AC 2012-3583: HOW WE TEACH: MATERIAL AND ENERGY BALANCES

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Dr. Margot A. Vigeant, Bucknell University

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How We Teach: Material and Energy Balances

Abstract

The authors present the results of the 2011 AIChE Education Division survey on how chemical engineering courses are taught. This year’s survey focuses on the undergraduate material and energy balance course. The survey was conducted of faculty recently teaching the course at their institution during the 2010-2011 academic year in the United States and in Canada. The report consists of two parts: the statistical and demographic characterization of the course and its content; and the remainder seeks to bring out the most innovative and effective approaches to teaching the course in use by instructors. Additionally, a limited historical comparison is made between the selected survey results and surveys on the same course conducted in 1972, 1990, and 1999.

Introduction

This survey represents the continuation of a series of surveys of undergraduate curricular topics begun in 1957 by the AIChE Education Projects Committee and more recently resumed by the AIChE Education Division. This paper presents the results for the third in the series of surveys conducted by the Education Division.

Survey Background

The Material and Energy Balance course (MEB) is the topic of the 2010 survey. The aforementioned AIChE Education Projects committee previously conducted surveys on the same course in 1972, 1990, and 1999. A 1982 survey was conducted but was unavailable to the authors, though some of its data was included in the 1990 survey. Portions of the current survey were intended to update the results published for those surveys. The structure for this report draws heavily on previous reports published on behalf of the Education Division.

The survey was conducted via internet server hosted by the University of Kentucky running LimeSurvey (limesurvey.org). E-mail invitations to participate were initially sent to all 158 department chairs in the United States and later those in Canada requesting participation from the faculty members teaching the relevant course(s). A separate request was sent to the instructors of record for the MEB course during the 2010-2011 academic year when that information was publically available. From that population, 76 usable surveys representing 67 institutions in the United States were received.

This 42% institutional response rate represents a continued improvement from the results of the 2009 survey (31%) and 2010 survey (38%), but still falls short of the response rates in 1990 (78%) and 1999 (51%). No response data is available for the 1972 survey.

The complete survey in print form is provided as Appendix A.
Quantity of Instruction

Of the sixty-three institutions responding to the question, fifty (79.3%) indicated they offered a single course in MEB. Twelve offered two courses, and one had three courses, though one of those courses was a general engineering course with related content. Of those institutions offering two or more courses, 3 were on the quarter system. Overall, institutions reported 4.7 h/wk total devoted to the course, broken up into an average 3.2 h/wk on lecture, 1.3 h on problem solving, and 0.2 h/wk on experimental laboratory.

In 1990, 74% of responding programs offered one course in MEB, with the remainder offering two courses. Laboratory courses were significantly more common, with 48 departments having dedicated laboratory time averaging 1.92 h/wk. The 1999 survey indicates that 81% of schools responding had one course.

Course Timing

The most common timing for the first course in MEB within a program’s curriculum was at the start of the sophomore year. The distribution of the timing of course offerings is given in Figure 1 below. Table 1 reports the course timing on a historical basis.

![Term of First Course](image)

Figure 1. 2010-2011 offerings of MEB by term as reported by instructors.
Table 1. Historical record of timing of MEB in curricula as reported by instructors. Data for 1982 was reported in the 1990 survey.

<table>
<thead>
<tr>
<th></th>
<th>First-year</th>
<th>Second-year</th>
<th>Later</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1982</td>
<td>1990</td>
<td>2011</td>
</tr>
<tr>
<td></td>
<td>1984</td>
<td>1991</td>
<td>2010</td>
</tr>
<tr>
<td>1\textsuperscript{st} Semester</td>
<td>4</td>
<td>0</td>
<td>45</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>53</td>
<td></td>
</tr>
<tr>
<td>2\textsuperscript{nd} Semester</td>
<td>8</td>
<td>5</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>35</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

Class Size

The typical size of a class section does not appear to have changed significantly over the past several decades, as shown in Figure 2. Low enrollments in 1990 appear to have demanded a shift to smaller class sizes than currently taught during a period of growing enrollment.

