasingly agricultural-based energy supply.

9) Dispersed energy supply systems may replace the centralized system for two reasons: economy (less intensive capital cost), and safety (less threat from terrorism and power failure). Such a technology and infrastructure leap-frog may be easier in China than in other developed countries where infrastructure already exists. As an example, China has leap-frogged from almost no phones to wide usage of wireless phones.

10) Sustainable development, a concept applied to design all environmental and energy systems and agro-eco-industrial complexes. Such complexes can be large-scale and mixed-mode of live/work environments including agricultural production systems for animals, plants, organisms, incorporating energy supplies, waste recycling and self-sustainability.

11) It is predicted that within next 50 years, township development will be a major task for ABE in China. Macroscale issues include water quality and energy supply (switch from traditional biomass to cleaner fuel). Microscale issues include food safety at consumers' dinner tables and supply sufficiency. Bal-

ance of technology and affordability must be considered during this developing period of time.

5 Summary

Agricultural Engineers have played a vital role in mechanizing agriculture, from farm machinery to rural electrification, from designing clear span wood trusses to protecting surface and ground water. We continue to improve the efficiency of agricultural production and also to explore product diversification and specialization, while at the same time ensuring sustainability and minimizing adverse environmental impacts. To gain further efficiency and maintain sustainability, agricultural engineering will need to rethink the basics of production agriculture. The agricultural engineering discipline has already evolved into a number of different dimensions beyond mechanization for production, addressing such issues as precision agriculture, optimizing food production processes, improving air quality in buildings and vehicles, utilizing biomass and bioenergy, and reducing water contamination through biofiltration and runoff control. The result is an increasing biological science and application emphasis. Rapid advances in technology allow us to take advantage of developments in Global Positioning Systems by satellite (GPS), distributed power supply, nanotechnology, neuronet systems, biosensors and robotics to develop precision agriculture, where each plant or animal is treated as an entity to maximize profitability and to minimize environmental impact. Other constant challenges, such as biomass and bioenergy, are revitalized in our research and economic domains. To meet these challenges, we must educate our students, and the profession, to be able to adapt changes, i.e., to be able to learn.

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