Int. J. Engng Ed. Vol. 23, No. 4, pp. 728–734, 2007
Printed in Great Britain.

0949-149X/91 $3.00+0.00

Designing a Design Course for Agricultural Engineering in Africa*

AJIT K. MAHAPATRA[1], KRISHAN L. KUMAR[2], JAMES L. JULSON[3] and K. MUTHUKUMARAPPAN[3]

[1]Agricutural Research Station, Fort Valley State University, 1005 State University Drive, Fort Valley, GA 31030, USA, E-mail: mahapatraa@fvsu.edu

[2] Department of Industrial Design & Technology, Faculty of Engineering & Technology, University of Botswana, Pvt Bag 0061, Gaborone, Botswana, E-mail: kumarkl@mopipi.ub.bw

[3] Agricultural & Biosystems Engineering Department, South Dakota State University, PO Box 2120, Brookings, SD 57007, USA, E-mail: james.julson@sdstate.edu

Design skill is an integral part of an engineer's education. Hence, incorporating a design course into agricultural engineering education in Africa will create agricultural engineers who are not only technically strong, but also innovators. The need for well-planned design input for agricultural engineering students is evident, by looking at the changing scenario in the world of work. It is envisaged that a formal course would serve better than occasional pieces of design-related information cited in individual subjects. A new core course on Design Methodology intended for agricultural engineering students in Africa is proposed and a framework of implementation and evaluation is presented. A design cycle consisting of needs analysis, concept hunt, environmental conditions, function-analysis, ergonomic and aesthetic parameters is described. The course incorporates elements of research, conceptualization and decision making. It is also expected to stimulate thinking, group discussions and creativity in general. The course would enable the students to conceive, formulate and take up design-orientated final year projects. The course proposed here may be introduced in agricultural engineering programmes throughout Africa to improve students' education. Whether they pursue careers in industry or academia, this course will prepare agricultural engineers in Africa to be engaged in problem solving from the moment they enter the professional field.

Keywords: design; agricultural engineering; Africa

INTRODUCTION

ENGINEERING AND TECHNOLOGY are a profession which is concerned with innovating, designing and manufacturing articles for the benefit of mankind. The basic purpose of all engineering is design of artifacts, systems and processes [1]. In this respect, design processes precede, empower and drive technology, as illustrated by a donkey-cart analogy in Figure 1. Design processes include conceptual and product design whereas technology includes the tools and processes of manufacturing. Agricultural engineers must, therefore, be able to conceive, design, make and evaluate agricultural implements. The agricultural engineer needs an understanding of design methodology in addition to the conventional subjects such as applied mechanics, strength of materials and theory of machines. Design of agricultural systems requires a systemic approach in order for the design criteria to be adequately realized.

Feasibility studies and economic viability must draw upon quantitative information and hence are dependent upon both biological and engineering design parameter specifications. Agricultural implements must be innovatively designed besides being mechanically strong and biologically sensitive. Currently such implements are designed and tested by agricultural engineers by virtue of the knowledge that is gained through the power and machinery curriculum. Likewise, drainage and irrigation systems and water control structures for reservoirs, floodways and channels, storage structures for grain, fruits and other food products, waste handling and storage facilities are all designed by virtue of the knowledge accumulated from specific subjects without the opportunity to apply this knowledge through the actual design methodology.

THE CHANGING SCENARIO

Curricula designed to apply engineering principles to living systems first began in the USA around 1912 and was called agricultural engineering because it focused on production for agriculture. During the past decade, several additional undergraduate engineering curricula focusing on living systems applications have been established in agricultural engineering [2]. Several develop-

* Accepted 14 June 2007.