Figure 2. Section size for the MEB course as reported by instructors. The 1990 data terminate with a maximum bin size of 60+ with no further detail.
Classes are primarily taught by professional instructors, with only 24 programs reporting teaching assistants (TA’s) delivering lectures or conducting recitations. Amongst those programs, a maximum of 25% of meetings were run by TA’s.

This chemical engineering course currently draws enrollment for students in many other majors, including:

- Civil, environmental engineering
- Aerospace engineering
- Agricultural and biosystems engineering, biomedical engineering, biological engineering
- Nanosystems engineering
- Paper science
- Materials science and engineering
- Mechanical engineering
- Textiles engineering
- Physics
- Chemistry
- Engineering management
- Pharmacy
- Engineering physics
- Petroleum engineering
- Industrial engineering

No historical data on enrollment from other disciplines was available.

A wide range of student deliverables was required, as shown in Figure 3. When likely “open-ended” problems (independent & team projects) are combined, about 54% of courses require open-ended design work. In the 1999 survey, 42% indicated they incorporated case studies or projects lasting more than a month. The 1990 survey reports 28% of departments indicating such a project was assigned. In that 1990 survey 87% of departments indicated they would occasionally or often use open-ended design problems if they were available in their textbook. The 1999 survey response to the same question indicated 93% would likely use case studies if available.
Figure 3. Deliverables required for the course in 2010-2011 as reported by instructors.

Twenty-five instructors specifically reported use of case studies in the 2011 survey. Of these 25, 12 said their case studies came from the course textbook, with the remainder coming from other sources such as:

- Multimedia Lab in the ChE Department at the University of Michigan.
- Other textbooks (Himmelblau, Murphy)
- CACHE
- Chemical Safety Board website
- “Introduction to Chemical Engineering” by Solen and Harb
- Case studies developed by the instructor or retained from their undergraduate studies
- Previous AIChE Design Contest problems
- CEP magazine, Science & Nature, catalysis journals, etc.
- Cases from the National Society of Professional Engineers Board of Ethical Review (http://www.murdough.ttu.edu/cases/) or Kohn and Hughson, "Perplexing problems in engineering ethics," Chemical Engineering, May 5, 1980, p. 100-107.
- Developed from materials that have been a part of senior capstone design

Software usage by programs was varied, as shown in Figure 4. In 1991, the most common language/program reported was FORTRAN (71 programs) followed by Lotus (presumably the 1-2-3 spreadsheet), Basic, Pascal, and Flowtran. Data for the current survey and the 1999 survey are presented in Figure 4.
Figure 4. Software used in the MEB course in 2010-2011 as reported by instructors.

The use of computer software in routine homework assignments is significant as shown in Figure 5, but also indicated most problems assigned are intended to be solved by use of a calculator. This is consistent with the 1999 survey: 85% of schools indicated some use of a computer for homework, but required usage was typically less than 10% of problems assigned.
Textbooks reported as currently in use include:

- Murphy, *Introduction to Chemical Processes: Principles, Analysis, Synthesis*
- Himmelblau and Riggs, *Basic Principles and Calculations in Chemical Engineering*
- Cerro, Higgins, Whitaker, *Material Balances for Chemical Engineers*
- Russell and Denn, *Introduction to Chemical Engineering Analysis*

Figure 6 illustrates the changes in popularity of MEB textbooks over the past 30 years.
Figure 6. Adoption of textbooks. For a particular author, multiple editions may be represented. The data for Himmelblau/Riggs includes previous versions with Himmelblau as sole author.
Figure 7. Emerging course topics taught as reported by instructors.

Coverage of non-technical topics in MEB in the 2011 survey is presented as Figure 7. Concepts that instructors report that students struggle with most in the course are presented as Figure 8. Interestingly, the most challenging topics for students are those tied to skills which separate chemical engineers from other engineering disciplines, such as reactive systems and phase equilibrium.
Figure 8. Concepts that students struggle with in the first MEB course for 2010-2011 as reported by instructors.

