122nd ASEE Annual Conference & Exposition
June 14 - 17, 2015
Seattle, WA
Making Value for Society
Paper ID #13665

Integrating biofuels education into chemical engineering curriculum

Dr. Q. Peter He, Tuskegee University

Dr. Q. Peter He is Associate Professor in the Department of Chemical Engineering at Tuskegee University. He obtained his BS degree in chemical engineering from Tsinghua University, Beijing, China, in 1996 and MS and PhD degrees in chemical engineering in 2002 and 2005 from the University of Texas, Austin. Besides engineering education, he is also interested in process modeling, monitoring, optimization and control; renewable energy; biostatistics and cancer informatics. He has published over 30 journal papers, over 20 conference proceedings, and two book chapters. He was the 2009 recipient of the Outstanding Faculty Performance Award in Research from Tuskegee University.

Dr. Jin Wang, Auburn University

Dr. Jin Wang is B. Redd Associate Professor in the Department of Chemical Engineering at Auburn University. She obtained her BS and PhD degrees in chemical engineering (specialized in biochemical engineering) from Tsinghua University in 1994, and 1999 respectively. She then obtained a PhD degree (specialized in control engineering) from the University of Texas at Austin in 2004. From 2002 to 2006 she was a development engineer and senior development engineer at Advanced Micro Devices, Inc. During her tenure at AMD, her R&D yielded 13 patents granted by USPTO. In addition, she received several prestigious corporate awards for being instrumental in developing effective advanced control solutions. Dr. Wang joined Auburn University in 2006 as B. Redd Assistant Professor. She was promoted to Associate Professor and granted tenure in 2011. The central theme of her current research is to apply systems engineering, in particular, control engineering principles and techniques to understand, predict and control complex dynamic systems which cover both industrial processes and microbial organisms. Currently, she has extended her research focus to metabolic network modeling and analysis, as well as related experimentations. The system identification based framework for metabolic network analysis has been proving to be a highly effective tool to extract biological knowledge from complex, genome-scale metabolic network models, and has been successfully applied to understanding several industrial relevant microbes. She was the 2008 recipient of the Ralph E. Powe Junior Faculty Enhancement Awards from Oak Ridge Associated Universities (ORAU). Her graduate student also won the inaugural AIChE CAST Director's Presentation Award in 2011. Her research is funded by various US federal and state funding agencies including NSF, USDA, Department of Education and DOT as well as private foundations. She has over 40 journal publications, plus additional conference proceedings (>40) and presentations (>70). Her recent publications mainly focus on biotechnology and bioengineering related modeling and experimental research.

Integrating biofuels education into chemical engineering curriculum

Q. Peter He[1] and Jin Wang[2]

[1] *Department of Chemical Engineering, Tuskegee University, Tuskegee, AL 36088*
[2] *Department of Chemical Engineering, Auburn University, Auburn, AL 36849*

Abstract: The primary goal of this project is to create educational materials that systematically integrate biofuels technology into undergraduate chemical engineering curriculum. The ultimate goal is to help prepare a technologically advanced workforce and innovative researchers for the biofuels technology field. In this work, we present the classroom and web modules being developed. We will also discuss the integration of the modules into two chemical engineering courses: thermodynamics and reaction engineering.

1 Introduction

It has been argued that the advanced biofuel industry will have significant impact on U.S. economic recovery and its transition to a sustainable green economy. The U.S. National Academies have identified renewable energy as a national scientific strategy aimed at replacing the oil-based refinery and transitioning to a green economy [1]. In addition, it has been shown that advanced biofuel industry will have significant impact on job creation and economic output in the near future [2].

Therefore, there is a pressing and immediate national need of skilled engineers and competent researchers in the biofuel field. This need also presents an exciting yet challenging opportunity for the engineering educators to expand their mission to addressing biofuel production, and to contribute to this coming wave of change in the industry [3].

To address the education need for the emerging biofuel industry, in the past a few years many universities have introduced biofuel or renewable energy education by offering courses and introducing programs [4,5,6,7,8,9,10,11]. However, most of these programs target general non-engineering audience (such as agricultural or environmental majors, professionals in management, or general public). As a result, these efforts usually cover non-engineering aspects such as national policies, environmental impact, economic analysis, and terminologies. In other words, they do not provide the technical education that is required to train technically advanced engineers and researchers.