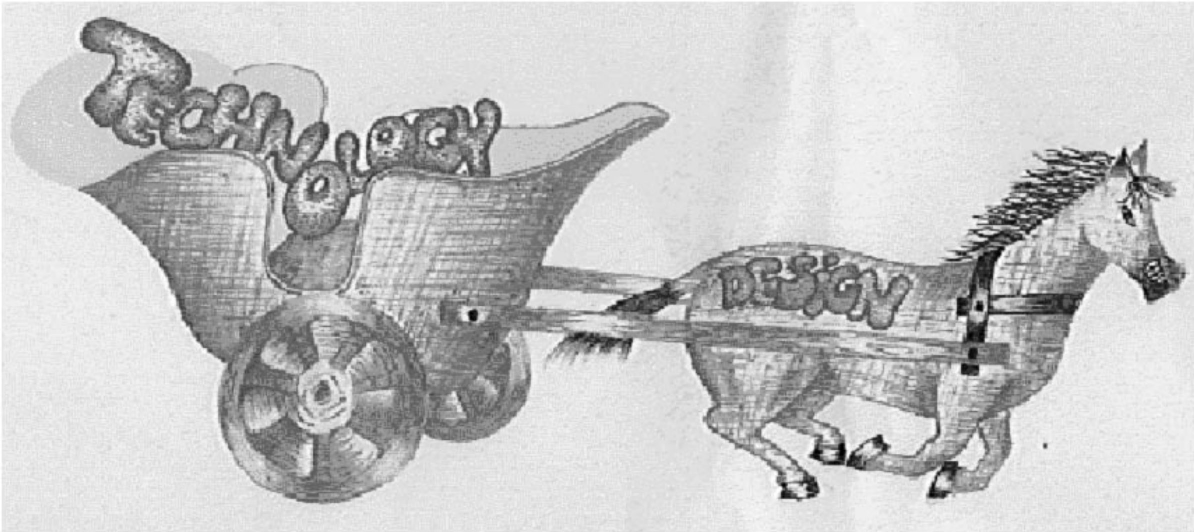

Fig. 1. Design driving technology

mental factors have necessitated the agricultural engineering departments in all parts of the world, including Africa, to restructure their programmes and curricula to meet the perceived challenges of the future.

The Faculty of Engineering at the University of Nairobi, Kenya embarked on a curriculum review exercise and proposed a new curriculum for engineering in 'agriculture and environment' [3]. The Faculty of Agricultural Sciences at the University of Goettingen, Germany completely restructured the curriculum by introducing the 'modular system' to make the programme more attractive and competitive [4]. The Departments of Agricultural Engineering in East African Universities have recognized the needs for curriculum changes and the realities of ever shifting manpower demands in their countries [5]. Many Agricultural Engineering Departments in the US and Canada have recognized the need for curriculum improvement and have restructured their programmes to meet the challenges of the future. Globalization poses opportunities and challenges for engineers. Hence, there is a serious need and potential to enhance the entrepreneurial and technological capacities of African industries to compete in the global market [6]. In Africa, it is necessary to ensure a continual upgrading of programmes to increase the ability of graduates and to ensure that they are capable of strengthening the African food and agricultural professional workforce.

A good engineering education is about process, about learning how to think like an engineer; it is much more than a prescription of content [7]. A study of the existing curricula in the African continent reveals that students are taught elements of mechanics, strength of materials, thermodynamics, etc. as core courses but there is no course on design methodology. A typical syllabus in Asia presently has several design related courses, i.e. elements of machine design and drawing, irrigation and drainage system design and pump design. However, the content of the curriculum is rather limited. Several leading universities across the world offer Capstone Senior Design Projects encompassing creative and functional design methods followed by sustained design in an area of the student's interest. The Ohio State University offers two such courses, AE 724 and AE 725 entitled Capstone Design in Food, Agricultural and Biological Engineering I and II respectively [8]. This is indeed in step with the proposal being made in this paper. It encourages agricultural engineering students to participate in the design of an engineering project useful to agriculture and provides an arena of professionalism in which the student can experience peer recognition of a well-conceived and well-implemented design project.