Chemical engineering programs are likely to use this course for ABET outcomes assessment. The fraction of reporting programs using this course for ABET a-k outcomes is shown in Figure 9.
Common Concerns

Survey respondents were asked what they believed were the biggest issues encountered by students taking this course. The majority of responses indicated the following common challenges: Was this an open-ended question or are there stats to indicate what % of people mentioned each response? Any value in reflecting that, or OK to lump together under general concerns?

- Cheating (downloadable solutions)
- Student maturity/seriousness
- Problem-solving skills
- Mathematical Software Skills
- Physics, chemistry & math preparation
- Preference for familiar units
- Limited contact time
- Broad range of student ability
- Getting through it all

Conclusions
The 2011 AIChE Education Division survey indicates that the Material & Energy Balances course remains largely unchanged in its time, structure, and core coverage. Use of computers has naturally increased, and modern topics involving chemical engineers such as sustainability, biological systems, and nanotechnology are being integrated into the course. There has been increased use of case studies to tie the subject matter to engineering practice, but not as much as would be expected based on the expressed interest of instructors in doing so.

Acknowledgements

The authors would like to thank all of the instructors who completed this survey; the department chairs who forwarded the request; University of Kentucky undergraduate Chris Carrico for identifying many of the relevant course instructors; and University of Kentucky College of Engineering computing services which hosted the survey.

References

Appendix A. Print version of online survey.
AICHE Best Practices in Teaching 2011

This Year's Theme: Material & Energy Balances.

Our goal with this survey is to improve our teaching. You add your unique style to how you teach your course. The purpose of this survey is to gather and share innovative ideas about how we teach the course selected for this year's theme. In addition, we collect basic information about course design to compare and contrast both what is presently taught and what was taught at the time of previous surveys on this subject (1970, 1980, 1990). Please share your approaches with us so that we can summarize the "state of the art" and have a "sharing session" at the annual AICHE meeting.

Welcome to the 2011 AICHE How We Teach survey. This year we will be seeking to develop a picture of how Material & Energy Balances (MEB) are taught across North America.

There are 52 questions in this survey

Part 0: Your information

Before we begin, we ask that you please provide us with your current course syllabus and schedule.

Please send these items to SilverDL@engr.uky.edu.

We have a few questions about the person completing this survey and other personnel involved in the course.

1 [1-Respondant] What is your name?

Please write your answer here:

2 [2-Email] What is your e-mail address? *

Please write your answer here:

Your email address will not be shared with anyone or used outside of the context of this survey.

3 [3-University] What is the name of your institution? *

Please write your answer here:
4 [QuSe] For the 2010-11 academic year, what term system did your institution use?

Please choose all that apply:

- [ ] Quarter
- [ ] Semester

5 [4-ReportCopy] Should we send the summary findings to you?

Please choose only one of the following:

- [ ] Yes
- [ ] No

6 [5-Colleagues] If this course is team taught, multiple courses on the subject are taught with different instructors, or multiple sections are taught by different instructors, please give the names and email addresses of your colleagues. Alternately, we request that you forward the invitation you received to those instructors.

Please write your answer here:
Part 1: The Course

When more than one course in material & energy balances is offered, please respond based on the first course unless otherwise specified. Do not include courses where the topic is introduced but not the primary focus of the course. Also do not include a thermodynamics course unless it is the first course in which conservation of mass and energy in a chemical process context is taught.

7 [6-NumC] How many courses focusing on material and energy balances are required for undergraduates? If you offer multiple tracks, please only consider the "traditional" or most common track.

Please choose only one of the following:

- ○ 1
- ○ 2
- ○ 3

8 [7-Titles] What are the course number(s) and title(s)?

Please write your answer here:

Please write your answer(s) here:

Lecture
Problem laboratory/Recitation
Experimental laboratory

9 [8-Time] How much time is available, on average, for each week for the following components. Please use a 50-minute "hour" and report times in hours. If reporting multiple courses, please give the total number of hours for the sequence. This amount should sum to the total contact hours for the course.