Contrary to the lack of efforts in biofuel education for engineering undergraduates, there are many specialized research centers on biofuel technologies established in the past few years, especially in the chemical engineering field. These research centers mainly focus on advanced research and graduate/post-graduate education in engineering [12,13,14,7]. The research results generated from these centers, and other research groups and individual researchers, are usually published in scientific journals, which involve high level technical knowledge and complexities that only specialized scientists can understand. As a result, the available biofuel educational materials are quite dispersed and no single comprehensive literature source on biofuel processes exists that is suitable for engineering undergraduate education. Consequently, there is a significant gap between advanced biofuel research and undergraduate biofuel education in engineering.

2 Approach/Method

Among different engineering majors, chemical engineering is in a unique position to address this educational need. This is because most biofuel processes are essentially chemical or biochemical processes, and all the underlying principles of biofuel processes, such as mass transfer, heat transfer and reaction engineering, are the same as those of traditional chemical or petrochemical processes. Therefore, there should be an easy transition from a traditional chemical engineer to a biofuel engineer compared with students from other engineering disciplines.

Of course, biofuel processes have their unique characteristics and challenges. For example, in general biofuel processes are more complex than the traditional chemical or petrochemical processes, especially when lignocellulosic biomass is involved. This perhaps is the major reason for the lack of comprehensive, yet simple enough material on biofuel processes that can be easily adopted into chemical engineering curricula. Although there are several excellent graduate textbooks on biofuel technology, undergraduates do not have adequate background knowledge to understand them. Due to the lack of appropriate educational materials, existing undergraduate biofuel educational efforts are often too fragmented to achieve critical mass for a visible impact on students' understanding of the biofuel technology when they graduate.

Over the years, chemical engineering curricula have primarily focused on traditional chemical and petrochemical industry. In other words, most examples, homework problems, exams and design problems are developed based on the traditional chemical and petrochemical processes. As fundamental principles and concepts involved in chemical processes (which are the same for biofuel processes) are introduced gradually and cumulatively throughout the chemical engineering curriculum, we believe that a better approach of teaching chemical engineering students biofuel technology is to adopt a piecemeal approach by creating a set of comprehensive yet flexible and apprehensible biofuel learning modules that spread across the entire chemical engineering curriculum.

Specifically, instead of developing a separate senior course that is devoted to biofuel processes, we propose to break down the biofuel processes into small pieces such as unit operations, and each piece can be further broken down and simplified to illustrate different chemical engineering principles or concepts. For example, a gasifier is one of the units in a gasification process; it can be further simplified to illustrate mass balance, or energy balance. Or it can be further broken down to different zones (e.g., drying, pyrolysis, partial oxidation and combustion) to illustrate different heat effects, such as sensible heat and heat of reaction. In this way, lower level students will not be overwhelmed by the complexity of a biofuel process when they do not yet have all the background knowledge to comprehend it as a whole; while higher level students will feel much more comfortable in designing a complex biofuel plant because they have seen all the pieces in their lower level courses, maybe even multiple times. We believe this modular or piecemeal approach will result in a better student learning outcome than the "single-course" approach.

Based on the modular or piecemeal approach, we have been developing a series of classroom learning modules that can be easily integrated into existing chemical engineering curricula. The key components of each module are: module learning objectives, associated sections in selected textbooks, process background and problem(s). The solution to module problem(s) will be provided upon request from instructors.

Due to the complex nature of the biofuel processes and students' limited exposure to biofuel technology, most students would feel incompetent in dealing with problems related to biofuel. To help students overcome this barrier, we have also been creating a series of web modules to accompany the classroom modules by exploiting two recently emerged instructional strategies: computer-assisted instruction and visual learning. Computer-assisted instruction is an innovative instructional strategy that has been receiving increasing attention in engineering education [16]. It has been shown that computer-assisted instruction provides students with rapid inquiry-based learning experiences, allowing students to proceed at their own pace and within their own schedule [17,18,19]. Visual learning – the use of graphics, images, and animations to enable and enhance learning – has been shown to be effective in exploiting students' visual senses to engage students in active learning, support traditional lessons, and make their learning experience stronger and deeper. [20,21,22,23,24,25,26]. This methodology also has the potential to increase the number of students in science, technology, engineering, and math (STEM) fields, especially of women and minority students [24].