A 'Capstone Problem Solving Course' revisited [9] after several years of its operation at a two-year technical college, Ohio State University, is an example of applying a systems approach to food and agricultural problems. Currently called T 292: Problem Solving Using Systems Approach, the course packet consists of several puzzles, problem solving strategies for critical thinking, scientific method, communication, group dynamics and finally, quantitative and qualitative methods of decision making. The course has resulted in an improvement of students' attitude and enthusiasm for tackling new problems. The course, however, did not focus on designing new products and processes, although it did achieve the goals of problem solving, group dynamics and decision making. Another example of 'designerly' thought [10] comes from the University of Florida where senior level horticulture students are offered a major Landscape Design Project together with knowledge in graphic and communication skills and the design process with reference to time, budgetary, installation and other constraints. It is claimed to result in a rich learning experience with a great deal of satisfaction and encouragement felt by the students. We have also drawn a parallel with the Orientation Course for technical students [11]. This is a core course, aimed at pointing students towards agricultural technology. It includes journal writing, group discussions, facilitation and application-orientated activities with the purpose of promoting student-centered learning.

In summary, agricultural engineering programmes in the US and elsewhere have been revised to include courses such as Introduction to Engineering Design, Capstone Engineering Design and components of Design Methodology. However, no such design courses are offered in African universities.

OBJECTIVES OF THE COURSE

Design methodology can be defined as the study of the principles, practices and procedures of design. Its primary focus should be to develop a deep and practical understanding of the design process and how this could be modified, made more effective and transparent and be managed to achieve sustainable design outcomes [12]. The proposed course on Design Methodology is intended for pre-final year students although it is without any prerequisites. Upon completion of the course, a learner will be able to [13]:

- Conceive and employ the design cycle.
- Identify the importance of divergent–convergent methodology.
- Conduct needs analysis and prepare specifications.
- Think laterally for alternative design of implements.
- Communicate effectively (both orally and written) at different stages in designing.
- Employ graphic communication during development.
- Consider ergonomic and aesthetic factors in design.
- Employ modeling and simulation practices.
- Ensure safety in processes and operation of implements.
- Incorporate quality aspects in product design.

Reference is made to a typical iterative cycle for engineering products as in Figure 2. It shows the essential steps of problem formulation, design brief, divergent thinking, selection of the most favoured solution from the conceived alternatives, preparation of specifications, model making and/or simulation, economic considerations, detailed design with regard to mechanics, ergonomics, etc. and finally the preparation and testing of the prototype.

It is often said that once a problem is well formulated, it is 50% on its way to solution! Roberts [14] spelled out the nature of problems in 'Design and Technology' as a felt discrepancy or incompatibility. He also stated that a designer usually starts from an ill-defined statement and redefines it by employing his/her sense of perception and preference, thus stressing a designer's capability to formulate problems and modelling for solutions. The content of the course derived from the above objectives is shown in Table 1.

It spans over 42 contact hours consisting of 14 lecture hours and 28 practical/tutorial hours in a single semester. A corresponding 'Specification Table' indicating weightages for the cognitive and psychomotor domains of learning is shown in Table 2. According to the well-accepted Bloom's Taxonomy [15], there are five levels of cognitive domain. Knowledge is the basic and then Comprehension and Application where Application covers Analysis, Synthesis and Evaluation as the highest. It is customary to use the terms Knowledge, Comprehension and Application to mean the whole spectrum. Table 2 presents a summary of the topics and their relative weightings with regard to different domains and their taxonomic levels. A 'Specification Table' is a good educational tool for spelling out all components of a course and relative importance of topics with respect to one another.