Please write your answer(s) here:

Lecture
Problem laboratory/Recitation
Experimental laboratory

10 [9-Objectives] Please list your course objectives, preferably by copying and pasting from the course syllabus. For multiple courses, please indicate for which objectives correspond to each course. If you have more detailed objectives you apply throughout the course, please include those here as well.

Please write your answer here:
11 [10-Exams] How many major tests, excluding the final exam, do you give in the course? For multiple courses, please indicate a number for the first course.

Please write your answer here:

12 [Grading] Which of the following activities are explicitly counted for a grade in this course (or course sequence)?

Please choose all that apply:

- [ ] Homework
- [ ] Lab reports
- [ ] Participation
- [ ] Independent project
- [ ] Team project
- [ ] Exams (hour or longer, not a final)
- [ ] Quizzes (shorter than exams)
- [ ] Final Exam
- [ ] Other: [ ]

13 [CaseStudies] Do you use case studies?

Please choose only one of the following:

- [ ] Yes, from the textbook
- [ ] Yes, from other sources (please list)
- [ ] No

Make a comment on your choice here:
14 [DescCaseStud] Please describe how you use case studies and/or projects in the course.

Only answer this question if the following conditions are met:
° Answer was 'Yes, from the textbook' or 'Yes, from other sources (please list)' at question '13 [CaseStudies]' (Do you use case studies?)

Please write your answer here:

15 [11-Dimensions] What percent of the problems you assign are solved in the SI system?

Please choose only one of the following:
- <40%
- 50%
- 60%
- 70%
- 80%
- 90+

16 [Dim2] What percent of the problems would you like to see solved in the SI system?

Please choose only one of the following:
- <40%
- 50%
- 60%
- 70%
- 80%
17 [Computing] Does your curriculum require a computing course for chemical engineering students?

Please choose all that apply:

- Yes, offered by our department
- Yes, offered outside our department

18 [CompSubj] Which of the following topics are covered in this course?

Only answer this question if the following conditions are met:
° Answer was 'Yes, offered outside our department' or 'Yes, offered by our department' at question '17 [Computing]' (Does your curriculum require a computing course for chemical engineering students?)

Please choose all that apply:

- FORTRAN
- Spreadsheets
- Word processing
- Presentation software
- Visual Basic or other BASIC
- Pascal
- C/C+/C++/C#
- Java
- Computerized Algebra System (Maple, Mathcad, Matlab, Mathematica)
- Statistics software
- Process simulator (ASPEN PLUS, Hisys, CHEMCAD, etc.)
- COMSOL Multiphysics
- CAD
- HTML/XML
- Database development
- Graphics software
- Other: [ ]

19 [CompTiming] In which year is the computing course typically taken by students?

Only answer this question if the following conditions are met:
° Answer was 'Yes, offered outside our department' or 'Yes, offered by our department' at question '17 [Computing]' (Does your curriculum require a computing course for chemical engineering students?)

Please choose only one of the following:
20 [12-Software] Which of the following software packages do students typically use as part of the material and energy balance course?

Please choose all that apply:

- Aspen Plus
- Comsol Multiphysics
- EZ Solve
- Maplesoft Maple
- Mathworks MATLAB
- Microsoft Excel
- Polymath
- PTC Mathcad
- Wolfram Mathematica
- Other: [ ]

21 [13-SoftUse] What percent of assignments did students in the material and energy balance course typically complete using a computer?

Please choose only one of the following:

- None
- 10%
- 20%
- 30%
- 40%
- 50%+
**22 [StuComp] Are students enrolled in your program required to purchase a computer?**

Please choose only one of the following:

- Yes
- No

**23 [CompOwn] What percent of your students own a PC?**

Only answer this question if the following conditions are met:
° Answer was 'No' at question '22 [StuComp]' (Are students enrolled in your program required to purchase a computer?)