The key components of the web modules include: glossary, process introduction, process flow diagram, captured and animated process video clips, visual encyclopedia of equipment, reference shelf, solved problems. While classroom modules focus on the fundamental aspects of biofuel technology that are more suited to the current undergraduate chemical engineering curriculum, the on-line web modules will provide more background knowledge and other resources to assist students with understanding classroom modules. In this way, students will not only be exposed to biofuel technology, but also get fresh stimulus in learning chemical engineering principles. Besides assisting students with classroom modules, another intended goal of the web modules is to use recently emerged effective teaching strategies combined with the "hot" topic of biofuel to stimulate students' interest in learning traditional chemical engineering principles.

3 Results

3.1 Classroom modules

We intended to develop classroom modules for Chemical Engineering Thermodynamics and Chemical Reaction Engineering classes. Specifically, modules will be developed for the following topics in Chemical Engineering Thermodynamics:

- Heat effects in biofuel processes
- Thermodynamic properties of fluids
- Vapor liquid equilibrium in biofuel processes
- Solution thermodynamics

Modules will also be developed for the following topics in Chemical Reaction Engineering:

- Design Equations for Batch and Continuous Gasifiers.
- Rate Laws and Stoichiometry for Various Biofuel Reactions
- Design of CSTRs and Packed Bed Reactors (PBRs) for Biofuel Processes
- Multiple Reactions in Biofuel Processes

A classroom module is provided in Figure 1 as an example. All classroom modules can be downloaded from our website: www.biofuelsacademy.org and solutions can be provided upon request from an instructor.

As can be seen from Figure 1, each classroom module is linked to one chapter or some sections of the most commonly used textbooks, as indicated in the "Associated Sections in Selected Textbooks" section of each module. In this way, there is no textbook or even the course syllabus change or addition needed, making adoption extremely easy – the instructor can straightforwardly replace or supplement some of the textbook examples and homework problems with the examples and problems provided by the classroom module.

Application of modified Raoult's law in a vacuum fermentation process

【Module Learning Objectives】

- VLE calculation using modified Raoult's law.

【Associated Sections in Selected Textbooks】

- Introduction to Chemical Engineering Thermodynamics [1] Sec. 10.5

【Problem】

Since typical fermentation broth contains low levels of ethanol, much of the energy consumption for commercial ethanol production is for distillation. Significant energy savings can thus be achieved if ethanol-rich fermentation broth is used. However, the growth and production ability of cells are inhibited by high ethanol and/or sugar concentration [2]. To prevent product inhibition, ethanol product must be removed from the fermentation broth as soon as it is formed. Simultaneous removal of ethanol stimulates the growth of yeast cells; thus, more sugars can be fermented and higher ethanol productivity was achieved as a result [2]. One way to achieve this is through vacuum fermentation. One particular design is shown in the following figure [3].

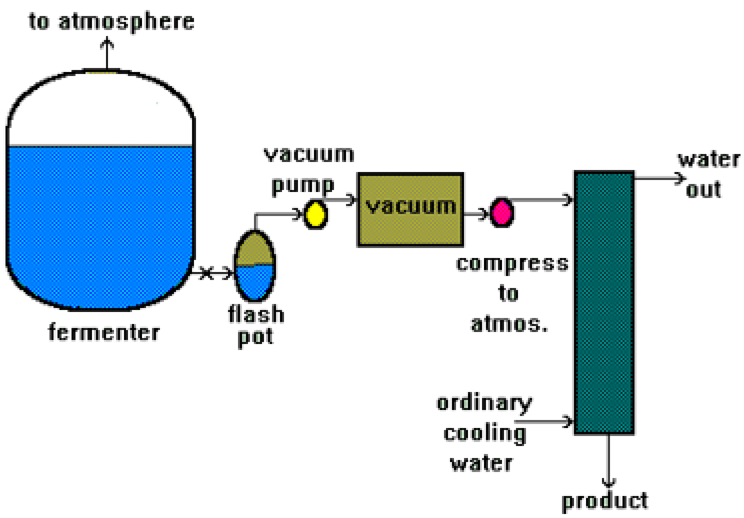

Figure 1. Schematic diagram of vacuum fermentation [3]

The fermentation broth is circulated through the flash pot for vaporization of the ethanol. The vacuum is adjusted to the vapor pressure of the alcohol-water solution at the fermentation temperature (30 to 40 ºC).