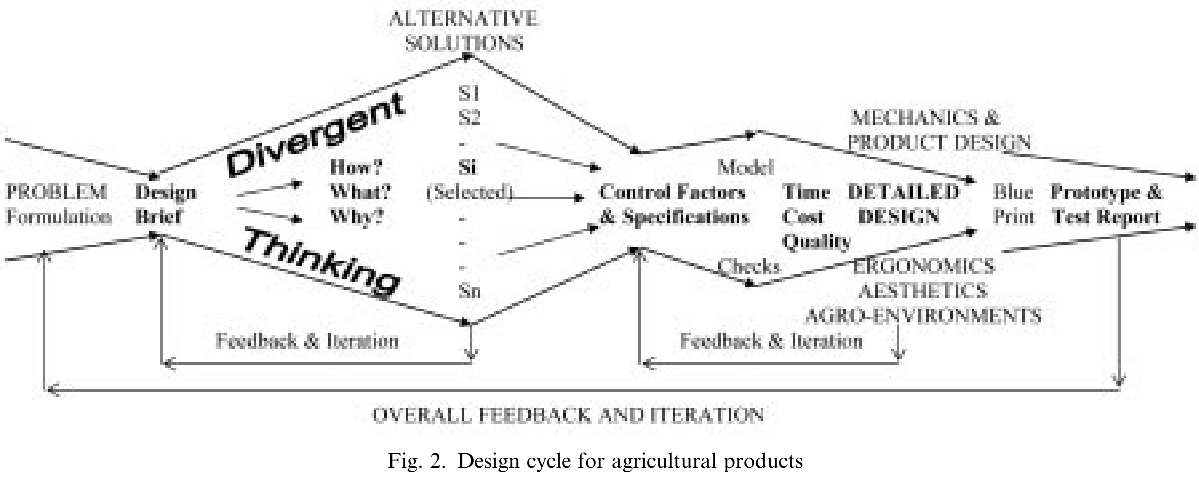

Fig. 2. Design cycle for agricultural products

Table 1. Course content for design methodology

S. No.	Topics	Hours		
		Lecture	Tutorial/Practical	Total
1	Design: A Process and a Product	1	–	1
2	The Design Cycle and Iterative Steps	1	2	3
3	Divergent-Convergent Methodology	1	2	3
4	Needs Analysis and Specifications	1	2	3
5	Research and Concept Hunt	1	2	3
6	Ergonomics and Aesthetics	2	4	6
7	Study of Existing Objects and Nature	1	4	5
8	Developing Alternative Designs	1	2	3
9	Role of Communication in Design	1	2	3
10	Graphic Communication	1	2	3
11	Environmental Factors in Design	1	2	3
12	Virtual Simulation and Modeling	1	2	3
13	Quality Concepts and Safety Aspects	1	2	3
Total:		14	28	42

Table 2. Specification table for proposed course in design methodology

S.N	Specification of Weightages	Cognitive Domain			Psychomotor Domain	Total % Weigt Ages
		Knowledge	Comprehen-sion	Application		
1.	Design: A Process and a Product	2	2	3	–	7
2.	The Design Cycle: Iterative Steps	2	3	–	–	5
3.	Convergent–Divergent Methodology	–	3	3	5	11
4.	Needs Analysis and Specifications	1	2	–	5	8
5.	Research and Concept Hunt	1	2	5	–	8
6.	Ergonomics and Aesthetics	1	3	3	5	12
7.	Study of Existing Objects and Nature	–	2	3	5	10
8.	Developing Alternative Designs	1	2	5	–	8
9.	Role of Communication in Design	–	2	2	5	9
10	Graphic Communication	–	3	2	–	5
11	Environmental Factors in Design	1	2	2	–	5
12	Virtual Simulation and Modeling	1	2	–	5	8
13	Quality Concepts and Safety Aspects	–	2	2	–	4
	Total % Weightages	10%	30%	30%	30%	100%

The table is thus intended to guide the teacher's lesson planning and time distribution, i.e. allocating number of lectures available to different topics and the extent to which topics may be covered. Different weightages in Table 2 refer to the percentage weight or importance of a particular domain in the curriculum. All weightages, should therefore add to 100.