Please choose only one of the following:

- 0%
- 10%
- 20%
- 30%
- 40%
- 50%
- 60%
- 70%
- 80%
- 90%
- 100%

**24 [Phone] What percentage of your students would you estimate have a smartphone (defined here as a cellular device capable of web browsing)?**

Please choose only one of the following:

- <25%
- Between 25 and 50%
- Between 50 and 75%
- >75%

**25 [CompLabs] Do your students have computing laboratories available?**

Please choose all that apply:

- Yes, maintained by the Department
- Yes, maintained by the College
26 [14-Textbook] Which textbook is primarily used in the course?

Please choose only one of the following:

- Felder/Rousseau, Elementary Principles of Chemical Processes
- Himmelblau/Riggs, Basic Principles and Calculations in Chemical Engineering
- Luyben/Wenzel, Chemical Process Analysis: Mass & Energy Balances
- Murphy, Introduction to Chemical Processes: Principles, Analysis, Synthesis
- Reklaitis, Introduction to Material and Energy Balances
- Other

If you are an author and your textbook is not listed, please accept my apologies and send me your textbook information which I will add to the list. The current list is based upon the bookshelf contents of the survey author.

27 [15-Chapters] Which chapters are covered in the course? Please consider only the primary textbook, but include coverage in multiple required courses in your material & energy balance sequence taught from the same text (if applicable).

Please choose all that apply:

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- 11
- 12
- 13
- 14
28 [16-StudentYear] What is the typical standing of students in the first material & energy balance course?

Please choose only one of the following:

- First term freshman
- Second term freshman
- Third term freshman (quarter system)
- First term sophomore
- Second term sophomore
- Third term sophomore (quarter system)
- First term junior
- Second term junior
- Third term junior (quarter system)
- Other

29 [17-Num Sections] How many lecture sections of the course were taught in 2010-11? If you have multiple courses, please only consider the first course.
30 [18-Enrollment] What was the average enrollment in each lecture section?

Please write your answer here:

31 [OtherMaj] From what majors other than chemical engineering do students enroll in your first course in material & energy balances?

Please write your answer here:

32 [19-GTA] Did graduate teaching assistants present any lectures or run recitation sessions in this course?

Please choose only one of the following:

- Yes
- No

33 [20-GTA Lectures] What percent of lectures or recitations were given by the graduate teaching assistant?

Only answer this question if the following conditions are met:

- Answer was 'Yes' at question '32 [19-GTA]' (Did graduate teaching assistants present any lectures or run recitation sessions in this course?)

Please write your answer here:

34 [22-Modern Topics] Which of the following topics do you cover in the material & energy balance course?

Please choose the appropriate response for each item:

<table>
<thead>
<tr>
<th>Topic</th>
<th>Discussed in lecture</th>
<th>Assigned related problems or projects</th>
<th>Both discussed and assigned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degree of freedom analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tests for independence of reactions/species/balances</td>
<td>O</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unsteady state balances</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### 35 [Concepts] What concepts do students struggle with most in this class?

Please choose all that apply:

- [ ] Conservation of mass
- [ ] Conservation of energy
- [ ] Material balances on non-reactive systems
- [ ] Material balances on reactive systems
- [ ] Energy balances on non-reactive systems
- [ ] Energy balances on reactive systems
- [ ] Unit conversions
- [ ] Process variables
- [ ] Equations of state
- [ ] Phase equilibrium
- [ ] Degrees of Freedom analysis
- [ ] Psychrometric charts
- [ ] Steam tables
- [ ] Identifying governing equations
36 [25-Prereqs] Which of the following courses are explicit or implicit prerequisites for the first material and energy balances course? An advanced level course in a subject is assumed to require the previous courses (i.e., Calc II requires Calc I).

Please choose all that apply:

- Differential Equations
- Calculus 1
- Calculus 2
- Calculus 3
- Physics 1
- Physics 2
- Materials Science
- Computer Programming
- Other computing course including use of spreadsheets or computer algebra systems
- General chemistry
- Organic chemistry
- Physical chemistry
- Thermodynamics

Other:
37 [Proj] Do you assign a project lasting one month or longer in this course?

Please choose only one of the following:

- Yes
- No
Part 2: Making the Course Even Better

Many would argue this is the most important part of the survey, where we ask you to share what you do in the course that can help other instructors improve their teaching. You may not have an answer for each question, but please try to share the information that makes your particular rendition of the course effective, unique, and valuable.