(continued on next page)

Assume the ethanol-water solution in the flash pot reaches equilibrium and the modified Raoult's law applies. The following equations provide a reasonable correlation for the activity coefficients:

$$ln\gamma_1 = Ax_2^2 \quad ln\gamma_2 = Ax_1^2 \quad \text{where } A = 2.65 - 0.00575T(K)$$

a) If the fermentation broth at 35°C contains 0.1 mole fraction of ethanol, what would be the pressure in the flash pot and what is the mole fraction of ethanol in the vapor phase?
b) If we want to achieve 0.5 mole fraction of ethanol in vapor phase at 35°C, what would be the ethanol mole fraction from the fermentation broth? And what would be the pressure in the flash pot?
c) If the fermentation broth contains 0.1 mole fraction of ethanol and we want to maintain the vapor pressure in the flash pot at 5 kPa, what would be the operation temperature of the flash pot? And what would be the mole fraction of ethanol in the vapor phase?
d) If we want to maintain the vapor pressure in the flash pot at 5 kPa, at the same time achieve 0.4 mole fraction of ethanol in the vapor phase, what would be the ethanol mole fraction from the fermentation broth? What would be the operation temperature of the flash pot?
e) Show whether or not the system exhibits an azeotrope at 25°C. If there is an azeotrope, what are the azeotropic pressure and the azeotropic compositions for t=25°C?

Bibliography

[1] J. Smith, H. Van Ness and M. Abbott, Introduction to Chemical Engineering Thermodynamics, 7th Ed. ed., New York: McGraw Hill, 2005.

[2] V. D. Nguyen, J. Auresenia, H. Kosuge, R. R. Tan and Y. Brondial, "Vacuum fermentation integrated with separation process for ethanol production," *Biochemical Engineering Journal,* vol. 55, pp. 208 - 214, 2011.

[3] W. Wan, "Product removal during fermentation," [Online]. Available: http://www.rpi.edu/dept/chem-eng/Biotech-Environ/FERMENT/vacferm.htm.

Figure 1 A classroom module on Raoult's law.

3.2 Web modules

For the web modules, we have been developing a glossary, collections of commonly used equipments, different biofuel processes, animated video clips, and a reference list.

Specifically, we have developed a comprehensive glossary of frequently used acronyms and definitions of various specialized terms used in the biofuel industry with hundreds of entries, which provides explanation to common terminologies in biofuel technology. Chemistry and chemical engineering details are included to make them more technical and job-oriented. At the time this paper is being written, we have included more than five hundred terms. This glossary serves as an essential resource for students with little or no biofuel background.

We also have developed a collection of common equipment used in biofuel processes, namely Visual Encyclopedia of Equipment, which includes a wealth of photographs, drawings, videos, and descriptions of different equipments used in different biofuel processes, such as gasifiers, pyrolyzers and reformers. This resource also serves as a tool to build up students' biofuel background. Besides individual equipment, we have developed web modules for different biofuel processes. Each module includes a technical introduction of the process, the process flow diagram, equipments or reactors, related videos and glossary terms, and references. To enhance students' visual learning, we have also developed animated video clips for some processes. The animated videos were created based on process flow diagrams, equipment illustrations, and cutaway drawings. A video clip provides a vivid description of how a process operates, including the flow of material streams, details of the reactions, energy exchanges, etc. Compared to verbal descriptions, these videos provide students a more intuitive and dynamic view of the process, which could significantly improve students' understanding of a process. All videos are accompanied with narrations and are shared on www. BiofuelsAcademy.org and YouTube.

Finally, we have compiled a comprehensive reference list, which students can find additional information and use for further study. The reference list includes hundreds of books, journal articles and website links related to biofuel technology.

3.3 Classroom integration

The developed modules were integrated into two courses at Tuskegee University: CENG350 Chemical Engineering Thermodynamics II and CENG360 Chemical Engineering Reaction Engineering. Overall, the project has been a tremendous success. Based on students' feedback, all objectives we set out were achieved.