Topics like Aesthetics and Ergonomics are important because people buy a new product not just for sensible and value-for-money reasons [16] but because it appeals to them. Aesthetic aspects such as repetition, harmony (or balance), contrast (or discord), rhythm and movement and unity may be included [17]. In fact, a product may be functionally superb but the customer may not be inclined to pick it up if it lacks eye-catching features. Topics like Studying Existing Objects and Nature are also introduced with the idea of developing design sensibilities. The subject of communication does not end with the designer's ability to communicate with others in respect to design but goes further until the product is able to communicate with the customer!

IMPLEMENTING THE COURSE

Teaching-learning processes in the course need to be geared to the learning objectives of the different topics. The two topics, i.e. concept of design cycle and the convergent-divergent methodology need to be discussed in-groups and brainstormed after a lead lecture. A typical group's work may involve concept generation followed by user needs and market assessment, and technology assessment followed by concept refinement [18]. Concept generation, as a rule, is the most creative phase of the design process and in many cases, the most difficult [19]. Discussions are aimed at creating collaborative and competitive environment, which is crucial to teamwork. Needs analysis may be demonstrated by case studies and a practical exercise of data collection by the students.

The importance of research and concept-hunt is better understood through application. This is also the stage where students are fully able to express their inventiveness, and where they quickly realize that each team member has a unique solution [20]. The teams could be assigned to build a scale model of their final design out of readily available materials in the laboratory. The purpose is to visualize the proportions, and identify any interference between parts. Principles of Ergonomics and Aesthetics may be covered in two lectures but their implication may be brought out by way of tutorial sheets with several practical assignments. Study of the nature of existing design will be taken up with criticism and evaluation of students' opinions.

Oral, written and graphic communication assumes special importance in communicating ideas and concepts and in developing new designs. Since the intention is to produce an engineered product, students need to sketch their ideas. Each group may submit 4–6 design concepts with at least one drawing each. Designing is not an end to itself; it is followed by manufacturing drawings complete with specification of materials and tolerances. Communication is best learned through communicating, i.e., application, practice and realization. Students must describe the process they followed in their design project in a complete report at the end of the course. Good designs must take environmental factors into account, which are best explained by case studies and examples. Students need to learn through modelling and virtual simulation of design parameters on computers. Since computer-aided design, computer-aided manufacturing and computer-aided engineering are powerful new tools for design engineers, they must be introduced and demonstrated [21]. In order to design inherently safer machinery, it is essential for agricultural engineers to attempt to foresee the risks associated with the use of a piece of machinery. Safety devices and safety features in design need to be pointed out in existing designs. Agricultural machines and equipment must be designed to best fit the people who use them, rather than for users to adapt to the design. Finally, the sense of quality consciousness, i.e. 'first-time-right', dependability and trouble-free operation and ease of maintenance will be developed through citing examples and non-examples.

The course also should include some traditional, individually prepared homework assignments addressing each learning domain and most of them should be open-ended. The homework will provide opportunities to practice techniques that are used in the design process. Examples of student work in different learning domains abound. Often, tutorials are conceived as brainteasers for ensuring knowledge and comprehension whereas tutorial problems are designed to build the application capability of students. It is advisable to commence a tutorial sheet with concept review questions and multiple choice or multiple response type questions because Bloom's theory on Hierarchy [15] requires that lower level abilities are developed before moving to higher level abilities. Tutorial problems also need to be graded incorporating the principle of 'simple to complex'!

EVALUATING THE COURSE

Evaluation, in this context, refers to peer-evaluation, student self-evaluation, instructor evaluation and employers' evaluation. We have taken the opportunity of consulting our colleagues and presenting the details of the course in seminars and at a conference [22] where we found overwhelming support. Once the course is introduced in some universities, we shall gear up to participate in its evaluation. As a matter of fact, risk-taking is a feature of creativity in the teaching and learning of design [23]. Design activity can acquire a creative leap to realize acceptable solutions. This is a skill valued by clients and customers. Lessons learned from the introduction of Design and Technology in the school sector reveal that there are benefits in offering a new course of this nature. It develops the general creativity potential of a person in addition to enhancing specific design skill capabilities. The effectiveness of different methods of implementation may need to be examined as part of course evaluation.