38 [26-Labs] Describe briefly (and send a copy of the procedure if you are willing to SilverDL@engr.uky.edu), any laboratory experiments or demonstrations which your department uses in material & energy balances or in other undergraduate courses to illustrate principles of material & energy balances.

Please write your answer here:

39 [27-Textbook] Do you feel there is a need for a better textbook for material and energy balances? How can the content or supplements of/for the text you now use be improved?

Please write your answer here:

40 [28-Distinctive] Please describe the distinctive features of the course as you teach it.

Please write your answer here:
41 [29-TLE] What is your learning environment? Do you: use ombusdpeople? restrict "teacher talk" to 20 minutes (use the feedback lecture approach)? include plant visits? Teach what real equipment looks like (how)? Use PBL, clickers, or video? Do students have computers accessible during class?

Please write your answer here:

42 [30-Goals] What are your prime goals when teaching this class? Some possibilities would be learning conservation principles, problem solving, using simulators, learning to apply numerical methods, learning to analyze processes for closure, etc.

Please write your answer here:

43 [31-Role] What do you see as your role in the course?

Please write your answer here:
44 [32-Explanations] What are some explanations of concepts in the course that you have found particularly effective?

Please write your answer here:

45 [33-Challenges] What do you see as the particular challenges in teaching material and energy balances?

Please write your answer here:

46 [Changes] How would you describe how your course and the way you teach it have changed over the past two or three years? How do you expect it to change over the next several years?

Please write your answer here:
47 [Students] How would you describe the characteristics of students in this course? What are their strengths and weaknesses?

Please write your answer here:

48 [35-Web] How do you use the internet in this course? Do you have materials we can see? Do you use your textbook’s site? Are there textbook supplements (online or otherwise) you find particularly useful? Do you use course management systems? What elements of those systems do you find most effective?

Please write your answer here:

49 [34-ABET Outcomes] Some programs will use this course to demonstrate graduates are achieving selected accreditation outcomes. With a rating system where 1=not really, 2=some, 3=quite a bit, and 4=extensively, which of the following outcomes are developed in your program extensively (rating 4)? Check any that rate 4 and please elaborate on how each is developed. Since this course is...
early in the curriculum, most programs will not use this for accreditation outcomes purposes though they may assess the course for internal use.

Please choose all that apply and provide a comment:

☐ (a) an ability to apply knowledge of mathematics, science, and engineering

☐ (b) an ability to design and conduct experiments, as well as to analyze and interpret data

☐ (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability

☐ (d) an ability to function on multidisciplinary teams

☐ (e) an ability to identify, formulate, and solve engineering problems

☐ (f) an understanding of professional and ethical responsibility

☐ (g) an ability to communicate effectively

☐ (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context

☐ (i) a recognition of the need for, and an ability to engage in life-long learning

☐ (j) a knowledge of contemporary issues

☐ (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

50 [36-AIChe] Would you be willing to discuss your answers to the questions on this page with a breakout group or the entire audience at a special session at the 2011...
AIChe National Meeting in Minneapolis (October 16-21)? Participation would be subject to your availability and the moderator's discretion. Invitations to participate will be extended early in the fall.

Please choose only one of the following:

- Yes
- No
Part 3: Wrapping up

We'll conclude with an opportunity for you to offer your closing comments on the course and survey. If you haven't already, please send an electronic copy of your course outline and/or course syllabus to David Silverstein to help us finish the survey. Your help is appreciated, and we truly appreciate the time you invest in this survey.

51 [3.1] Any other comments regarding the material and energy balance course experience of your chemical engineering students would be welcome.

Please write your answer here:

52 [3.2] Any comments regarding this survey would be welcome.

Please write your answer here:
Thank you for your participation. If you have requested a copy of the results be sent to you, expect to see that in the spring of 2012.

12-31-1969 – 19:00
Please fax your completed survey to: 270-534-6317
Submit your survey.
Thank you for completing this survey.