About the classroom modules, students' feedback shows that the students were made aware of biofuel technology in the chemical engineering field and were able to see how biofuel technologies are related to what they learn in classes. The modular approach was proposed to facilitate straightforward integration for instructors and easy acceptance for students, which is confirmed by comments such as "The application of real-world problems was beneficial because it exposed us to different types of problems; meanwhile, it did not change the way we carried out the steps to complete the problems." Also, the objective we set to enhance students' understanding of chemical engineering principles by exposing them to contemporary issues and industrial/national needs was achieved. Some students wrote that the "biofuel topics sparked interest and increased focus on the topic being taught", and "felt enlightenment about real life applications of biofuel technology".

About the web modules, it was apparent that the students liked the usage of self-paced web modules developed based on the strategies of computer-assisted instruction and visual learning. Students felt they are "excellent source of information for anything related to biofuels". Students often "go look at the website because it has a plethora of information on biofuels" and enable them to "utilize outside sources to bring all the information full circle". Students liked "using visuals to better understand biofuel technology. For example, videos, diagrams, etc. It helps us connect what we learned to our world. Shows how it is relevant." Also, the animated videos we created to illustrate various biofuel processes were shared on YouTube, which have been viewed tens of thousands of times. It is worth noting that people who benefit from the online materials are not limited to chemical engineering students at AU and TU. We have been contacted by people from industry and federal/state governments for various questions. Our online modules have received many positive comments, such as "The most straight forward explanation I've seen so far. Thanks !!!".

4 Conclusions

This work was motivated by the potential need of a technologically advanced workforce and innovative researchers in the biofuel field. To address this need, we first identified the gap between advanced biofuel research and undergraduate biofuel education in engineering. We then introduced a modular approach to bridge this gap by creating educational materials that systematically integrate biofuel education into chemical engineering curriculum. Specifically, we have created a set of classroom modules by simplifying and decomposing complex biofuels processes. Each classroom module focuses on one aspect of fundamental chemical engineering principles, e.g., one chapter of a typical textbook, making it easy for wide adoption. To address different learning styles and enhance students' active engagement through computer-assisted instruction and visual learning, we have also created a series of web modules to accompany the classroom modules. We expect the unique combination of classroom modules with web modules will effectively enhance students' understanding of chemical engineering principles, as well as significantly increase students' exposure to biofuel technology.

We expect wide adoption of our learning materials among chemical engineering educators because our approach can effectively address the following three major obstacles of introducing biofuel education into chemical engineering curricula: (1) there is a lack of learning materials that are appropriate for undergraduate; (2) not all academic programs will be able to accommodate additional course(s) with all other programmatic requirements currently in place; and (3) any changes to the curriculum that requires significant effort from faculty or staff would be difficult to sell and adopted widely.

In the proposed framework, the classroom modules serve as the supplementary materials to existing chemical engineering textbooks. In other words, our primary goal is still for students to understand and apply chemical engineering principles. Introducing biofuels education is the secondary goal, which exposes students to contemporary issues and industrial/national needs. Therefore, the basic concepts and fundamental principles are still from the textbooks and are taught in the same way as in a traditional chemical engineering class. The examples and homework problems provided in the developed biofuel modules can be used to replace/supplement some of the textbook examples and homework problems.

5 Acknowledgement

Financial supports from the National Science Foundation (under Grant No. 1044300) and the U.S. Department of Agriculture (through the Southeast Partnership for Integrated Biomass Supply System (IBSS)) are greatly appreciated.

References:

1. The National Academies. *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future;* The National Academies Press: Washington, D.C., 2007.
2. Biotechnology Industry Organization. BIO. http://bio.org/news/pressreleases/newsitem.asp?id=2009_0225_02&p=yes (accessed Feb 10, 2010).
3. Rosentrater, K. A.; Balamuralikrishna, R. The growing importance of emerging biobased industries to engineering and technology. *The International Journal of Applied Management and Technology* **2007,** 16-33.
4. MIT Professional Education. http://web.mit.edu/professional/short-programs/courses/biofuels_biomass.html.
5. Iowa Central Community College. Biofuels Technology Program. http://www.iowacentral.edu/mathscience/science/programs/biofuels/index.asp.
6. University of Colorado at Boulder. The Renewable and Sustainable Energy Institute (RASEI). http://rasei.colorado.edu/index.php?id=1&page=Home.
7. University of Connecticut. UConn Biofuels Consortium. http://biodiesel.engr.uconn.edu/index.html (accessed 2010).
8. University of Kentucky Center for Applied Energy Research. Biomass to Energy: An Overiew Short Course. http://www.caer.uky.edu/events/biofuels2010.html.
9. University of Louisiana at Lafayette. Department of Renewable Resources. http://rres.louisiana.edu/Leon.htm.
10. University of Wyoming. The Department of Renewable Resources. http://www.uwyo.edu/renewable/.
11. Varde, K. S. Undergraduate Research Experience in Energy Conversion and Alternate Energy Systems. *9th International Conference on Engineering Education*, San Juan, PR, 2006; pp M5K-10-13.
12. The University of Massachusetts Amherst. The Institute for Massachusetts Biofuel Research. http://www.ecs.umass.edu/timbr/index.html.
13. UC BERKELEY. ENERGY BIOSCIENCES INSTITUTE. http://www.energybiosciencesinstitute.org/ (accessed 2010).
14. University of California, Davis. Bioenergy Research Center at UC Davis. http://bioenergy.ucdavis.edu/index.php (accessed 2010).
15. Vogels, J. The Carbo-V® gasification process for the production of syngas. *International Seminar on Gasification andMethanation*, Gothenburg, Sweden, 2007.
16. Abu-Hajar, A.; Holden, M. INTERACTIVE COMPUTER-BASED VIRTUAL CLASSROOM FOR ENGINEERING COURSES. *American Society for Engineering Education*, Honolulu, Hawaii, 2007; p 1808.
17. Fang, N.; Stewardson, G. A.; Lubke, M. M. Enhancing Student Learning of an Undergraduate Manufacturing Course with Computer Simulations. *Int. J. Engng Ed.* **2008,** 558-566.

18. MIT. Open Courseware. http://ocw.mit.edu/index.html.

19. Hogan, K., Pressley, M., Eds. *Scaffolding Student Learning: Instructional Approaches & Issues. Advances in Teaching and Learning Series;* Brookline Books: Cambridge, MA, 1997.

20. Laws, P. Using digital video analysis in introductory mechanics projects. *The Physics Teacher* **1998,** *36* (5), 282-287.

21. Konyalioglu, S.; Konyalioglu, A. C.; S., I. A.; A., I. The Role of Visualization Approach on Student's Conceptual Learning. *Interntational Journal for Mathematics Teaching and Learning* **2005**.

22. Blanchard, P. Easy Animations. In *Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education;* AAAS Press, 2005; pp 147-149.

23. Konyalioglu, A. C. An evaluation from studennts' perspective on visualization approach used in linear algebra instructions. *World Applied Science Journal* **2009,** 1046-1052.

24. McGrath, M. B.; Brown, J. R. Visual learning for science and engineering. *IEEE Computer Graphics and Applications* **2005,** 56-63.

25. Bransford, J. D., Brown, A. L., Cocking, R. R., Eds. *How People Learn: Brain, Mind, Experience, and School;* National Academies Press: Washington, DC, 1999.

26. Frankel, F. Translating Science into Pictures: A Powerful Learning Tool. In *Invention and Impact: Building Excellence in Undergraduate Science, Technology, Engineering, and Mathematics (STEM) Education;* AAAS Press, 2005; pp 155-158.

27. Smith, J. M.; Van Ness, H. C.; Abbott, M. M. *Introduction to Chemical Engineering Thermodynamics,* 7th ed.; McGraw Hill: New York, 2005.

28. Sandler, S. I. *Chemical, Biochemical, and Engineering Thermodynamics,* 4th ed.; John Wiley & Sons, Inc.: New York, 2006.

29. Clark, J. H., Deswarte, F. E. I., Eds. *Introduction to Chemicals from Biomass (Wiley Series in Renewable Resource);* Wiley: West Sussex, 2008.

30. Demirbas, A. *Biofuels: Securing the Planets Future Energy Needs;* Springer: London, 2009.

31. Drapcho, C.; Nghiem, J.; Walker, T. *Biofuels Engineering Process Technology;* McGraw Hill: New York, 2008.

32. Soetaert, W., Vandamme, E., Eds. *Biofuels (Wiley Series in Renewable Resource);* Wiley: West Sussex, 2009.