CONCLUSIONS

Design skills are invaluable to agricultural engineers. By giving students the opportunity to solve design problems early in their education, they will acquire technical knowledge that can readily be applied to real-life problems. Agricultural engineering programmes in Africa would be in tune with the general concept of engineering and more likely to stand the test of time if courses were revised so that essential elements of Design Methodology could be incorporated into the curriculum. This would produce top quality, competent agricultural engineers equipped to meet the challenges of a changing world. The graduates would have the confidence and skill to embrace market demands and expected developments in the agro-industrial sector. Design Methodology would constitute the central element of the programme. Agricultural engineering design projects undertaken during the final years of the programme would help to bring out the innovative and creative aspects of agricultural engineering students. The course is intended not only to provide a meaningful design experience but also to accomplish a confidence building transition in the role of the practicing agricultural engineer.

REFERENCES

1. J. Gowing, Biological engineering: into a new era for the profession. *Agr. Eng*. **50**(2), 1995, pp. 29–30.
2. R. E. Young, Carving niches in biological engineering. *Resource,* **5**(3), 1998. http://www.asae.org/resource/ryoung.html
3. L. O. Gumbe, D. A. Mutili, M. O. Marenya and S. N. Ngigi, Proposed new curriculum in engineering for agriculture and the environment at the University of Nairobi, in: *Proc. Int. Conf. on Agr. Eng. Curriculum and Employment Profile*, Lusaka, Zambia. (1999).
4. G. Kreykenbohm and W. Lucke, *Modern study of agricultural sciences in Goettingen (Germany): New focal points, reorganization and internationalization of the curriculum.* ASAE Paper No. 997023, ASAE, St. Joseph, MI: Amer. Soc. of Agr. Eng. (1999).
5. H. J. McRota, Agricultural engineering curriculum and employment profile: Core and elective courses at Egerton Univ, in: *Proc. Int. Conf. on Agr. Eng. Curriculum and Employment Profile*, Lusaka, Zambia. (1999).
6. J. C. Diehl and H. Christians, Product innovation for cleaner production (ECO-DESIGN) in Africa, in: *Proc. Int. Conf. on Industrial Design Eng.*, Dar es Salaam, Tanzania. (2003).
7. C. L. Dym, Design, systems, and engineering education. *Int. J. Eng. Educ*. **20**(3), 2004, pp. 305–312.
8. OSU, Ohio State Univ. Web site: http://www.oardc.ohio-state.edu/fabe/724.htm (1999).
9. A. P. Zimmerman, A capstone problem-solving course revisited. *NACTA J.* **41**(3), 1997, pp. 41–47.
10. G. L. Davis, Landscape design courses provide opportunity for service learning. *NACTA J.* **43**(1), 1999, pp. 23–25.
11. A. P. Zimmerman, Developing and teaching an orientation course for students at a technical college. *NACTA J.* **43**(1), 1999, pp. 25–31.
12. L. N. Green and E. Bonollo, The development of a suite of design methods appropriate for teaching product design. *Global J. Eng. Educ*. **6**(1), 2002, pp. 45–51.
13. A. K. Mahapatra and K. L. Kumar, A new course on design methodology for agricultural engineering students. *Agr. Eng. South Africa*, **32**(1), 2000, pp. 44–55.
14. P. Roberts, Models of design and technology and their significance for research and curriculum development. *Des. Technol. Assoc. J*. **4**(2), 1999, pp. 124–131.
15. 'Bloom, B. S. *Taxonomy of Educational Objectives: The Classification of Educational Goals.* David McKay Company, Inc. New York. (1965).
16. R. Kimble, Why do we buy? *Des. Technol. Assoc. J*. **3**(2), 1998, pp. 99–100.
17. C. F. Chuang, A project design and implementation program for industrial technology teachers. *Global J. Eng. Educ*. **5**(2), 2001, pp. 203–208.
18. J. E. Colgate, A. Mckenna and B. Ankenman, IDEA: implementing design throughout the curriculum at Northwestern. *Int. J. Eng. Educ*. **20**(3), 2004, pp. 405–411.
19. M. A. Angelov, M. B. Friedman and A. A. Renshaw, Introducing engineering design into the first year curriculum, in: *Proc. 29th ASEE/IEEE Frontiers in Education Conf.*, San Juan, Puerto Rico (1999).
20. M. Meier, Best practice in product design: concept outlines and experiences in project-oriented product design education. *Int. J. Eng. Educ*. **19**(2), 2003, pp. 338–345.
21. L. L. Christianson and R. P. Rohrbach, *Design in agricultural engineering*. St Joseph, MI: Amer. Soc. of Agr. Eng. (1986).
22. A. K. Mahapatra and K. L. Kumar, Introducing design methodology in agricultural engineering curriculum, in: *Proc. Int. Conf. on Agr. Eng. Curriculum and Employment Profile*, Lusaka, Zambia, (1999).
23. T. Davies, Taking risks as a feature of creativity in teaching and learning of design technology. *Des. Technol. Assoc. J*. **4**(2), 1999, pp. 101–108.

Ajit K. Mahapatra is a Research Professional at the Agricultural Research Station at Fort Valley State University (FVSU), Fort Valley, GA, USA. Before joining FVSU, he worked as a Research Associate for more than three years in the Department of Agricultural & Biosystems Engineering at South Dakota State University (SDSU), Brookings, SD, USA. He received BS (Agr Eng) from the Orissa University of Agr. & Technol., Bhubaneswar, India and his MS (Agr & Food Process Eng) from the Indian Institute of Technology (IIT), Kharagpur. He earned a Ph.D. from the Hungarian Academy of Sciences, Budapest, Hungary. Before coming to US, he taught several courses in Agricultural Engineering for eight years as a Faculty at University of Zambia in Lusaka (Zambia) and University of Botswana-College of Agriculture in Gaborone (Botswana).

Krishan L. Kumar received a Ph.D. degree in Mechanical Engineering from University of London, Imperial College. He subsequently joined Indian Institute of Technology (IIT), Delhi, where he was a Professor and Head of Educational Technology Department. He was a recipient of a national award for his outstanding contribution to Educational Technology in India. He currently holds the position of Professor and Head, Department of Industrial Design and Technology at University of Botswana in Gaborone, Botswana. His expertise and current research interests include design basics, functional design, industrial design &

technology, ergonomic and aesthetic design of products. He has extensive experience in engineering education research, curriculum development and assessment and is a member of Design and Technology Association, UK.

James L. Julson is an Associate Professor in the Ag & Biosystems Engineering Department at SDSU in Brookings, SD, USA. He completed his BS degree at the same University. In 1975, he earned his MS from South Dakota State University and his Ph.D. from the University of Nebraska, Lincoln, Nebraska, USA. Before entering the academic sector, he worked for Lester's of Minnesota, Inc. (USA.) as a livestock environment engineer. His current research interests include thermal gasification of lignocellulose material for production of biopolymers, the inclusion of C-4 fibres in panel boards and plastic for the production of biocomposites.

K. Muthukumarappan is an Associate Professor in the Ag & Biosystems Engineering Department at SDSU in Brookings, SD, USA. He completed his BS in Mathematics and Agricultural Engineering from Tamilnadu, India. In 1988, he earned his MS from Asian Institute of Technology. He obtained his Ph.D. from the University of Wisconsin, Madison, Wisconsin, USA. Before joining SDSU, he worked as a Research Associate at UW-Madison in the development of novel methods to characterize functional properties of dairy products. He is currently involved in teaching undergraduate and graduate level food and bioprocessing courses. His current research interests include functional and structural properties of food and biomaterials and value-added uses of corn ethanol byproducts.